ELECTRICIAN

NSQF (LEVEL - 5)

3rd Semester

TRADE THEORY

SECTOR: Electrical

Directorate General of Training

DIRECTORATE GENERAL OF TRAINING
MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP
GOVERNMENT OF INDIA

NATIONAL INSTRUCTIONAL MEDIA INSTITUTE, CHENNAI

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FOREWORD

The Government of India has set an ambitious target of imparting skills to 30 crores people, one out of every four Indians, by 2020 to help them secure jobs as part of the National Skills Development Policy. Industrial Training Institutes (ITIs) play a vital role in this process especially in terms of providing skilled manpower. Keeping this in mind, and for providing the current industry relevant skill training to Trainees, ITI syllabus has been recently updated with the help of Mentor Councils comprising of various stakeholder's viz. Industries, Entrepreneurs, Academicians and representatives from ITIs.

National Instructional Media Institute (NIMI), Chennai has come up with instructional material to suit the revised curriculum for **Electrician 3rd Semester Trade Theory NSQF (LEVEL - 5)** in **Electrical** sector under Semester Pattern required for ITIs and related institutions imparting skill development. The NSQF (LEVEL - 5) will help the trainees to get an international equivalency standard where their skill proficiency and competency will be duly recognized across the globe and this will also increase the scope of recognition of prior learning. NSQF (LEVEL - 5) trainees will also get the opportunities to promote life long learning and skill development. I have no doubt that with NSQF (LEVEL - 5) the trainers and trainees of ITIs, and all stakeholders will derive maximum benefits from these IMPs and that NIMI's effort will go a long way in improving the quality of Vocational training in the country.

The Executive Director & Staff of NIMI and members of Media Development Committee deserve appreciation for their contribution in bringing out this publication.

Jai Hind

RAJESH AGGARWAL
Director General / Addl. Secretary,
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PREFACE

The National Instructional Media Institute (NIMI) was established in 1986 at Chennai by then Directorate General of Training (D.G.T), Ministry of Labour and Employment, (now under Directorate General of Training (D.G.T), Ministry of Skill Development and Entrepreneurship) (MSDE) Government of India, with technical assistance from the Govt. of the Federal Republic of Germany. The prime objective of this institute is to develop and provide instructional materials for various trades as per the prescribed syllabi (NSQF) under the Craftsman and Apprenticeship Training Schemes.

The instructional materials are created keeping in mind, the main objective of Vocational Training under NCVT/NAC in India, which is to help an individual to master skills to do a job. The instructional materials are generated in the form of Instructional Media Packages (IMPs). An IMP consists of Theory book, Practical book, Test and Assignment book, Instructor Guide, Audio Visual Aid (Wall charts and Transparencies) and other supporting materials.

The trade theory book provides related theoretical knowledge required to enable the trainee to do a job. The test and assignments will enable the instructor to give assignments for the evaluation of the performance of a trainee. The wall charts and transparencies are unique, as they not only help the instructor to effectively present a topic but also help him to assess the trainee's understanding. The instructor guide enables the instructor to plan his schedule of instruction, plan the raw material requirements, day to day lessons and demonstrations.

IMPs also deals with the complex skills required to be developed for effective team work. Necessary care has also been taken to include important skill areas of allied trades as prescribed in the syllabus.

The availability of a complete Instructional Media Package in an institute helps both the trainer and management to impart effective training.

The IMPs are the outcome of collective efforts of the staff members of NIMI and the members of the Media Development Committees specially drawn from Public and Private sector industries, various training institutes under the Directorate General of Training (DGT), Government and Private ITIs.

NIMI would like to take this opportunity to convey sincere thanks to the Directors of Employment & Training of various State Governments, Training Departments of Industries both in the Public and Private sectors, Officers of DGT and DGT field institutes, proof readers, individual media developers and coordinators, but for whose active support NIMI would not have been able to bring out this materials.

R. P. DHINGRA
Chennai - 600 032 **EXECUTIVE DIRECTOR**

ACKNOWLEDGEMENT

National Instructional Media Institute (NIMI) sincerely acknowledges with thanks for the co-operation and contribution extended by the following Media Developers and their sponsoring organisations to bring out this Instructional Material **(Trade Theory)** for the trade of **Electrician NSQF (LEVEL - 5)** under **Electrical** Sector for ITIs.

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NIMI records its appreciation for the Data Entry, CAD, DTP operators for their excellent and devoted services in the process of development of this Instructional Material.

NIMI also acknowledges with thanks the invaluable efforts rendered by all other NIMI staff who have contributed towards the development of this Instructional Material.

NIMI is also grateful to everyone who has directly or indirectly helped in developing this Instructional Material.

INTRODUCTION

This manual for trade Theory is intended for use in the ITI workshop. It consists of a series of practical exercises that are to be completed by the trainees during the Third semester of course is the **Electrician trade under Electrical Sector. It is National Skills Qualifications Framework NSQF (LEVEL - 5),** supplemented and supported by instructions/information to assist the trainees in performing the exercises. The syllabus for the 3rd Semester **Electrician NSQF (LEVEL - 5)** Trade under **Electrical Sector** Trade Practical is divided into six modules.The allocation of time for the various modules is given below:

Module 1 - DC Generator	7 Exercises	78 Hrs
Module 2 - DC Motor	9 Exercises	122 Hrs
Module 3 - AC Three Phase Motor	11 Exercises	125 Hrs
Module 4 - AC Single Phase Motor	9 Exercises	100 Hrs
Module 5 - Alternator	5 Exercises	50 Hrs
Module 6 - Synchronous Motor and MG Set	4 Exercises	50 Hrs
Total	45 Exercises	525 Hrs

The syllabus and the content in the modules are interlinked. As the number of workstations available in the electrical section is limited by the machinery and equipment, it is necessary to interpolate the exercises in the modules to form a proper teaching and learning sequence. The sequence of instruction is given in the schedule of instruction which is incorporated in the Instructor's Guide. With 25 practical hours a week of 5 working days 100 hours of practical per month is available.

The procedure for working through the 45 exercises for the 3rd semester with the specific objectives to be achieved as the learning out comes at the end of each exercise is given in this book.

The symbols used in the diagrams comply with the Bureau of Indian Standards (BIS) specifications.

This manual on trade Theory forms part of the Written Instructional Material (WIM), which includes manual on trade practical and assignment/test.

CONTENTS

CONTENTS

ASSESSABLE / LEARNING OUTCOME

On completion of this book you shall be able to

- **Plan, execute commissioning and evaluate performance of DC machines.**
- **Execute testing and maintenance of DC machines and motor starters.**
- **Plan, execute commissioning and evaluate performance of AC motors.**
- **Execute testing and maintenance of AC motors and starters.**
- **Plan, execute testing, evaluate performance and carry out maintenance of Alternator/MG set.**
- **Execute parallel operation of Alternators.**
- **Distinguish organize and perform motor winding.**

SYLLABUS

Third Semester **Duration: Six Month**

Week No.	Ref. Learning Outcome	Professional Skills(Trade Practical) with Indicative hours	Professional Knowledge (Trade Theory)
53 - 54	• Plan, Execute commis -sioning and evaluate performance of DC machines	115. Identify terminals, parts and connections of different types of DC machines. (10 Hrs) 116. Measure field and armature resistance of DC machines. (10 Hrs) 117. Determine build up voltage of DC shunt generator with varying field excitation and performance analysis on load. (15 Hrs) 118. Test for continuity and insulation resistance of DC machine. (5 Hrs) 119. Start, run and reverse direction of rotation of DC series, shunt and compound motors. (10 Hrs)	General concept of rotating electrical machines. Principle of DC generator. Use of Armature, Field Coil, Polarity, Yoke, Cooling Fan, Commutator, slip ring and Brushes, Laminated core etc. E.M.F. equation Separately excited and self excited generators. Series, shunt and compound generators
55 - 56	• Plan, Execute commissioning and evaluate performance of DC machines. • Execute testing, and maintenanceof DC machines and motor starters	120. Perform no load and load test and determine characteristics of series and shunt generators. (12 Hrs) 121. Perform no load and load test and determine characteristics of compound generators (cumulative and differential). (13 Hrs) 122. Practice dismantling and assembling in DC shunt motor. (12 Hrs) 123. Practice dismantling and assembling in DC compound generator. (13 Hrs)	Armature reaction, Commutation, inter poles and connection of inter poles. Parallel Operation of DC Generators. Load characteristics of DC generators. Application, losses & efficiency of DC Generators. Routine & maintenance
57 - 58	• Plan, Execute commissioning and evaluate performance of DC machines. • Execute testing, and maintenance of DC machines and motor starters	124. Conduct performance analysis of DC series, shunt and compound motors. (15 Hrs) 125. Dismantle and identify parts of three point and four point DC motor starters. (10 Hrs) 126. Assemble, Service and repair three point and four point DC motor starters. (15 Hrs)	Principle and types of DC motor. Relation between applied voltage back e.m.f., armature voltage drop, speed and flux of DC motor. DC motor Starters, relation between torque, flux and armature current. Changing the direction of rotation.

		127. Practice maintenance of carbon brushes, brush holders, Commutator and slip-rings. (10 Hrs)	Characteristics, Losses & Efficiency of DC motors. Routine and maintenance
59 - 60	• Execute testing, and maintenance of DC machines and motor starters. • Distinguish, organise and perform motor winding	128. Perform speed control of DC motors - field and armature control method. (10 Hrs) 129. Carry out overhauling of DC machines. (15 Hrs) 130. Perform DC machine winding by developing connection diagram, test on growler and assemble. (25 Hrs)	Methods of speed control of DC motors. Lap and wave winding and related terms
61 - 62	• Plan, Execute commissioning and evaluate performance of AC motors. • Execute testing, and maintenanceof AC motors and starters	131. Identify parts and terminals of three phase AC motors. (5 Hrs) 132. Make an internal connection of automatic star-delta starter with three contactors. (10 Hrs) 133. Connect, start and run three phase induction motors by using DOL, stardelta and auto-transformer starters. (20 Hrs) 134. Connect, start, run and reverse direction of rotation of slip-ring motor through rotor resistance starter and determine performance characteristic. (15 Hrs)	Working principle of three phase induction motor. Squirrel Cage Induction motor, Slip-ring induction motor; construction, characteristics, Slip and Torque. Different types of starters for three phase induction motors, its necessity, basic contactor circuit, parts and their functions
63 - 64	• Plan, Execute commi -ssioning and evaluate performance of AC motors. • Execute testing, and maintenance of AC motors and starters	135. Determine the efficiency of squirrel cage induction motor by brake test. (8 Hrs) 136. Determine the efficiency of three phase squirrel cage induction motor by no load test and blocked rotor test. (8 Hrs) 137. Measure slip and power factor to draw speedtorque (slip/torque) characteristics. (14 Hrs) 138. Test for continuity and insulation resistance of three phase induction motors. (5 Hrs)	Single phasing prevention. No load test and blocked rotor test of induction motor. Losses & efficiency. Various methods of speed control. Braking system of motor. Maintenance and repair

		139. Perform speed control of three phase induction motors by various methods like rheostatic control, autotransformer etc. (15 Hrs)	
65	• Distinguish organise and perform motor winding	140. Perform winding of three phase AC motor by developing connection diagram, test and assemble. (20 Hrs) 141. Maintain, service and troubleshoot the AC motor starter. (05 Hrs)	Concentric/ distributed, single/ double layer winding and related terms
66 - 67	• Plan, Execute commissioning and evaluate performance of AC motors. • Execute testing, and maintenance of AC motors and starters	142. Identify parts and terminals of different types of single phase AC motors.(5 Hrs) 143. Install, connect and determine performance single phase AC motors.(15 Hrs) 144. Start, run and reverse the direction of rotation of single phase AC motors.(10 Hrs) 145. Practice on speed control of single phase AC motors.(10 Hrs) 146. Compare starting and running winding currents of a capacitor run motor at various loads and measure the speed. (10 Hrs)	Working principle, different method of starting and running of various single phase AC motors. Domestic and industrial applications of different single phase AC motors. Characteristics, losses and efficiency
68 - 69	• Distinguish organise and perform motor winding	147. Carry out maintenance, service and repair of single phase AC motors. (10 Hrs) 148. Practice on single/double layer and concentric winding for AC motors, testing and assembling. (25 Hrs) 149. Connect, start, run and reverse the direction of rotation of universal motor. (10 Hrs) 150. Carry out maintenance and servicing of universal motor. (05 Hrs)	Concentric/ distributed, single/ double layer winding and related terms. Troubleshooting of single phase AC induction motors and universal motor

70 - 71	• Plan, execute testing, evaluate performance and carry out maintenance of Alternator / MG set. • Execute parallel operation of alternators	151. Install an alternator, identify parts and terminals of alternator. (10 Hrs) 152. Test for continuity and insulation resistance of alternator. (5 Hrs) 153. Connect, start and run an alternator and build up the voltage. (10 Hrs) 154. Determine the load performance and voltage regulation of three phase alternator. (10 Hrs) 155. Parallel operation and synchronization of three phase alternators. (15 Hrs)	Principle of alternator, e.m.f. equation, relation between poles, speed and frequency. Types and construction. Efficiency, characteristics, regulation, phase sequence and parallel operation. Effect of changing the field excitation and power factor correction
72	• Plan, execute testing, evaluate performance and carry out maintenance of Alternator / MG set	156. Install a synchronous motor, identify its parts and terminals. (10 Hrs) 157. Connect, start and plot Vcurves for synchronous motor under different excitation and load conditions. (15 Hrs)	Working principle of synchronous motor. Effect of change of excitation and load. V and anti V curve. Power factor improvement
73	• Plan, execute testing, evaluate performance and carry out maintenanceof Alternator / MG set	158. Identify parts and terminals of MG set. (5 Hrs) 159. Start and load MG set with 3 phase induction motor coupled to DC shunt generator. (20 Hrs)	Rotary Converter, MG Set description and Maintenance
74 - 75		Project work/Industrial visit (optional) Broad Areas: a) Phase sequence checker for 3 phase supply b) Induction motor protection system c) Motor starters with protection d) Solar/wind power generation	
76 - 77		Revision	
78		Examination	

DC generator - principle - parts - types - function - e.m.f. equation

Objectives: At the end of this lesson you shall be able to
- **state the general concepts of rotating electrical machine**
- **state the principle of the DC generator**
- **explain the faraday's of laws of electro magnetic induction**
- **explain the production of dynamically induced e.m.f., its magnitude and direction**
- **describe the parts of a DC generator and their function**
- **classify and identify the different type of generators and their terminal markings**
- **explain the armature circuit resistance and its relation**
- **derive the emf equation and calculation of a DC generator**
- **explain about separately excited DC generator with different types of windings.**

General concept of rotating electrical machine

In rotating machines, there are two parts, the stator and rotor. Rotating electrical machines are also of two types - DC and AC machines. Electrical machines are widely used. In DC machines the stator is used as a field and the rotor is used as an armature, while reverse is the case for AC machines. That is synchronous generators and synchronous motors. The induction motor is another kind of AC machine, which is singly excited; that is AC supply voltage is only given to the stator and no supply is given to the rotor. In DC machines and synchronous machines, the field is always excited.

Generator:An electrical generator is a machine which converts mechanical energy into electrical energy.

Principle of the generator:To facilitate this energy conversion, the generator works on the principle of Faraday's Laws of Electromagnetic Induction.

Faraday's Laws of Electromagnetic Induction: There are two laws.

The first law states:

First law: Whenever the flux linking to a conductor or circuit changes, an emf will be induced.

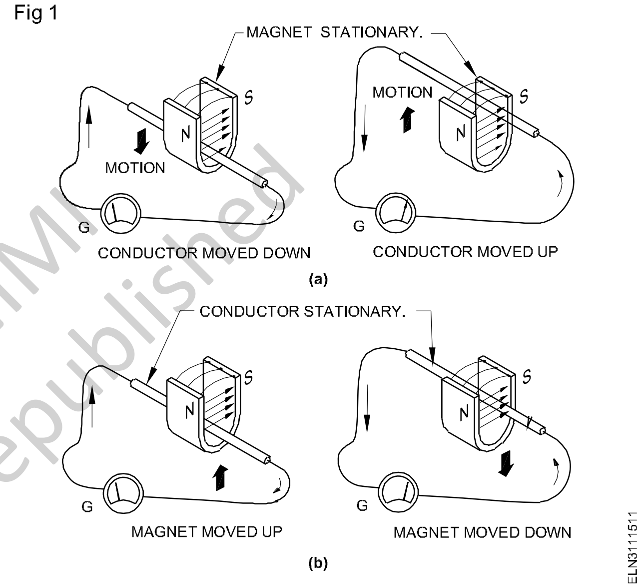
The second law states: The magnitude of such induced emf depends upon the rate of change of the flux linkage.

$$\text{emf} \propto \frac{\text{Change of flux}}{\text{Time taken for change}}.$$

Types of emf: According to Faraday's Laws, an emf can be induced, either by the relative movement of the conductor and the magnetic field or by the change of flux linking on a stationary conductor.

Dynamically induced emf: In case, the induced emf is due to the movement of the conductor in a stationary magnetic field as shown in Fig 1a or by the movement of the magnetic field on a stationary conductor as shown in Fig 1b, the induced emf is called dynamically induced emf.

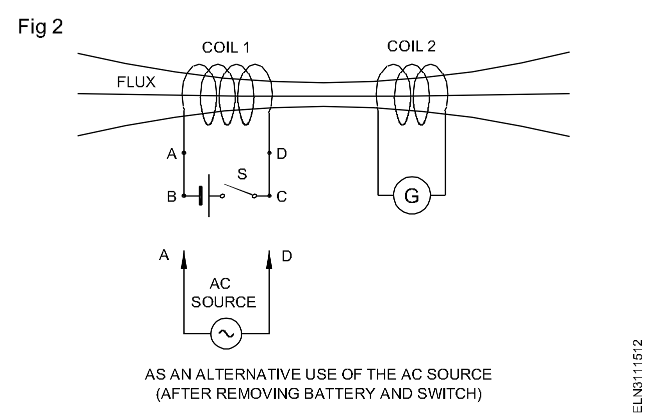
Fig 1



As shown in Figs 1a & 1b, the conductor cuts the lines of force in both cases to induce an emf, and the presence of the emf could be found by the deflection of the needle of the galvanometer `G'. This principle is used in DC and AC generators to produce electricity.

Statically induced emf: In case, the induced emf is due to change of flux linkage over a stationary conductor as shown in Fig 2, the emf thus induced is termed as statically induced emf. The coils 1 and 2 shown in Fig 2 are not touching each other, and there is no electrical connection between them.

According to Fig 2, when the battery (DC) supply is used in coil 1, an emf will be induced in coil 2 only at the time of closing or opening of the switch S. If the switch is permanently closed or opened, the flux produced by coil 1 becomes static or zero respectively and no emf will be induced in coil 2. EMF will be induced only when there is a change in flux which happens during the closing or opening of the circuit of coil 1 by the switch in a DC circuit.



Alternatively the battery and switch could be removed and coil 1 can be connected to an AC supply as shown in Fig 2. Then an emf will be induced in coil 2 continuously as long as coil 1 is connected to an AC source which produces alternating magnetic flux in coil 1 and links with coil 2. This principle is used in transformers.

Production of dynamically induced emf: Whenever a conductor cuts the magnetic flux, a dynamically induced emf is produced in it. This emf causes a current to flow if the circuit of the conductor is closed.

For producing dynamically induced emf, the requirements are:

- magnetic field
- conductor
- relative motion between the conductor and the magnetic field.

If the conductor moves with a relative velocity 'v' with respect to the field, then the induced emf `E' will be

E = BLV Sinθ Volts

where

B = magnetic flux density, measured in tesla

L = effective length of the conductor in the field in metres

V = relative velocity between field and conductor in metre/second

θ = the angle at which the conductor cuts the magnetic field.

Let us consider Fig 3a in which conductors A to I are placed on the periphery of the armature under magnetic poles. Assume for this particular generator shown in Fig 3a, the value of BLV = 100V.

Accordingly the conductor A induces an emf

= BLV Sin θ where θ = zero and Sin zero is equal to zero

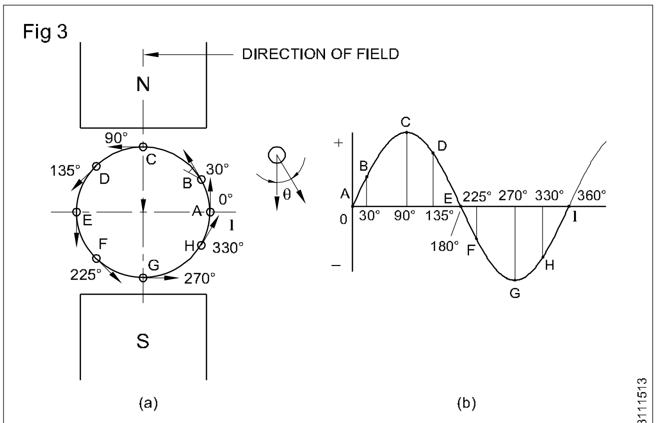
= 100 x 0 = zero.

emf induced in

Conductor B = BLV Sin 30°

= 100 x 0.50

= 50 volts.



PRODUCTION OF THE SINEWAVE

emf induced in

Conductor C = BLV Sin 90°

= 100 x 1

= 100 V.

emf induced in

Conductor D = BLV Sin 135°

= BLV Sin 45°

= 100 x 0.707

= 70.7 volts.

emf induced in

Conductor E = BLV Sin 180°

= Sin 180°= 0

= 100 x 0

= zero.

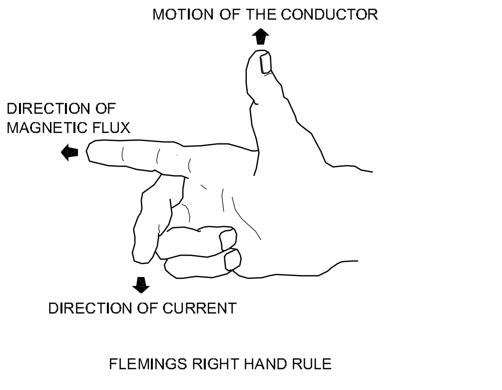
Likewise for every position of the remaining conductors in the periphery, the emf induced could be calculated. If these values are plotted on a graph, it will represent the sine wave pattern of induced emf in a conductor when it rotates under N and S poles of uniform magnetic field.

As in Fig 3b the emf induced by this process is basically alternating in nature, and this alternating current is converted into direct current in a DC generator by the commutator.

Fleming's right hand rule: The direction of dynamically induced emf can be identified by this rule. Hold the thumb, forefinger and middle finger of the right hand at right angles to each other as shown in Fig 4 such that the forefinger is in the direction of flux and the thumb is in the direction of the motion of the conductor, then the middle finger indicates the direction of emf induced, i.e. towards the observer or away from the observer.

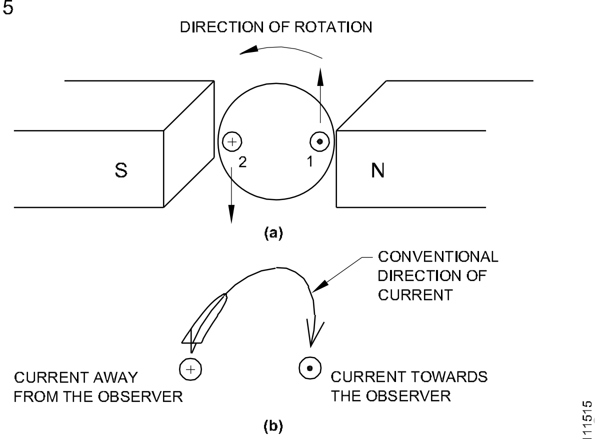
Imagine a conductor moving in between north and south poles in an anticlockwise direction as shown in Fig 5a.

Fig 4



FLEMINGS RIGHT HAND RULE

Fig 5



DIRECTION OF THE INDUCED CURRENT

Applying Fleming's right hand rule, we find that the conductor 1 which is moving upwards under the north pole will induce an emf in the direction towards the observer indicated by the dot sign and the conductor 2 which is moving down under the south pole will induce an emf in the direction away from the observer indicated by the plus sign.

Fig 5b indicates the current direction in the form of an arrow. The dot sign indicates the pointed head of the arrow showing the current direction towards the observer and the plus sign indicates the cross-feather of the arrow showing the current direction away from the observer.

Parts of DC generator

A DC generator consists of the following essential parts as shown in Fig 6.

1 Frame or yoke

2 Field poles and pole-shoes (Figs 8,9 & 10)

3 Field coils or field winding (Fig 11)

4 Armature core

5 Armature windings or armature conductors

6 Commutator

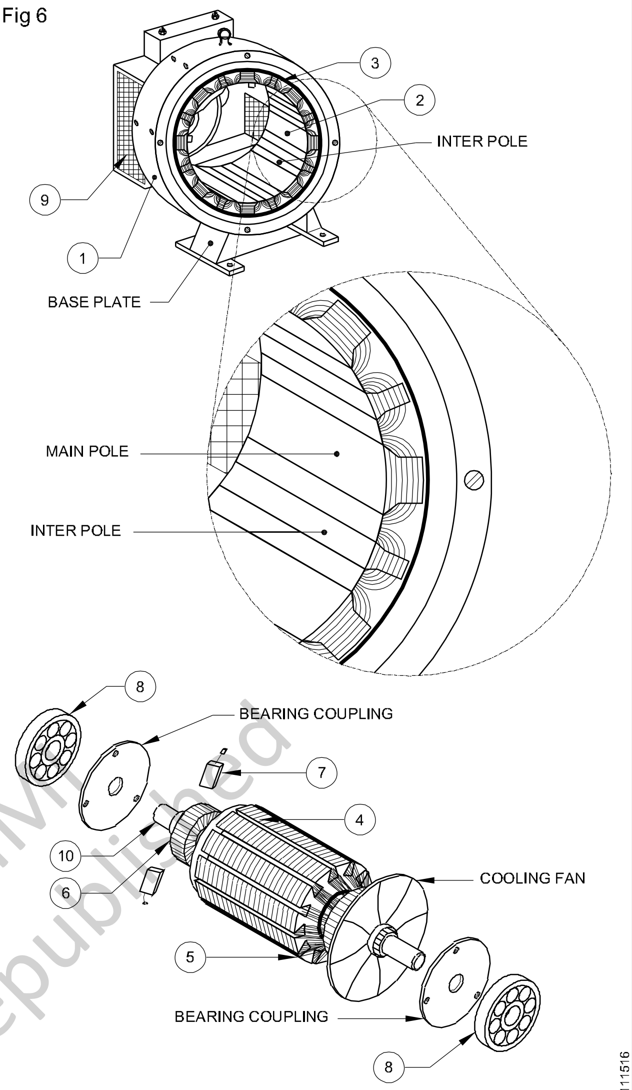
7 Brushes

8 Bearings and end plates

9 Air filter for fan

10 Shaft

Fig 6



PARTS OF A DC MACHINE

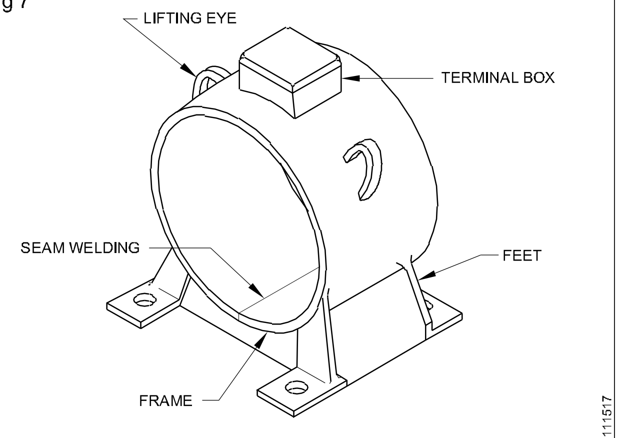
The yoke, the pole cores, the armature core and the air gaps between the poles and the armature core form the magnetic circuit, whereas the armature conductors, field coils, commutators, and brushes form the electrical circuit.

Yoke: The outer frame or yoke serves a dual purpose. Firstly, it provides mechanical support for the poles and acts as a protecting cover for the whole machine as shown in Fig 6. Secondly, it allows the magnetic circuit to complete through it.

In small generators where cheapness rather than weight is the main consideration, yokes are made of cast iron. But for large machines usually cast steel or rolled steel is used. The modern process of forming the yoke consists of rolling a steel slab round a cylindrical mandrel, and then welding it at the seams. The feet, the terminal box etc. are welded to the frame afterwards as shown in Fig 7. Such yokes possess sufficient mechanical strength and have high permeability.

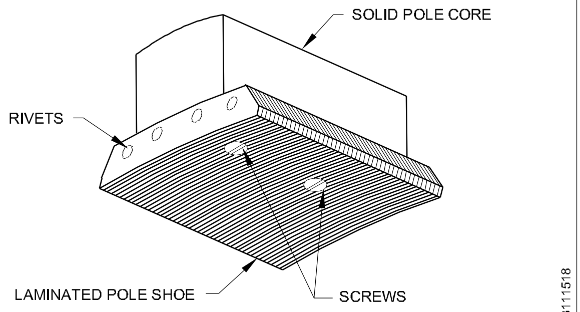
Poles cores and pole shoes (Fig 8): The field magnets consist of pole cores and pole shoes. The pole shoes serve two purposes; (i) they spread out the flux in the air gap uniformly and also, being of a larger cross-section, reduce the reluctance of the magnetic path, and (ii) they also support the field coils.

Fig 7



YOKE

Fig 8



SEPERATE POLE SHOE BOLTED TO POLE CORE

There are two main types of pole construction.

The pole core itself may be a solid piece made out of either cast iron or cast steel but the pole shoe is laminated and is fastened to the pole face by means of countersunk screws as shown in Fig 8.

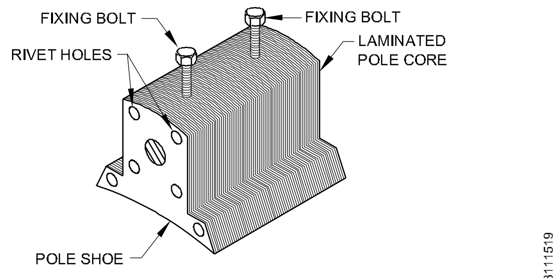
In modern designs, the complete pole cores and pole shoes are built of thin laminations of annealed steel which are riveted together under hydraulic pressure. The thickness of laminations varies from 1mm to 0.25mm. The laminated poles may be secured to the yoke in any of the following two ways.

Either the pole is secured to the yoke by means of screws bolted through the yoke and into the pole body as in Fig 9 or holding screws are bolted into a steel bar which passes through the pole across the plane of laminations as in Fig 10.

Pole coils (Field coils): The field coils or pole coils, which consist of copper wire or strip are former-wound for the correct dimension. Then the former is removed and the wound coils are put into place over the core as shown in Fig 11.

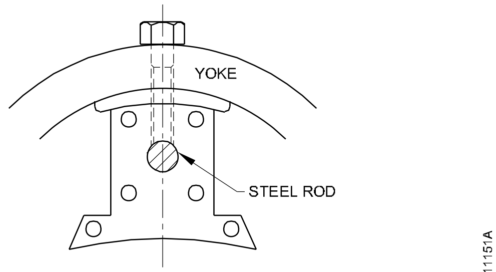
When a current is passed through the coils, they magnetise the poles which produce the necessary flux that is cut by revolving armature conductors.

Fig 9



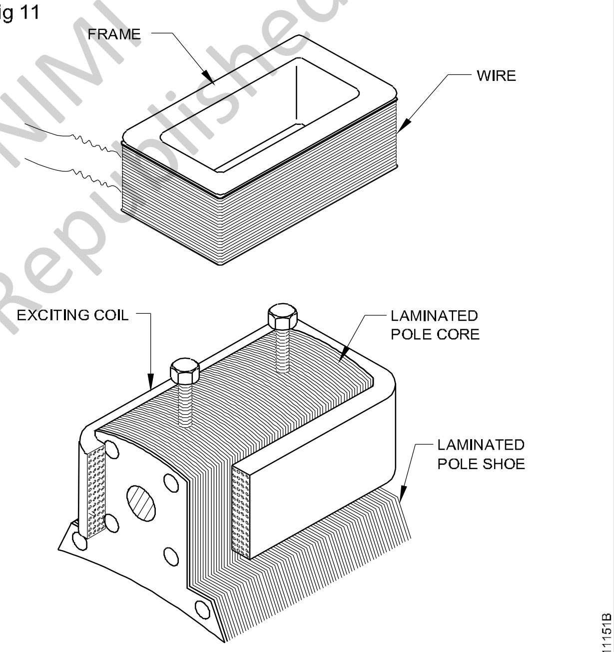
LAMINATED POLE CORE

Fig 10



HOLDING SCREW BOLTED IN TO STEEL BAR POLE CORE ASSEMBLY

Fig 11



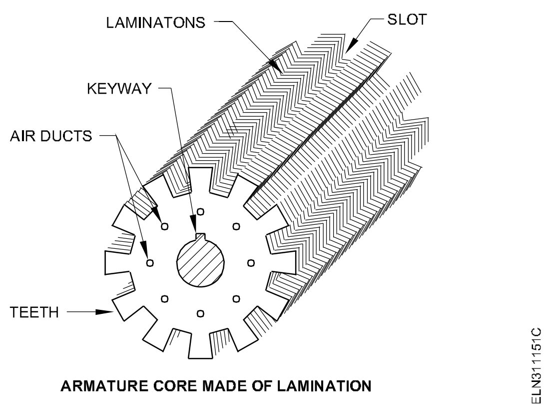
POLE ASSEMBLY

Both thick gauge wire winding (series) and thin gauge winding (shunt) are wound, one over the other with separate insulations, and the terminals are brought out separately.

Armature core: The armature core houses the armature conductors and rotate in the magnetic field so as to make the conductors to cut the magnetic flux. In addition to this, its most important function is to provide a path of very low reluctance to the field flux, thereby allowing the magnetic circuit to complete through the yoke and the poles.

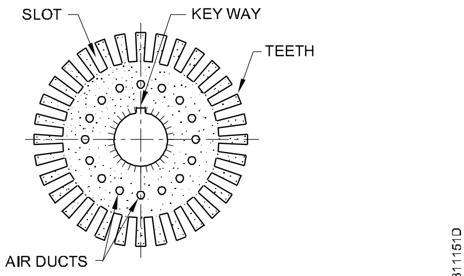
The armature core is cylindrical or drum-shaped as shown in Fig 12, and build up of circular sheet steel discs or laminations approximately 0.5mm thick as shown in Fig 13.

Fig 12



ARMATURE CORE MADE OF LAMINATION

Fig 13



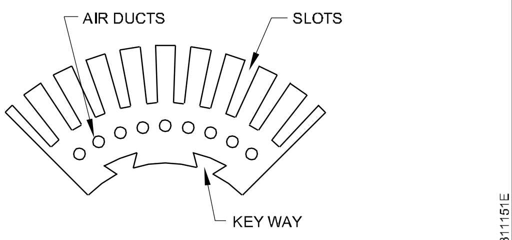
ARMATURE CORE LAMINATIONS

The slots are either die-cut or punched on the outer periphery of the disc and the keyway is located on the inner diameter as shown. In small machines, the armature stampings are keyed directly to the shaft. Usually these laminations are perforated for air ducts which permit axial flow of air through the armature for cooling purposes. Such ventilating holes are clearly visible in the laminations shown in Figs 12,13 and 14.

Up to armature diameters of about one metre, the circular stampings are cut out in one piece as shown in Fig 13. But above this size, these circles, especially of very thin sections, are difficult to handle because they tend to distort and become wavy when assembled together. Hence, the circular laminations, instead of being cut out in one piece, are cut in a number of suitable sections of segments which form part of a complete ring.

A complete circular lamination is made up of four or six or even eight segmental laminations. Usually, two keyways are notched in each segment and are dovetailed or wedge-shaped to make the laminations self-locking in position as shown in Fig 14.

Fig 14



SEGMENTAL LAMINATION

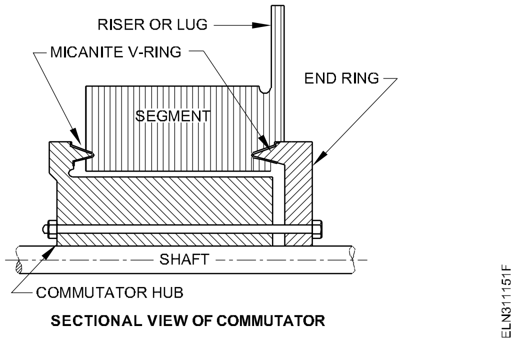
The purpose of using lamination is to reduce the loss due to eddy currents. Thinner the laminations are, greater the resistance offered against eddy current loss.

Armature windings: The armature windings are usually former-wound. These are first wound in the form of flat rectangular coils and are then pulled into their proper shape with a coil puller. Various conductors of the coils are insulated from each other. The conductors are placed in the armature slots which are lined with tough insulating material. After placing the conductors in the slot, this slot insulation is folded over the armature conductors, and is secured in place by special, hard, wooden or fibre wedges.

Commutator: The function of the commutator is to facilitate collection of current from the armature conductors. It rectifies i.e. converts the alternating current induced in the armature conductors into uni-directional current for the external load circuit. It is of cylindrical structure and is built up of wedge-shaped segments of high conductivity, hard-drawn or drop-forged copper. These segments are insulated from each other by thin layers of mica. The number of segments is equal to the number of armature coils.

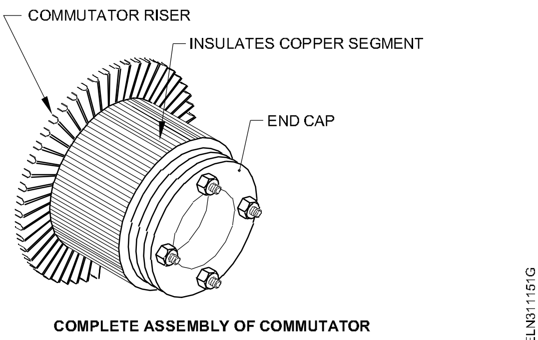
Each commutator segment is connected to the armature conductor by means of a copper lug or riser. To prevent them from flying out under the action of centrifugal forces, the segments have V-grooves, these grooves being insulated by conical micanite rings. A sectional view of a commutator is shown in Fig 15, whose general appearance when assembled is shown in Fig 16.

Fig 15



SECTIONAL VIEW OF COMMUTATOR

Fig 16

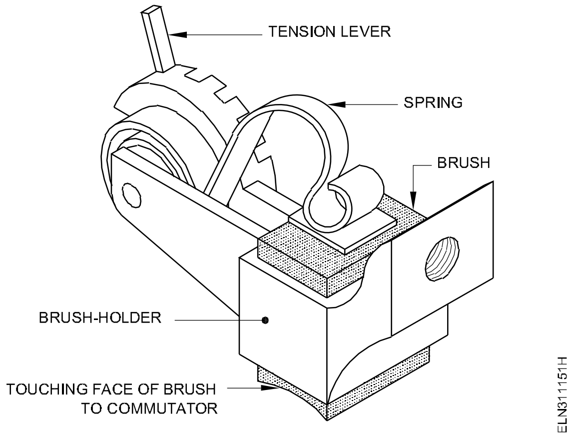


COMPLETE ASSEMBLY OF COMMUTATOR

Brushes: The brushes whose function is to collect current from the commutator are usually made of carbon and graphite and are in the shape of a rectangular block.

These brushes are housed in brush-holders, shown in Fig 17, which have a box-holder for the brush, a spring to maintain the brush tension and a hole to fix the holder to the rocker arm. The brushes can slide in the rectangular box, open at both ends. The brushes are made to bear down on the commutator by a spring whose tension can be adjusted by changing the position of the tension lever in the notches. A flexible, copper pigtail mounted at the top of the brush conveys the current from the brushes to the holder. The number of brushes per spindle depends on the magnitude of the current to be collected from the commutator.

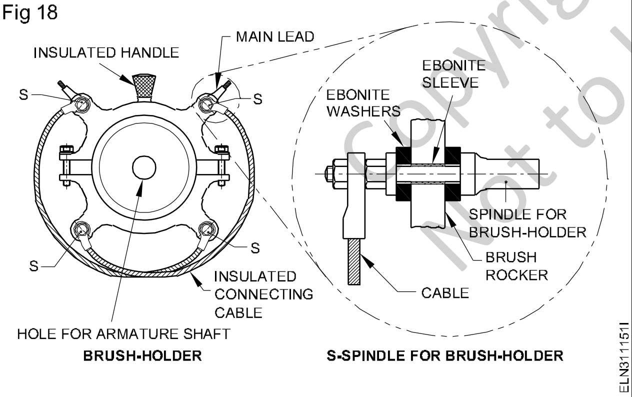
Fig 17



Brush-rocker: The spindle is used to have a number of brushes connected in a large machine. There may be only two brushes for a small machine. All the spindles are insulated and attached to the brush rocker.

The brush-rocker may either be supported by a bearing cover in a small machine or by brackets attached to the yoke as shown in Fig 18. The brush position to the neutral axis can be set by changing the position of the brush-rocker.

Fig 18



Bearings (Fig 19): Because of their reliability, half-bearings are frequently employed, though for heavy duties roller bearings are preferable. The ball and rollers are generally filled with hard oil for quieter operation and for reduced bearing wear. When sleeve bearings are used, these are lubricated by ring oilers fed from an oil reservoir in the bearing bracket.

End plates (Fig 20): The bearings are housed in these end plates, and they are fixed to the yoke. They help the armature for frictionless rotation and to position the armature in the air gap of the field poles.

Fig 19

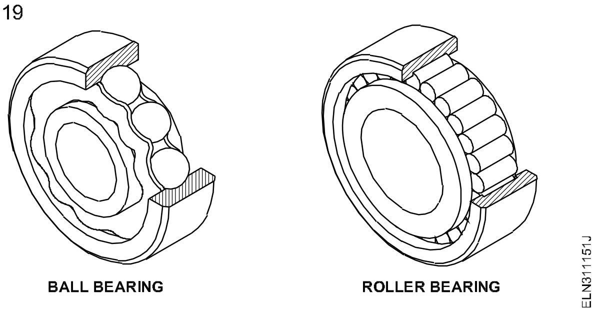
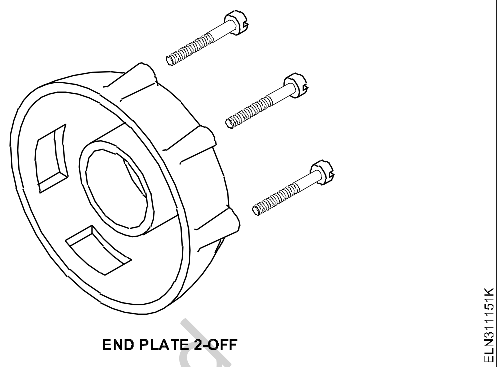


Fig 20

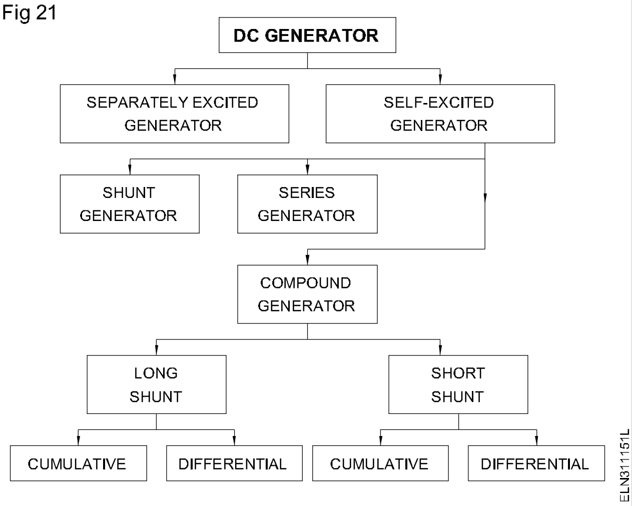


Cooling fan

DC Machines are often selected based upon a particular work or load requirement. In most cases, heat dissipation is achieved through a cooling fan fitted on the DC Machine shaft. Another method to remove heat from DC machine is by providing forced air cooling. This is commonly done by providing an electric fan externally to blow air over the DC machine. Forced air cooling can reduce the amount of heat transferred into the machine structure and allow the machine to be operated at a higher load.

Types of DC generators: The type of a DC generator is determined by the manner in which the field excitation is provided. In general, the methods employed to connect the field and armature windings, fall into the following groups.(Fig 21)

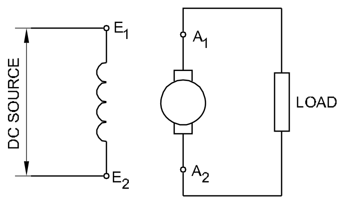
Fig 21



Separately excited generator: The field excitation for a separately excited generator, shown in Fig 22, is supplied from an independent source, such as storage battery, separate DC generator or rectified DC supply from an AC source.

The field excitation voltage may be the same as that of generated (armature) voltage or may differ. Generally, the excitation voltage will be of low voltage, say 24, 36 or 48V DC.

Fig 22

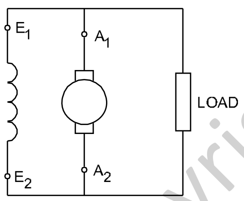


CONNECTION DIAGRAM OF SEPARATELY EXCITED DC GENERATOR

Self-excited generator: The field excitation is provided by its own armature. In this type of generators, initially the voltage is built up by residual magnetism retained in the field poles. Self-excited generators may be further classified as shunt, series and compound generators.

Shunt generator: The field winding is connected to the armature terminals as shown in Fig 23. (i.e. shunt field winding is connected in parallel with armature winding). The shunt field contains many turns of relatively fine wire and carries a comparatively small current only which is a small percentage of the rated current of the generator.

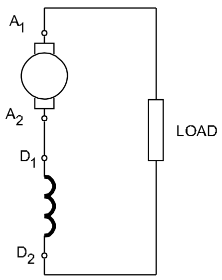
Fig 23



SHUNT GENERATOR

Series generator: The field winding is connected in series with the armature winding as shown in Fig 24. The series field winding has a few turns of heavy wire. Since it is in series with the armature it carries the load current.

Fig 24

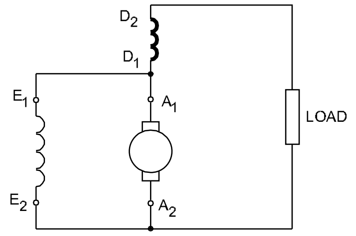


SERIES GENERATOR

Compound generator: The field excitation is provided by a combination of shunt and series field windings.

Short-shunt compound generator: This is a generator in which the shunt field is directly across the armature as shown in Fig 25.

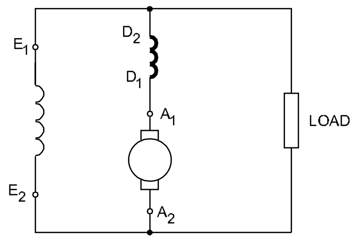
Fig 25



SHORT SHUNT COMPOUND GENERATOR

Long-shunt compound generator: This is a generator in which the shunt field is connected after the series field as shown in Fig 26.

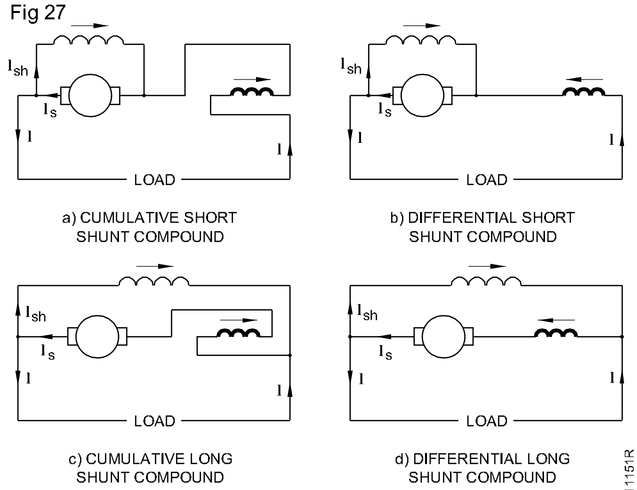
Fig 26



LONG SHUNT COMPOUND GENERATOR

Differential and cumulative compound generator: The compound generators can also be further classified as cumulative and differential. In cumulative compound generators the magnetising forces of the shunt and the series field ampere-turns are cumulative, i.e. they both tend to set up flux in the air gap in the same direction. However, in case the ampere turns of the shunt widning oppose those of the series winding, the machine is said to be differentially compound wound generator. Both the types are shown in Fig 27.

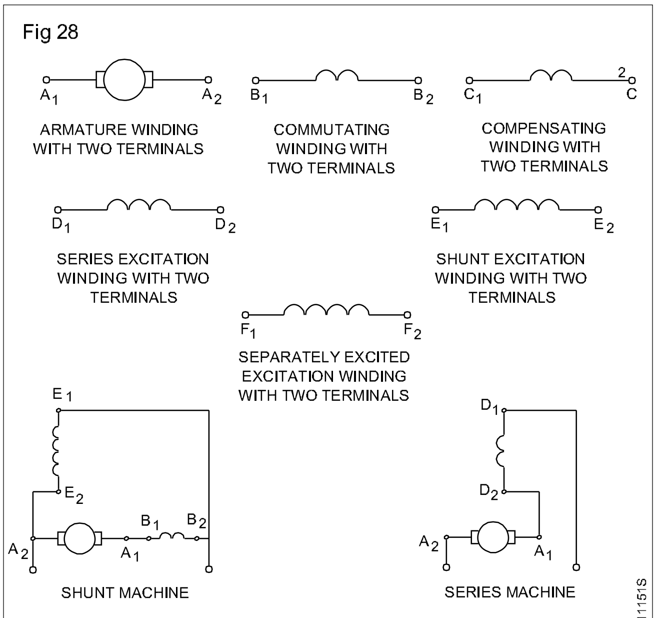
Fig 27



TYPES OF DC COMPOUND GENERATORS

Terminal markings : As per BIS 4718-1975 the terminal markings for DC commutator machines shall be according to the marking principles stated below.

- Windings are distinguished by capital letters.
- End points and intermediate points of windings are distinguished by a numerical suffix.
- Winding letters for DC windings are chosen from the earlier part of the alphabet.(Fig 28)

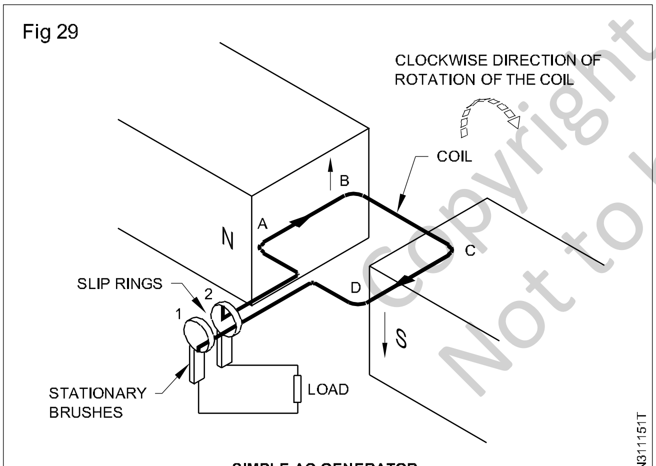


TERMINAL MARKING OF DC MACHINES AS PER BIS

Commutator (Split rings)

A generator produces electrical power with the help of the rotation of a group of conductors in a magnetic field. It uses the principle of electromagnetic induction to convert the input mechanical power into electrical power.

Slip rings: Let us consider a simple AC generator having a single loop of wire and rotated within a fixed magnetic field, as shown in Fig 29.



SIMPLE AC GENERATOR

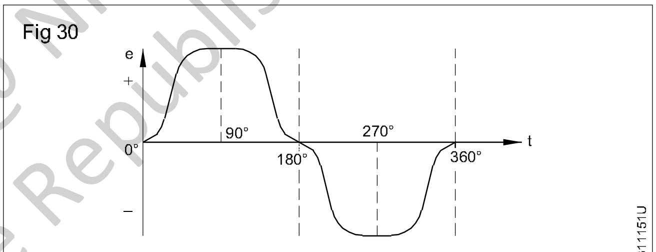
Let each end of the single loop coil be connected to copper or brass rings called slip rings. These slip-rings are insulated from each other, insulated and mounted on the shaft. In a broader sense this rotating assembly (coil,shaft & slip-ring) is called armature. The wire loop (armature coil) is connected to an external circuit by means of two brushes which are positioned to rub against the slip-rings. As the armature is rotated at a uniform angular velocity, the generated voltage in the loop conductor will actually be of alternating voltage.

For the clockwise rotation indicated, the direction of generated voltage and the resulting current in the coil side under the north pole will be directed from A to B making the slip-ring 2 negative. This is readily confirmed by using Fleming's right hand rule. Similarly the direction of the induced voltage and the resulting current under the south pole is to be directed from C to D making the slip- ring 1 as positive. When the conductor AB moves from the north pole to the south pole, the direction of induced emf in it will reverse, so that the current will now flow from B to A making the slip-ring 2 positive. At the same time coil side CD has moved into the north pole region and its induced emf is reversed and current will flow from D to C making the slip-ring 1 negative.

Thus for one half of a revolution (for a two-pole generator) the emf is directed around the coils A to B & C to D. For the other half of the revolution the emf is directed around the coil D to C and B to A. The current in the externally connected load resistor via the stationary brushes in contact with the pair of slip rings `1'and `2' will be alternating (AC) in nature.

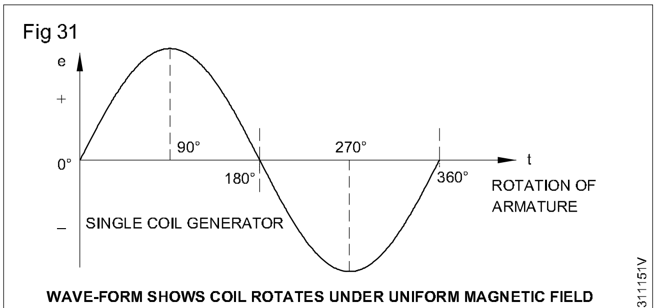
Wave-shape of the induced voltage: When the output voltage is plotted against electrical degrees we get the output wave-form.

The output wave-form obtained across the load, according to the pole shape shown in Fig 29, will not be of sinusoidal shape due to un-uniform magnetic field but of rectangular shape as shown in Fig 30.



WAVE-FORM SHOWS COIL ROTATES UNDER UN-UNIFORM MAGNETIC FIELD

However, if the magnetic field is uniform, the output wave-form will be of sinusoidal shape as shown in Fig 31.



WAVE-FORM SHOWS COIL ROTATES UNDER UNIFORM MAGNETIC FIELD (SINE WAVE)

Simple generator with split-rings: A direct current generator is simply an AC generator provided with split rings instead of slip-rings.

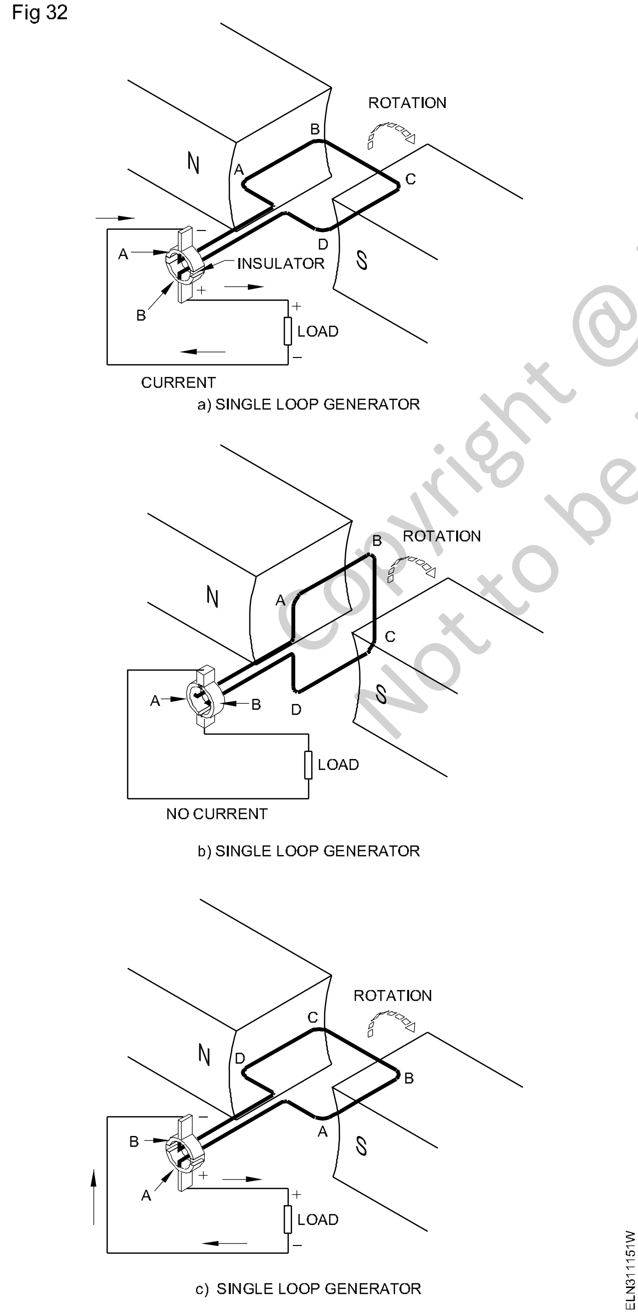
The split ring is a ring made up of hard drawn copper cut into two segments, insulated from each other and the shaft in which it is mounted. A commercial generator uses a number of split rings called commutators. The split ring is a device for reversing the brush contact with the armature coil terminals, every time the induced current in the coil reverses, so that the output current taken by the brushes remains always in the same direction.

As shown in Fig 32a, if the armature rotates clockwise the split ring rotates with it, and the brushes and the poles are stationary in their position. As shown in Fig 4a, when the moving coil is in the horizontal position, the induced current will flow through the coil from ABCD to the segment `B' via the positive brush and load to the negative brush and segment A. The direction of current flow in the external circuit is shown in Figures 32a and 32c.

When the armature rotates so that the coil just assumes a vertical position as in Fig 32b, the brushes will short-circuit both the segments. The induced emf is zero and no current flows through the load circuit for a short moment.

When the armature rotates and the coil assumes the position as indicated in Fig 32c, the coil side AB will enter the south pole region and its induced emf will reverse, compared to the direction it had while moving under the north pole region as shown in Fig 32a.

Fig 32



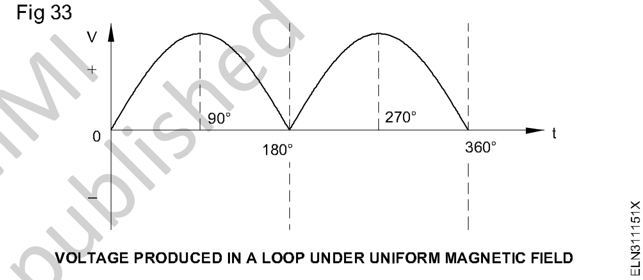
But when this happens the split ring segments `A' and `B' will also have exchanged their positions since they rotate along with the coil.

As the emfs in the coil sides AB and CD reverse their polarity, the split ring segments to which they are connected simultaneously change their positions under the stationary brushes. As a result, the polarity of the brushes remains fixed and the current direction through the load remains as shown in Fig 32c which is the same as shown in Fig 32a.

Figure 33 represents the generated voltage of a simple DC generator. The voltage is uni-directional due to the split ring action.

The induced emf by a single loop (one turn) coil is very small in magnitude and pulsating in nature as shown in Fig 33. Coils, having a number of turns in series, multiply the generated emf by the same number. However to get a steady (DC) current it is necessary to increase the pulses produced in the armature; thereby their average value is constant.

Fig 33



VOLTAGE PRODUCED IN A LOOP UNDER UNIFORM MAGNETIC FIELD

There are two ways to increase the number of pulses during each rotation of the armature.

- Increase the number of field poles.
- Increase the number of separate coils (multi-coil) in the armature.

The multi-coils necessitate a multiple segment split-rings which is called a commutator.

Fig 34 represents the generated voltages and their wave shapes when the armature has different number of split rings, i.e. commutator segments. The practical generator will have more number of commutator segments as shown in Fig 34c, and the induced emf will be as shown in the adjoining graph.

Armature circuit resistance and its relation with different types of windings and brush resistance

Armature windings (Fig 35 Lap winding, Fig 36 wave winding): We have seen earlier, when a single loop conductor is rotated through a magnetic field, an alternating voltage is induced in it. This alternating voltage can be changed into direct voltage (rectified) by the commutator. In practice, there are several coils in the armature, each with a large number of turns laid in the slots of the armature core. This arrangement of the coil is called armature winding. The ends of the coils are soldered to the commutator raisers, depending on the kind of winding i.e. lap or wave, which decides the number of parallel paths in the armature.

Fig 34a

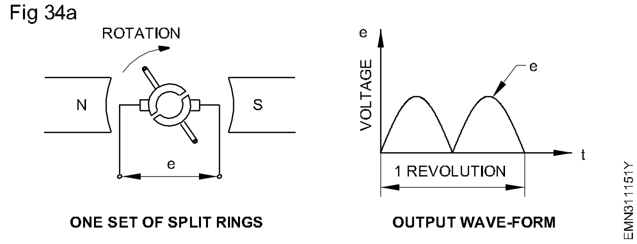


Fig 34b

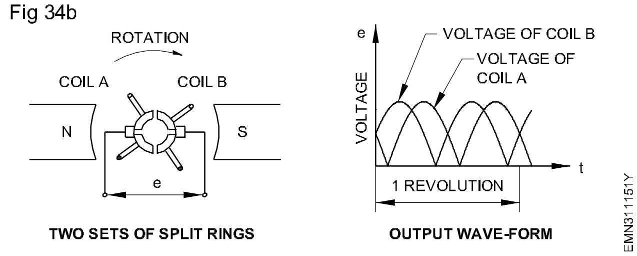
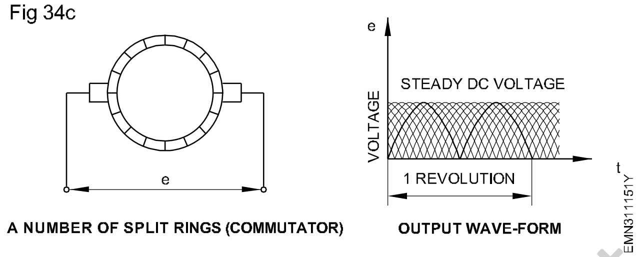


Fig 34c



i.e. lap or wave, which decides the numbers of parallel paths in the armature.

A preliminary knowledge about the different types of winding is essential to tackle problems related to the calculation of induced voltage in various types of generators.

Lap and wave windings could readily be identified by the manner in which the coil ends are connected to the commutator bars. As shown in Fig 35, in a simplex lap winding, the ends of a coil are connected to adjacent commutator segments. Fig 36 shows the simplex wave winding in which the coil ends are connected to the commutator segments almost equal to the distance between poles of the same polarity.

Fig 35

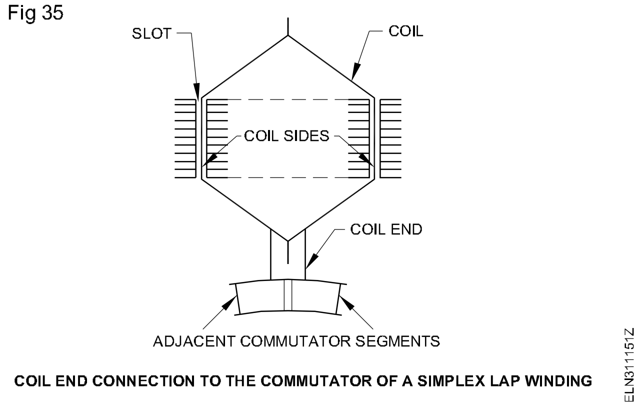


Fig 36

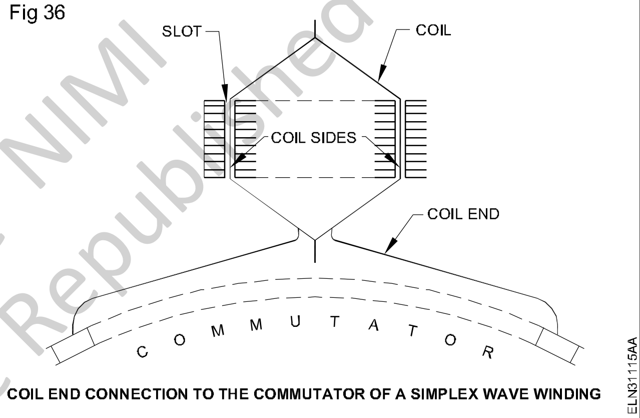


Table 1 shows the main differences between lap and wave winding.

Table 1

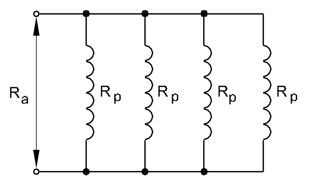
Lap winding	Wave winding
The two ends of each armature coil are connected to adjacent commutator segments in the case of simplex, two segments apart in duplex and three segments apart in triplex.	The two ends of each coil connect to the commutator segments placed between adjacent poles of the same polarity.
There are many parallel paths for current as there are field poles in the case of lap winding	There are two parallel paths regardless of the number of field poles in the case of simplex wave winding.
No. of parallel paths = Number of poles x plex of the winding	Number of parallel paths in wave windings = 2 x plex of the winding where plex for-simplex is 1, duplex is 2 and triplex is 3.
The number of brush positions is equal to the number of poles.	Only two brush positions are required regardless of the number of field poles.
Used for machines having low voltage and high current capacity.	Used in machines having low current and high voltage capacity.

DC armature circuit - voltage drop and its importance: One of the major reasons for the drop in voltage at the terminals of a loaded generator is due to armature voltage drop. This depends on the armature circuit resistance and the armature current. A thorough understanding of the armature resistance, apart from helping an electrician to calculate the efficiency of a DC machine, is of great help to check the correctness of the rewind armature without physically checking the number of turns and the size of the winding wire. This is done in all established factories, where a record is maintained to indicate voltage drop across the armature of each DC machine, at a specified armature current. Any variation from this recorded value to the value obtained from the rewind armature (having the same grade of brushes), clearly indicates either the size of the winding wire or the number of turns has changed, and the performance of the machine will not be the same as earlier. Normally armature circuit resistance will be in the order of one ohm or below.

Voltage drop: This could be calculated by finding the total resistance of the armature conductors in series per parallel path and dividing it by the number of parallel paths, but in actual practice it is calculated by the voltage drop method.

Refer to the circuit shown in Fig 37.

Fig 37



4-POLE SIMPLEX LAP-WOUND MACHINE WITH 4 PARALLEL PATHS

Let 'r' be the specific resistance of the armature conductors,

'a' be the area of the cross-section of the armature conductor in sq. cm.

'L' be the length of the conductor in cms.

'R_a' - armature resistance in ohms.

'R_p' - resistance per parallel path in ohms.

Method of calculating the armature resistance: Let P be the number of parallel paths in the armature,

Z be the total conductors in armature.

Then the number of conductors per parallel path = Z/P.

Resistance per parallel path $R_p = \frac{Z}{P} \times \frac{\rho L}{a}$

Armature resistance in ohms = R_a

$$R_a = \frac{R_P}{\text{No. of parallel paths}}$$

Example: In a DC 4-pole lap-wound machine the resistance of one conductor is 0.1 ohm; there are 48 conductors. Calculate the armature resistance.

Since it is lap-wound,

No. of parallel paths=No.of poles (assuming simplex winding).

Therefore, No. of parallel paths = 4.

Conductors per

$$\text{parallel path} = \frac{\text{Total No. of conductors}}{\text{No. of parallel paths}} = \frac{48}{4} = 12.$$

Resistance per parallel path = 12 x 0.1 = 1.2 ohms.

Therefore the total armature resistance for 4 parallel paths = 1.2/4 = 0.3 ohms.

In addition to this, the total armature circuit resistance includes brush resistance and brush contact resistance. Hence the value measured will be more than 0.3 ohms in the above example.

Brushes: The main function of the brushes is to transfer the energy present at the armature to the external circuit. Brushes are usually made from a compound of carbon and graphite. Graphite content provides a self-lubricating action as the brushes rub against the commutator.

The most important characteristics of brushes are specific resistance, friction coefficient, current-carrying capacity, maximum operating speed and abrasiveness.

Specific resistance is the resistivity of the brush material.

Friction coefficient is the ratio of the force on the surface to the force required to slide another surface over it, and is influenced by the brush temperature, pressure, current, atmospheric condition, mechanical condition, commutator material, surface films and speed. The resulting high brush friction often causes the brush to chatter and chip. Since friction serves no useful purpose, low brush friction is preferred. Low brush friction will have a friction coefficient in the order 0.22 or below whereas a high brush friction will have a friction coefficient above 0.4.

Current-carrying capacity: It depends on the brush material, operating conditions, type of ventilation and operating temperature. If the temperature is high due to high current density, the brush life will be shortened.

Speed: The allowable speed depends upon the characteristics of the brush material, spring pressure, current density, types of brush-holders, brush angle and the area of contact of the commutator.

Abrasiveness: The ability of the brush to prevent excessive build up of film usually caused by corrosive or oily atmosphere is called the abrasiveness or polishing action.

Grade and types of brushes: There are four major brush families classified according to the manufacturing process.

- Graphite
- Carbon and carbon graphite
- Electro-graphite
- Metal graphite

Graphite: Graphite brushes are usually made of natural or artificial graphite. Natural graphite contains impurities. Artificial graphite is usually pure. It is used in fractional HP machines.

Carbon and carbon graphite: It has high hardness, high mechanical strength, cleaning action and long brush life.

Electro-graphite: It consists of various forms of amorphous carbon. These brushes usually have higher current density, lower strength, lower hardness and lower specific resistance. They generally have good commutating characteristic but may not always be used because of the lesser requirement of high current, and the requirement of severe mechanical conditions.

Metal graphite: It is generally made from natural graphite, and finally divided into metal powders. Copper is the most common metal constituent, but silver, tin, lead and other metals are sometimes used. The metal content ranges from approximately 10 to 95% by weight. A high metal content provides greater current capacity, higher mechanical strength and also certain combined characteristics of contact drop and friction. It is used where high current and low voltages are involved. Its typical applications are for electroplating generators, battery chargers, welding generators and other high current equipment.

Whenever the brushes are to be changed, the same grade of brushes is to be procured and used to get the same performance characteristics from the machine.

As an accepted procedure, every electrician should identify the brush grade of each machine, either from service manuals or by visual inspection, and record it in the maintenance card of the machine for proper selection of replacement at a later date.

Brush contact resistance is the resistance offered between the brush and the commutator for the current flow. This resistance value depends upon the grade of brushes, material used for the commutator, contact area between the brush and commutator, and the brush tension. Normally the brush contact resistance is measured in terms of voltage drop at specific current ratings.

Table 2 shows the different grades of brushes and their characteristics.

Table 2

Characteristics of brushes

Grade of carbon	Max. current density A/cm^2	Max.contact resistance $ohms/cm^2$	Pressure on commutator kg/cm^2	Voltage drop in volts
Soft graphite	9 to 9.5 A/cm^2	–	0.12	1.6
Copper carbon	15 to 16 A/cm^2	0.00000465	0.15-0.18	0.25-0.35
Carbon	5.5 to 6.5 A/cm^2	0.000062	0.22-0.27	2
Electro-graphite	8.5 to 9 A/cm^2	0.000031	0.22	1.7-1.8

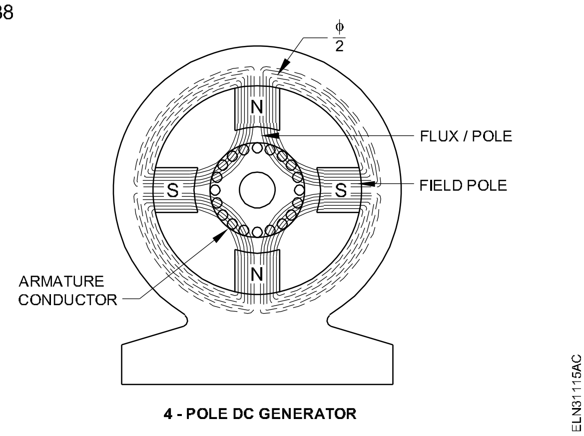
EMF equation of DC generator

When the armature of a DC generator, containing a number of conductors in the form of a winding, rotates at a specific speed in the magnetic field, emf is induced in the armature winding and is available across the brushes. The equation and the numerical problems given as examples will help an electrician to better his understanding about the construction of a DC machine.

Induced emf in a DC generator can be calculated as explained below.

Figure 38 is given for your reference.

Fig 38



Let Ø = flux/pole in weber

Z = total number of armature conductors = No. of slots x No.of conductors/slot

P = No. of poles in the generator

A = No. of parallel paths in armature

N = armature revolution per minute (r.p.m.)

E = emf induced in the generator.

Average emf generated per conductor in one revolution = Rate of change of flux (Faraday's Laws of Electromagnetic induction

$\frac{d\varnothing}{dt}$ volt (since N = 1)

Now, flux cut/conductor in one revolution, (dØ) = PØ Wb

No. of revolutions/second = N/60

Time for one revolution, (dt) = 60/N second

According to Faraday's Laws of Electromagnetic Induction, we have emf generated/conductor/second

$$= \frac{d\varnothing}{dt} = \frac{P\varnothing N}{60} \text{ volts}$$

emf generated in `Z'conductors in the armature assuming

they are all in series $= \frac{P\varnothing ZN}{60}$ volts.

The emf generated in the armature of the DC generator when there are `A' parallel paths in the armature

$$= \frac{P\varnothing ZN}{60\,A} \text{ volts.}$$

Could be written as $= \frac{\varnothing ZN}{60} \times \frac{P}{A}$ volts.

A = 2 - for simplex wave winding

= P - for simplex lap winding.

Example: A four-pole generator, having a simplex wave-wound armature has 51 slots, each slot containing 20 conductors. What will be the voltage generated in the machine, when driven at 1500 r.p.m assuming the flux per pole to be 7.0 mWb?

Solution: $E = \frac{\varnothing ZN}{60} \times \frac{P}{A}$ volts.

Here, Ø= 7x 10^{-3} Wb, Z = 51 x 20 = 1020, P=4, N = 1500 r.p.m.

A = 2 as the winding is simplex wave.

$$E = \frac{7 \times 10^{-3} \times 1020 \times 1500}{60} \times \frac{4}{2} = 357\text{V.}$$

An 8-pole DC generator has 960 armature conductors and a flux per pole of 20mWb running at 500 r.p.m. Calculate the emf generated when the armature is connected as (i) a simplex lap-winding, (ii) a simplex wave winding.

Solution

(i) Simplex lap winding

$$E = \frac{\varnothing ZN}{60} \times \frac{P}{A}$$

$$E = \frac{20 \times 10^{-3} \times 960 \times 500}{60} \times \frac{8}{8} = 160\text{V.}$$

(ii) Simplex wave winding

$$E = \frac{20 \times 10^{-3} \times 960 \times 500}{60} \times \frac{8}{2} = 640\text{V.}$$

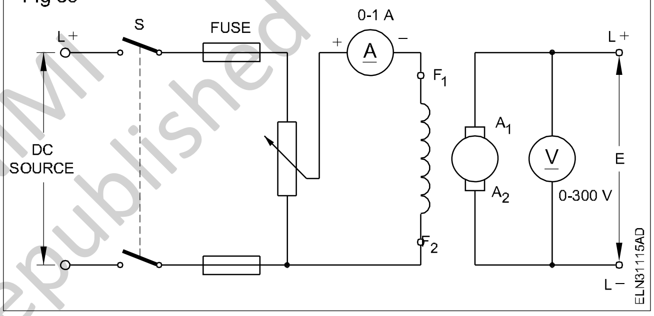
Separately excited DC generator

Introduction

A DC generator is the most commonly used separately excited generator, used for electroplating and battery charging. A separately excited generator is one in which the magnetic field is excited from an external DC source. The DC source may be a DC generator or a battery or a metal rectifier connected to an AC supply. Generally a potential divider is connected across the DC source, and the required DC voltage is supplied to the field as shown in Fig 39.

An ammeter is connected in the field circuit to measure the field current. The shaft of the generator is coupled to a prime mover. (Not shown in Fig 39)

Fig 39



Magnetisation characteristic: This characteristic gives the relation between the field flux and the induced voltage in a generator. However, it is difficult to measure the field flux, and, hence, the field current is taken instead of the field flux. The characteristic curve is drawn by keeping the field current in the `X' axis and the induced emf in the `Y' axis. To draw the characteristic curve, the connections are made as shown in Fig 39, and then, the prime mover is started and made to run at its rated speed, keeping the field switch `s' open. The terminal voltage which appears at the armature terminals is measured and recorded. This small voltage E_r is known as residual voltage which is due to the residual magnetism available in the field cores.

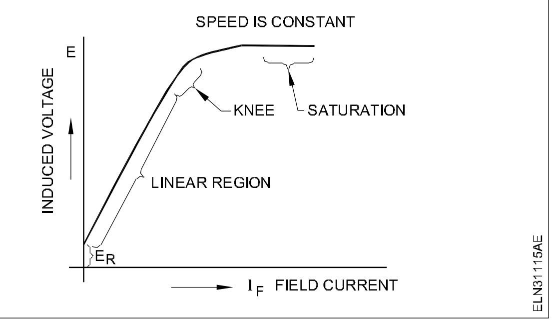
Throughout the experiment, the speed of the generator is held constant. Next, the field switch `S' is closed keeping the potential divider at its minimum position, and gradually the field current is increased in steps. For each step, the field current and the corresponding voltage at the armature terminals are noted. The readings are tabulated in Table 3.

Table 3

Sl.No.	Field current	Terminal voltage

If a graph is plotted between the field current and the terminal voltage, the curve will be as shown in Fig 40. The field current is taken on the X-axis and the emf E on the Y-axis. The curve drawn is known as the magnetisation characteristic of a separately excited generator.

Fig 40



A study of the curve indicates that it starts just above the origin, travels straight in the linear region indicating that the emf induced is directly proportional to the field current I_f.

As the poles are in the process of saturation, the relation between the terminal voltage and the field current no longer stands in direct proportion as indicated by the knee portion of the curve.

Finally when the poles get fully saturated the induced emf ceases to increase even at the increased field current which is indicated by the last portion of the curve and named as saturation region.

Reasons for not building up of voltage in a separately excited generator and their remedies

Sometimes a separately excited generator may not build up voltage. The probable reasons and remedies thereof are given in Table 4.

Load characteristic of a separately excited generator: The load characteristic shows the relation between the load current and the terminal voltage. Through this characteristic curve, we can determine the behaviour of the generator on load.

Fig 41 shows the method of connecting the separately excited DC generator to obtain the load characteristic. The generator speed should be brought to the rated value with the help of the prime mover and the voltage is built up to its normal rated voltage. Then the load switch is closed. Gradually the load is increased in steps. Each time, the load current I_L in amps and the corresponding terminal voltage `V' in volts are noted. The readings are tabulated in Table 5.

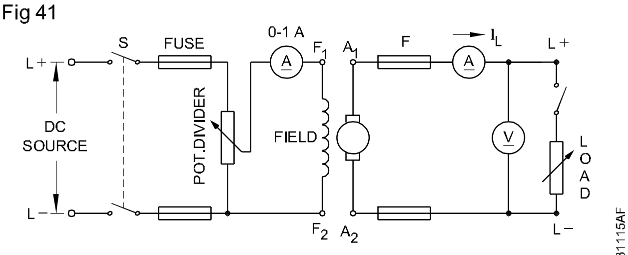
Table 4

Reasons	Remedies
A break or opening in the armature or field circuit.	Test the field and armature circuits for open circuit. Locate the fault and rectify.
A short circuit in the armature or field.	Test the field and armature for short circuit. Locate the fault and rectify.
Loose brush connections or loose brush contact.	Tighten the brush connections. Check up the brush tension. Adjust, if necessary. If the brushes are worn out, replace them.
A dirty or severely pitted commutator.	Clean the commutator for dirt, dust and greasy material. Use trichloroethylene. If the segments are pitted, dress them up.
The speed is too low.	Increase the speed of the generator to its rated speed.
The DC supply for excitation is absent.	Check the DC supply across the field winding terminals. If the supply is not there, check the supply source and rectify the fault Where AC main supply is converted as DC supply through rectifiers, the fault may be located in the rectifier circuit.

Table 5

Sl.No.	Load current I_L in amps	Terminal voltage in volts

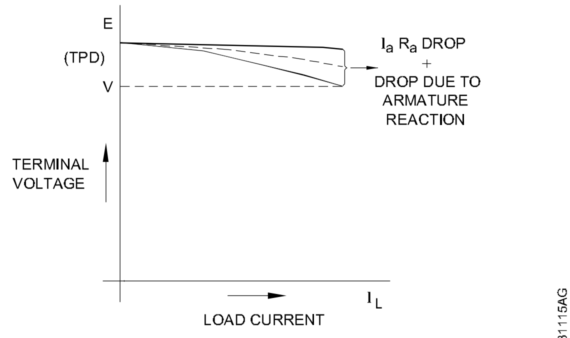
Fig 41



SEPARATELY EXCITED DC GENERATOR

The graph shown in Fig 42 is the load characteristic or external characteristic of a separately excited generator having load current in the X axis and terminal voltage in the Y axis.

Fig 42



EXTERNAL CHARACTERISTIC OF A SEPARATELY EXCITED DC GENERATOR

It is observed from the graph that a slight voltage drop occurs when the generator is loaded. This is due to the armature voltage drop (I_aR_a) and armature reaction.

If the voltage drop from no load to full load is very small, the separately excited DC generator can be regarded as a constant voltage generator.

Advantages of a separately excited generator

The terminal voltage remains almost stable when compared to the self-excited generators because the field circuit is independent of the induced voltage.

As the field is independent, the I_aR_a drop in the armature will not affect the field flux.

This generator can be used where a wide range of terminal voltage is required.

Disadvantage

1 The disadvantage of a separately excited generator is the inconvenience of providing a separate DC source for excitation.

2 Besides it is expensive.

Building up of a DC shunt generator

Objectives: At the end of this lesson you shall be able to
- **explain the conditions and method of building up of voltage in a DC shunt generator**
- **explain the method of creating residual magnetism in the poles of a DC generator**
- **determine the magnetization characteristic of a DC shunt generator**
- **estimate the value of field critical resistance in the DC shunt generator.**

Condition for a self-excited DC generator to build up voltage: For a self-excited DC generator to build up voltage, the following conditions should be fulfilled, assuming the generator is in sound condition.

- There must be residual magnetism in the field cores.
- The field resistance should be below the field critical resistance value.
- The generator should run at the rated speed.
- There must be a proper relation between the direction of rotation and the direction of field current. It could be explained as stated below.

The polarity of the induced voltage must be in such a direction as to produce the field current to assist the residual magnetism.

The polarity of the induced emf depends upon the direction of rotation and the polarity of the field poles depends upon the field current direction.

Even after fulfilling the above conditions, if the self-excited DC shunt generator fails to build up voltage, there may be other reasons as listed in Table 1.

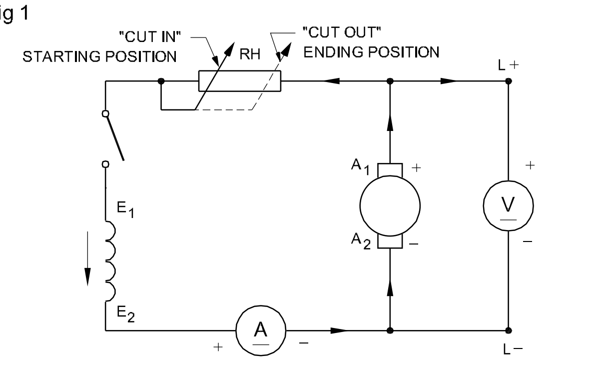
Table 1

Sl.No.	Causes	Reasons	Remedies
1	A break or opening in the field or armature circuit.	Break or loose connection in the field or in the armature winding/circuit. High resistance in the field circuit beyond the field critical resistance value.	Locate the open circuit and rectify. Reduce the resistance of the field regulator.
2	Loose brush connections or contacts.	Improper brush contact/loose brush connections.	Check the brushes for excessive wear, and replace them, if necessary. Check the commutator for pitting. If necessary, turn down the commutator. Always clean the commutator when poor brush contact is discovered. Check the brush tension and readjust it, if necessary Tighten any loose connections.
3	A dirty or severely pitted commutator.	Severe sparking due to overload.	In this case, follow the same procedure as outlined above.
4	A short circuit in the armature or field	Overload or excess heating.	Do a resistance check, ascertain, locate and remove the fault.

Method of building up voltage in a DC shunt generator: Fig 1 shows the circuit diagram for building up voltage in a DC shunt generator. When the generator is made to run at its rated speed initially, the voltmeter reads a small amount of voltage say, 4 to 10 volts. It is due to the residual magnetism. Since the field coils are connected across the armature terminals, this voltage causes a small amount of current to flow through the field coil. If the current flow in the field coils is in the correct direction, it will strengthen the residual magnetism and induce more voltage.

As such, the generated voltage will rise marginally. This rise in voltage, in turn, will further strengthen the increasing field current and induce more voltage. This rise in voltage, in turn, will further strengthen the increasing field current. This cumulative action will build up voltage until saturation is reached. After saturation, any increase in the field current will not increase the induced voltage. However, the whole procedure of building up of voltage takes a few seconds only.

Fig 1



DC SHUNT GENERATOR

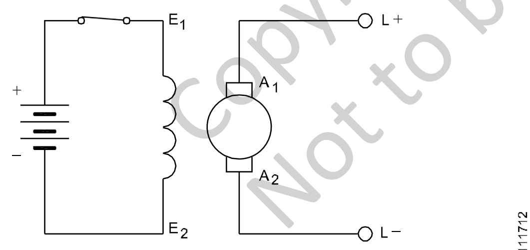
Method of creating residual magnetism: Without residual magnetism, a self-excited generator will not build up its voltage. A generator may lose its residual magnetism due to any one of the following reasons.

- The generator is kept idle for a long time.
- Heavy short circuit.
- Heavy overloading.
- The generator is subjected to too much heat.

When the generator loses its residual magnetism, it can be re-created as stated below.

Flashing of field: One of the methods to create residual magnetism is called the flashing of the `field'. This can be done by connecting the shunt field across a battery or any DC source for a few minutes as shown in Fig 2.

Fig 2



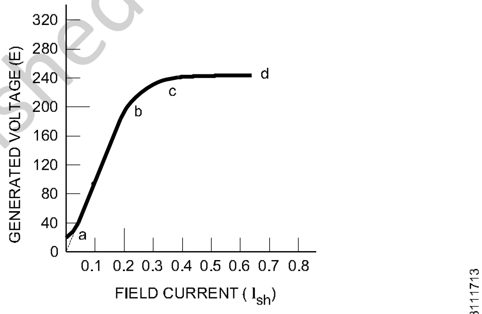
FLASHING OF THE FIELD

While flashing the field, the polarity of the magnetic field, now created, should be the same as that of the residual magnetic field it lost earlier.

In practice, this checking may not be possible. Alternatively note the polarity of the DC supply used for flashing the field and the corresponding field terminals. Run the generator in the specified direction at its rated speed. Measure the residual voltage induced and its polarity. Check whether the polarity of the residual voltage is the same as that of the DC generator. If found reversed, flash the field again by connecting the supply voltage in reverse polarity.

Magnetisation characteristic of a DC shunt generator: The magnetisation characteristic curve shown in Fig 3 gives the relation between the field current and the induced voltage. Referring to the emf equation, the induced emf in a generator is proportional to the flux per pole and the revolutions per minute of the generator. At a constant speed, the generated emf becomes directly proportional to the field flux. In a given machine, the flux depends upon the field current. The graph (Fig 3) illustrates this feature. Because of the residual magnetism, the curved part below point `a' does not start at zero. Between the points `ab', the curve is in almost a straight line indicating that the voltage in the area is proportional to the field current. Between points `b' and `c' a large increase in field current causes only a slight increase in the voltage. It indicates that the field cores are reaching saturation and this part of the curve is called the `knee' of the curve. Between points `c' and `d', the curve is flat indicating that the increased field current is not able to increase the induced voltage. This is due to saturation of the field cores. Because of saturation, the field flux becomes constant, and the induced voltage will not be in a position to increase further. This curve is also called a no-load or open-circuit characteristic curve.

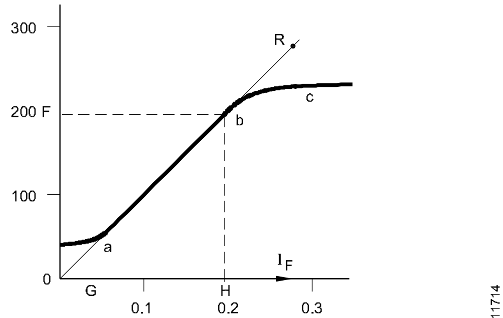
Fig 3



MAGNETISATON CHARACTERISTIC OF A DC SHUNT GENERATOR

Critical resistance: If the shunt field circuit resistance is too large, it does not allow sufficient current to flow into the field to build up its voltage. In other words, it acts like an open field. Therefore, the field circuit resistance should be smaller than a value called critical field resistance. Critical field resistance is the highest value of resistance of the shunt field circuit with which a DC shunt generator can build up voltage. Beyond this value of resistance, the generator fails to build up voltage. The value of the critical resistance can be determined by drawing a tangential line to the open circuit characteristic curve as shown in Fig 4.

Fig 4



FIELD CRITICAL RESISTANCE

For example, by drawing the tangent on the open-circuit characteristic curve as shown by line OR of Fig 4, we find the tangent is parting at point `b' from the curve. By drawing ordinates from point `b' to x and y axis, the value of critical resistance (R_c) can be determined as below.

R_c = Field critical resistance

$$= \frac{\text{voltage represented by the tangent}}{\text{current represented by the tangent}}$$

$$= \frac{OF}{OH} = \frac{200\ V}{0.2\ A} = 1000 \text{ ohms.}$$

Field circuit resistance is the sum of the field resistance and field rheostat resistance. This value should be less than, say 1000 ohms (field circuit resistance) to enable the generator to build up voltage, if the generator is intended to self-excite. Normally this happens when the field regulator resistance is set at a high value.

Test a DC machine for continuity and insulation resistance

Objectives: At the end of this lesson you shall be able to
- **state the necessity of measuring the insulation resistance of an electrical machine**
- **state the frequency of tests**
- **state the required conditions for the tests**
- **state the reasons for the low value of insulation resistance in the machines**
- **state the method of improving the insulation resistance of DC machines.**

Necessity of measuring insulation resistance: The most important aspect in the maintenance of DC machines is taking care of the insulation. Electrical insulation of DC machine windings is designed for the satisfactory operation at the specified voltage, temperature and to retain the electrical and mechanical strength and the dimensional stability over many years of operation. The insulation resistance of DC machines in service should be checked periodically, preferably every month. The possibility of reduction in the value of insulation resistance is due to the continuous working of the machine under full load condition, the heat generated in the winding and local atmospheric moisture, dust and dirt. If they are not checked in time, the insulation becomes weak and the winding will loose its dielectric property, and will ultimately lead to failure of the machine. Periodical checks and measurement of insulation resistance and improvement thereof to the required level will ensure prevention of failure of insulation, and thereby, the breakdown of the machine.

A common device for measuring insulation resistance is a direct indicating insulation tester or Megger. The measurements are made at voltages 500/1000 volt DC depending upon the voltage rating of the machine.

Measurement of insulation resistance: Insulation resistance shall be measured between the winding and frame (earth), and between windings.

For low and medium voltage rated machines, the insulation resistance, when the high voltage test is applied, shall not be less than one megohm as per B.I.S. 9320 - 1979. The insulation resistance shall be measured with a DC voltage of about 500 V applied for a sufficient time for the reading of the indicator to become practically steady, such voltage being taken from an independent source or generated in the measuring instrument.

When it is required to dry out windings at site to obtain the minimum value of insulation resistance, it is recommended that the procedure for drying out as specified in IS:900-1965 may be followed.

Frequency of test: Periodical checks or tests are predetermined in preventive maintenance programmes with a forethought. The planning of the preventive maintenance (PM) schedule should be based on the past experience of maintenance personnel, and the recommendations made by the machine manufacturer. Usually the measurement of insulation resistance is a must during the period of overhauls. The duration of overhaul will be once in 6 months, ideal for DC machines where they are working continuously. Overhauling is done once a year, for such of those machines as are not working continuously. The overhauling is done during plant shut-down periods.

However in DC machines where the overhaul interval is too long, or delayed, it is advisable to have constant vigil and check the insulation resistance at least once a month regularly, and maintain a record of the values of the insulation resistance tests as shown in Table 1.

Table 1

Insulation resistance test

Date	Time	Weather condition	Duty cycle	Test between terminals	Insulation resistance	Remarks

Required conditions for test: The high potential dielectric test and the insulation resistance test are the principal methods of evaluating insulation capability and condition of the machine. The insulation resistance test is often used as a measure of the condition of the winding. Insulation resistance is the ratio of the applied voltage to the leakage current which passes in the circuit at some specified time after the voltage is applied. Direct, rather, than alternating voltages are used for measuring insulation resistance.

The principal currents affecting insulation resistance on application of the test potential for sufficient time are (1) leakage current over the winding surface (2) conduction in current through the insulation material and (3) absorption current in the insulation. The first two currents are steady with time, but the last current delays approximately exponentially from an initial high value. Such insulation resistance measurements are affected by surface conditions (dirt or moisture on the windings), moisture within the insulation wall and the insulation temperature. The magnitude of the test potential may also affect the insulation value, especially if the insulation is not in good condition. Therefore, it is desirable to use insulation resistance as a measure to determine the condition of the machine over a period of years, and to make readings under similar conditions each time and record the values in the test card of the machine in a table similar to Table 1. However, before testing the winding for insulation resistance, it is recommended that the continuity test should be conducted in the armature and field windings to ensure soundness of the respective circuits. As sometimes continuity tests will not reveal internal short circuits, resistance measurement test is recommended, and a record should be maintained for comparison at intervals.

Reasons for low value insulation resistance: The low value of insulation resistance in DC machines is due to excess heat developed in the winding due to their routine working with full load condition or overloading at times or frequent starting with loads. In addition to this, high ambient temperatures are also the reason for low insulation resistance. The other possibility is accumulation of unnecessary local dust and dirt, carbonisation due to brush, local atmospheric moisture, acids and alkalies present in the surroundings of the machine etc. All these are collectively or individually responsible for the weakening of insulation resistance of the winding. Because of these conditions the dielectric property of the insulating material gets reduced, which, in turn, results in low or poor insulation resistance, responsible for the breakdown of the winding due to insulation failure.

Method of improving insulation resistance: On identifying the weak insulation resistance, during the course of preventive maintenance observation in a DC machine, it is necessary to improve the insulation resistance to restore it to a safe value.

Improvement of insulation resistance could be done by any one of the following methods after cleaning the dust and dirt from the machinery.

- By blowing hot air through the machines.
- By heating the machine with carbon filament or incandescent lamps.
- By dismantling and varnishing the winding of the machine.

The following steps are to be adopted for dismantling and varnishing.

- Measure the insulation resistance value between the windings and the frame of the machine and record the value.
- Mark and dismantle the machine.
- Remove dirt and dust in the field winding by blowing dry air with the help of an electric blower.
- Clean and remove dirt, dust and carbon on the armature with special attention to the commutators.
- Clean the brushes, brush-holders and rocker arms.
- Measure the insulation resistance of the winding with an insulation tester; note the values.
- Heat and dry the field coils and armature by external measures.
- Apply insulating varnish of air-drying type to field coils and armature conductors.
- Dry the varnish coating on field coils and armature by external means.
- Measure the insulation resistance and note the improved value of insulation resistance.
- Assemble the machine.
- Measure the insulation value between the windings and the frame of the machine; record the values. Compare these results with those of the first step and make sure the present value shows improvement.
- Connect the machine to the system and run it to check its normal working condition.

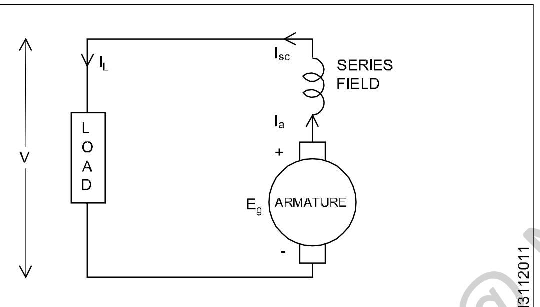
Characteristics of DC generator

Objectives: At the end of this lesson you shall be able to
- **explain the characteristic of DC series generator**
- **explain the characteristic of DC shunt generator**
- **explain the characteristic of DC compound generator**
- **explain the operation of paralleling of DC shunt generators**
- **explain the effect of armature reaction and remedies**
- **explain losses and efficiency of DC generators**
- **explain the routine and maintenance of DC generator.**

Characeteristics of series generator

In these types of generators the field windings, armature windings and external load circuit all are connected in series as shown in Figure 1.

Fig 1



SERIES WOUND GENERATOR

Therefore, the same current flows through armature winding, field winding and the load. Let, $I = I_a = I_{sc} = I_L$ Here, I_a = armature current I_{sc} = series field current I_L = load current There are generally three most important characteristics of series wound DC generator which show the relation between various quantities such as series field current or excitation current, generated voltage, terminal voltage and load current.

Magentic or open circuit characteristic of series wound DC generator

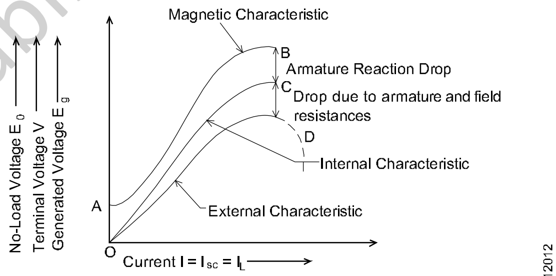
The curve which shows the relation between no load voltage and the field excitation current is called magnetic or open circuit characteristic curve. As during no load, the load terminals are open circuited, there will be no field current in the field since, the armature, field and load are series conected and these three make a closed loop of circuit. So, this curve can be obtained practically by separating the field winding and exciting the DC generator by an external source.

Here in the diagram below AB curve is showing the magnetic characteristic of sereis wound DC generator. The linearity of the curve will continue till the saturation of the poles. After that there will be no further significant change of terminal voltage of DC generator for increasing field current. Due to residual magnetism there will be a small initial voltage across the armature that is why the curve started from a point A which is a little above the origin O.

Internal characteristic of series wound DC generator

The internal characteristic curve gives the relation between voltage generated in the armature and the load current. This curve is obtained by subtracting the drop due to the demagnetizing effect of armature reaction from the no load voltage. So, the actual generated voltage (E_g) will be less than the no load voltage (E_0). That is why the curve is slightly dropping from the open circuit characteristic curve. Here in the diagram below OC curve is showing the internal characteristic or total characteristic of the series wound DC generator. (Fig 2)

Fig 2



Characteristic Curves of Series Wound DC generators

External characteristic of series wound DC generator

The external characteristic curve shows the variation of terminal voltage (V) with the load current (I_L). Terminal voltage of this type of generator is obtained by subtracting ohmic drop due to armature resistance (R_a) and series field resistance (R_{sc}) from the actually generated voltage (E_g). Terminal voltage $V = E_g - I (R_a + R_{sc})$ The external characteristic curve lies below the internal characeristic curve because the value of terminal voltage is less than the generated voltage. Here in the Figure 2 OD curve is showing the external characteristic of the series wound DC generator

Characteristic curves of series wound DC generators

It can be observed from the characteristics of series wound DC generator, that with the increase in load (load is increased when load current increases) the terminal voltage of the machine increases. But after reaching its maximum value it starts to decrease due to excessive demagnetizing effect of armature reaction. This phenomenon is shown in the figure by the dotted line.

Dotted portion of the characteristic gives approximately constant current irrespective of the external load resistance. This is because if load is increased, the field current is increased as field is series connected with load. Similarly if load is increased, armature current is increased as the armature is also series connected with load. But due to saturation, there will be no further significance raise of magnetic field strength hence any further increase in induced voltage. But due to increased armature current the affect of armature reaction increases significantly which causes significant fall in load voltage. If load voltage falls, the load current is also decreased proportionally since current is proportional to voltage as per ohm's law. So increasing load tends to increase the load current, but decreasing load voltage, tends to decrease load current. Due to these two simultaneous effects, there will be no significant change in load current in dotted portion of external characteristics of series wound DC generator. That is why series DC generator is called constant current DC generator.

The external/load characteristic of a shunt generator: The external/load characteristic is important for judging the suitability of a generator for a particular purpose. When the DC shunt generator is loaded, it is found that the terminal voltage drops with increase in the load current. In a shunt generator, the field current appears to be constant, and, hence, `V' also should remain constant and be independent of the load. But, it is not so practically. There are two main reasons for the drop in terminal voltage. They are :

- armature resistance drop (directly)
- armature reaction drop (indirectly).

Because of the above two reasons, the terminal voltage is reduced. This in turn affects the field current also. The decreased field current reduces the field flux which further reduces the induced emf.

Armature resistance drop: According to formula

Terminal voltage = Induced emf – armature voltage drop

$V = E - I_a R_a$

where I_a is the armature current

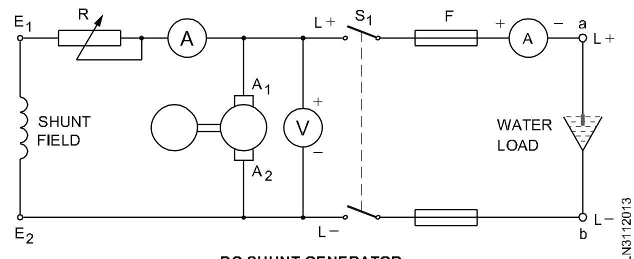
and R_a is the armature circuit resistance.

As such, when the load current is increased, more voltage is dropped in the armature circuit. Hence, the terminal voltage `V' decreases, under load condition.

Armature reaction drop: Due to the demagnetising effect of armature reaction, the main pole flux is weakened, and the induced emf (E) will be reduced in its magnitude.

The external characteristic gives the relation between terminal voltage and load current. Fig 3 gives the circuit diagram to determine this characteristic. The generator is first built up to its rated voltage. Then it is loaded in suitable steps up to full load. The terminal voltage and the corresponding load currents are noted for each step.

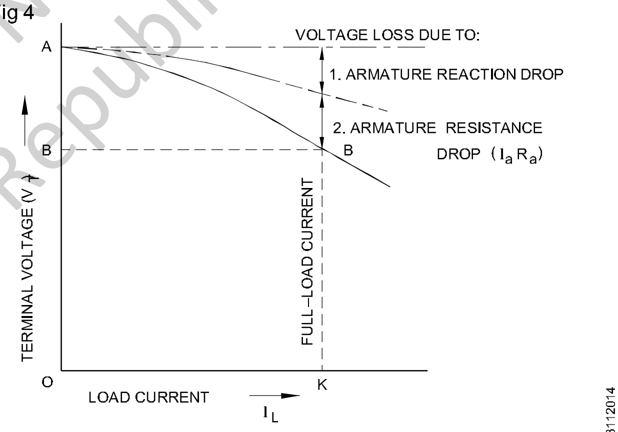
Fig 3



DC SHUNT GENERATOR

In this experiment, the field current has to be kept constant. This is due to the fact that when terminal potential decreases on load, the field which is connected across the armature will have a decreased current. This effect, if allowed, will reduce the field flux, thereby, decreasing the induced voltage. This effect cumulatively reduces the terminal voltage further. From the obtained values of the terminal voltage V_T and load current IL, the external characteristic curve is plotted as shown in Fig 4, keeping in V_T on `Y' axis and I_L on X axis. From the curve it will be observed that the no-load voltage OA is maximum, and it falls to OB when loaded, to indicate that the full load current value is OK as noted in the name-plate of the generator.

Fig 4

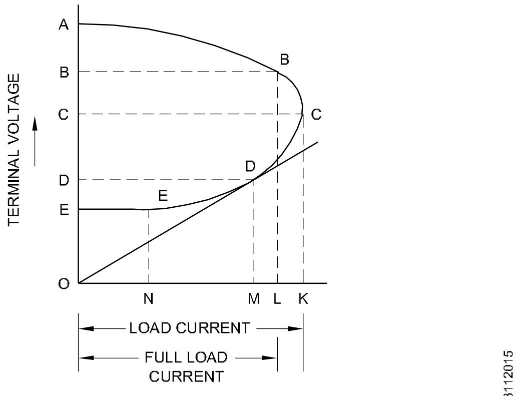


EXTERNAL CHARACTERISTIC CURVE OF DC SHUNT GENERATOR

Fall of voltage from no load to full load, which is due to armature reaction, and the armature voltage drop are found to be not appreciable. Normally the generators are designed to deliver full load current I_L, and the fall of voltage will be about 5 to 8 percent of the no-load voltage which can be regarded as negligible. If the load current is further increased by decreasing the load resistance, the curve reaches a point `C' as shown in Fig 5. At this point, the terminal voltage falls to OC which will be an appreciable fall when compared to the no-load terminal voltage. At this point `C', though the load current is maximum (OK), the terminal voltage will be much less than the no-load voltage.

However, when the load resistance is further decreased the load current decreases to OM and V_T is reduced to `OD', that means the load current cannot be increased beyond OK and the point `C' is called the breakdown point. It is the maximum possible current that a generator can supply. Beyond this point `C', the curve drops rapidly with decrease in the load resistance, indicating that the load current is also decreasing, instead of increasing. At point `E' the generator is virtually short-circuited, and all the voltage induced is dropped to near zero due to IaRa drop and armature reaction. Rather, we can say OE is the residual voltage of the generator. Practically all the generators operate only on the portion `AB' of the curve where the efficiency of the generator is maximum.

Fig 5



EXTERNAL CHARACTERISTIC CURVE (FULL CURVE)

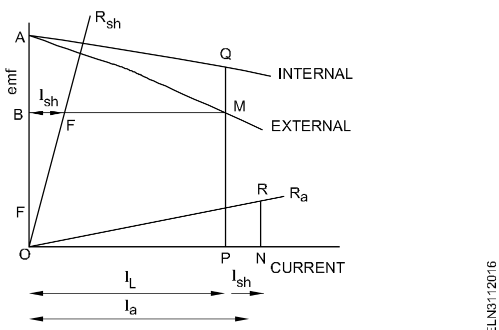
Internal characteristic: The internal characteristic gives the relation between induced voltage and the armature current. In a shunt generator,

$$I_a = I_L + I_{sh} \qquad E = V_T + I_a R_a$$

$$I_{sh} = \frac{V_T}{R_{sh}}$$

So, E/I_a curve can be obtained from the external characteristic shown in Fig 4. By plotting `$I_{sh}$' horizontally against `V', we get Rsh line which is a straight line through the origin, but because of the high resistance of the shunt field it has a very steep gradient as shown in Fig 6. Also draw the armature resistance(R_a) line by plotting the drop in voltage against the armature current as shown in Fig 4. Take any point `M' on the external characteristic (Fig 4) and draw the perpendicular `MP'. Then for the given terminal voltage the load current I_L = OP. Draw 'MB' horizontally, then BF = I_{sh}, and mark off PN = BF in the 'X' axis.

Fig 6



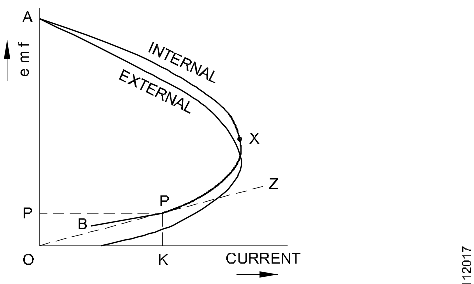
Then ON = OP + PN = ($I_L + I_{sh}$) = I_a.

Draw a line vertically from N to meet the armature resistance line Ra at `R'. Then, the vertical line `RN' is equal to the drop in the armature and, therefore, if the line PM is extended further to point `Q', making MQ = RN, the total length `PQ' is the sum of the terminal voltage and total armature drop, which is equal to the emf generated. Thus a point `Q' on the internal characteristic is obtained, and the total (internal) characteristic can be drawn by joining points A and Q.

If the load resistance is decreased, then the curve turns back as in Fig 7. If the load resistance is too small, then the generator is short-circuited and there is no generated emf due to heavy demagnetisation of the main poles.

Load critical resistance: It is defined as the minimum value of load resistance with which the generator builds up voltage, and, just below this value of load resistance the DC shunt generator will fail to build up its voltage when started with the load. When the DC shunt generator is started with the load, the terminal voltage may not raise beyond about 10V, the reason is the load resistance is so low, as if the generator is short-circuited. In Fig 7 the tangent line `OZ' to the internal characteristic APB is drawn. Its slope will give the value of the load critical resistance. As the DC shunt generator will not build up emf when made to build up with load below this value of resistance, it is called the load critical resistance.

Fig 7



INTERNAL & EXTERNAL CHARACTERISTIC CURVE

Load critical resistance in ohms =

$$\frac{\text{Voltage at point 'P'}}{\text{Load current at point 'P' (amps)}} = \frac{OP}{OK}$$

There are thus two critical resistances for a shunt generator, one for the field circuit and the other for the load external circuit.

Applications of DC shunt generator: According to the load characteristic of the DC shunt generator, the drop in voltage from no load to full load is not appreciable, up to its rated value of load current. Hence, it can be called a constant voltage generator. Therefore, it can be used for constant loads like:

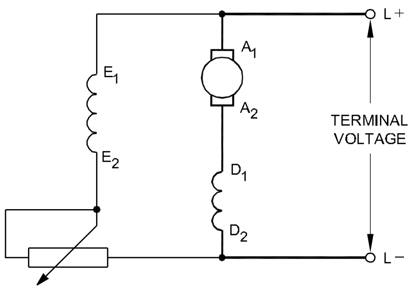
- centrifugal pump
- lighting load
- fans

- battery charging and electroplating.

Compound generator: Combination of shunt field and series field within one generator provides two sources of excitation, and such a generator is called a compound generator.

Long shunt compound generator: When the shunt field is connected in parallel with the series combination of the armature and the series field, the generator is said to be connected as a long shunt compound generator which is shown in Fig 8.

Fig 8

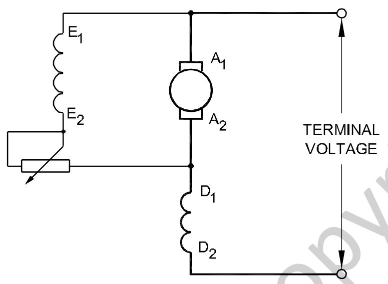


LONG SHUNT COMPOUND GENERATOR

ELN3112018

Short shunt compound generator: When the shunt field is connected in parallel with only the armature, the generator is said to be connected as a short shunt compound generator which is shown in Fig 9.

Fig 9



SHORT SHUNT COMPOUND GENERATOR

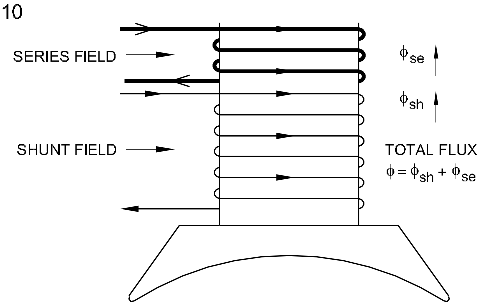
ELN3112019

Cumulative compound generator: The shunt field excitation flux is usually more or less steady, and is affected only slightly as the terminal voltage fluctuates. The flux of the series field is quite variable because its ampere-turns depend upon the load current. When the load current is zero, it produces less flux (long shunt) or no flux (short shunt) and when the load current is high, it creates a good amount of flux. How much flux it must develop depends upon the extent to which it must compensate for the voltage drop. In a compound machine, the series field is wound directly over the shunt field with proper separation by insulations.

The series field coils may be connected to `assist' or `aid' the shunt field, as shown in Fig 10. Then this machine is said to be a cumulative (increasing by successive additions) compound generator. The ampere turns of the series field determines the amount of compounding.

Differentially compounded generator: If the flux produced by the series field opposes the shunt field flux as shown in Fig 11, then the action is called `bucking' and the machine is said to be a differential (decreasing by successive subtractions) compound generator.

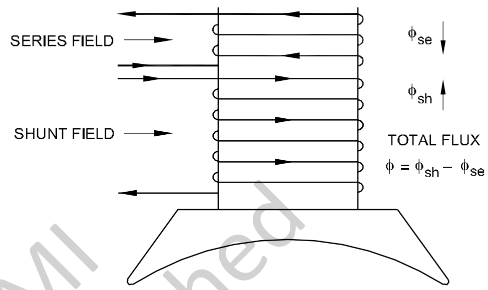
Fig 10



CUMULATIVE COMPOUNDING

ELN311201A

Fig 11



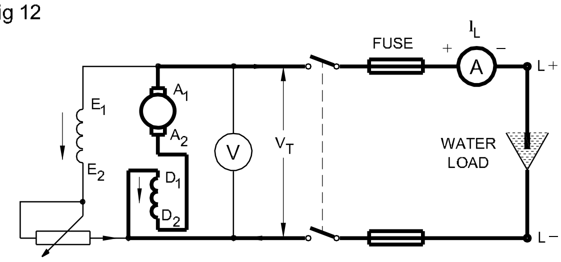
DIFFERENTIAL COMPOUNDING

ELN311201B

External characteristics of DC compound generator

Cumulative compound generator: Fig 12 shows the connection diagram for a long shunt cumulative compound generator. In such a connection, the series field aids the shunt field and the total flux is equal to the sum of both the fluxes. By taking a set of readings for different load currents I_L and the corresponding terminal voltage V_T, we can draw a graph showing the relation between V_T and I_L. This curve is called the external characteristic curve.

Fig 12

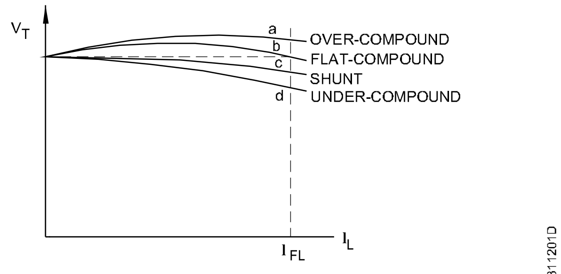


LONG SHUNT CUMULATIVE COMPOUND GENERATOR CONNECTION DIAGRAM

ELN311201C

If the shape of the curve is as shown in curve `C' of Figure 13, then it will be the same as the curve shown for the shunt generator, and this generator could be used for constant voltage loads. If the shape of the curve is as shown in curve `a' of Fig 13, it shows that the terminal voltage goes on increasing with an increase of the load current. It is due to the reason that the series ampere-turns produce more flux than the flux required to over come the IaRa drop and the armature reaction. Such a machine is called an over-compounded generator, and this generator could be used for supplying load to long distance distribution lines so that the voltage drop in the line could be compensated by increased voltage.

Fig 13



EXTERNAL CHARACTERISTICS OF COMULATIVE COMPOUND DC GENERATORS

If the shape of the curve is as shown in curve `b' of Fig 13, it shows that the series ampere-turns at light load are producing more flux than required to overcome the I_aR_a drop but at full load the series field flux is just sufficient to overcome the I_aR_a drop and armature reaction. Such a machine is called a flat (level) compounded generator, and this generator could be used for supplying power to constant loads requiring specified terminal voltage.

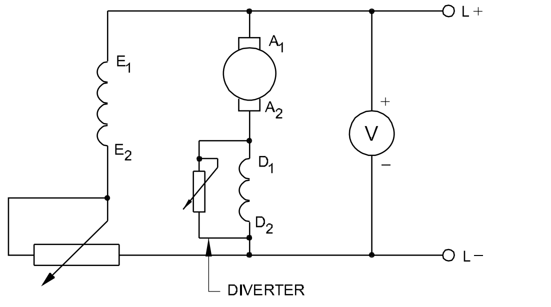
If the shape of the curve is as shown in curve `D', it shows that the series ampere-turns are not sufficient to overcome the drop in the terminal voltage due to the I_aR_a drop and the armature reaction but still they are aiding the shunt field. Such a machine is called an under-compounded generator, and this generator may be used for electroplating or lighting.

Degree of compoundings in a cumulative compound generator: The level of compounding in a generator can be altered by the amount of the series field current. Hence to adjust the series field current, a diverter may be connected as shown in Fig 14.

Differential compound generator: If the series field terminals are interchanged as shown in Fig 15, then the curve obtained may be as shown in Fig 16. In such a connection, the series field opposes the shunt field, and the generator becomes a differential compound generator. The total flux produced will be equal to the shunt field flux minus the series field flux. From the curve, it is clear that the terminal voltage drastically reduces with increase in the load current. It is due to the reason that series ampere-turns produce flux which are opposing or bucking the shunt field flux. This characteristic may be used in welding work, where the potential difference between the electrode and the job before striking an arc is in the order of, say 100V, and when the arc strikes it falls to, say 40 to 50 V, to maintain the flow of current.

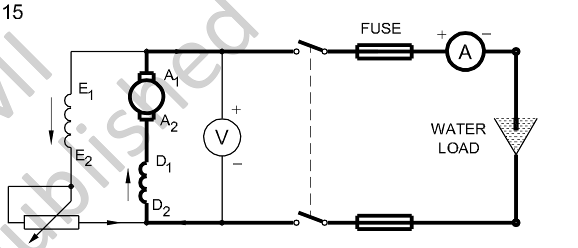
Application of a compound generator: Table 1 gives the different types of compound generators and their application in industry.

Fig 14



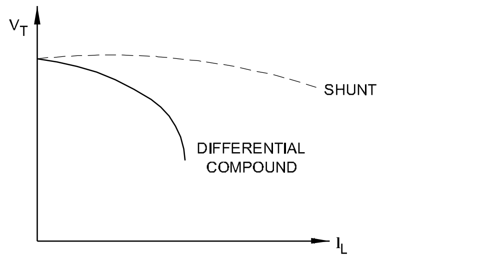
SERIES FIELD DIVERTER IN COMPOUND GENERATOR

Fig 15



CUMULATIVE COMPOUND GENERATOR CIRCUIT

Fig 16



EXTERNAL CHARACTERISTIC OF DIFFERENTIAL COMPOUND DC GENERATOR

Table 1

Sl.No.	Type of compound generator	Uses
1	Cumulative compound generator	
	a. Over-compounded	Used where the load is at a considerable distance from the generator as in railways, street lights etc.
	b. Flat or level compound	Used where the load is nearby, such as lighting loads and power loads of small buildings or lathes which require constant voltage.
	c. Under-compounded	Used for electroplating, lighting, etc.
2	Differential compound generator	Used for arc welding generators.

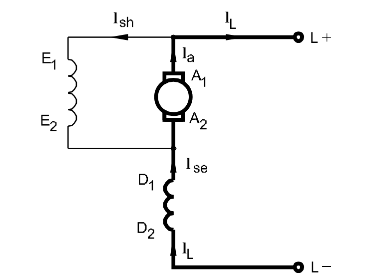
Numerical problems pertaining to DC generator: When the generator is loaded, there will be voltage drops in the armature resistance and series field resistance. To calculate the induced emf from the available data, the following steps should be adopted.

$Eg = V + I_a R_a + I_{se} R_{se}$

In the case of a short shunt compound generator

shown in Fig 17, $I_{se} = I_L$ and $I_a = I_L + I_{sh}$.

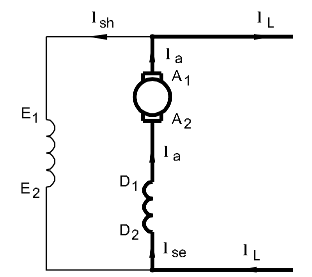
Fig 17



SHORT SHUNT COMPOUND GENERATOR

In the case of a long shunt compound generator shown in Fig 18 $I_{se} = I_a$ and $Ia = I_L + I_{sh} = I_{se}$

Fig 18



LONG SHUNT COMPOUND GENERATOR

where I_a = armature current in amps

I_{sh} = shunt field current in amps

I_{se} = series field current in amps

I_L = load current in amps.

Example: A long-shunt compound generator delivers a load current of 100 A at 400 V, and has armature, series field and shunt field resistances of 0.1 ohm, 0.03 ohm and 200 ohm respectively. Calculate the generated voltage and the armature current. Allow 1 V per brush for contact drop.

Solution

Generator circuit is shown in Fig 19.

I_{sh} = 400/200 = 2 A

Current through armature and series winding is the same. Hence $I_a = I_{se}$ = 100 + 2 = 102 A.

Voltage drop in series field winding= $I_{se} R_{se}$ =102 x 0.03 = 3.06 V

Armature voltage drop $I_a R_a$ = 102 x 0.1 = 10.2 V.

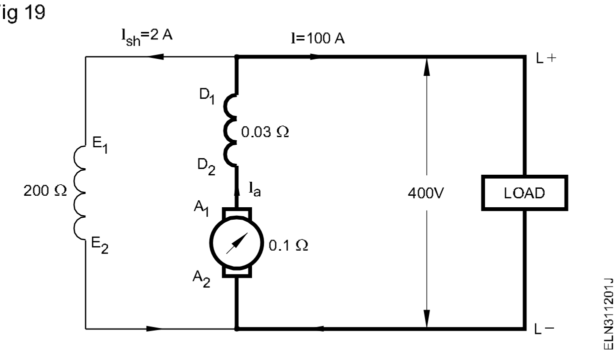
Assuming 2 brushes,

drop at brushes = 2 x 1 = 2 V.

Now, $E_g = V + I_a R_a$ + series drop + brush drop

= 400 + 10.2 + 3.06 + 2 = 415.26 V

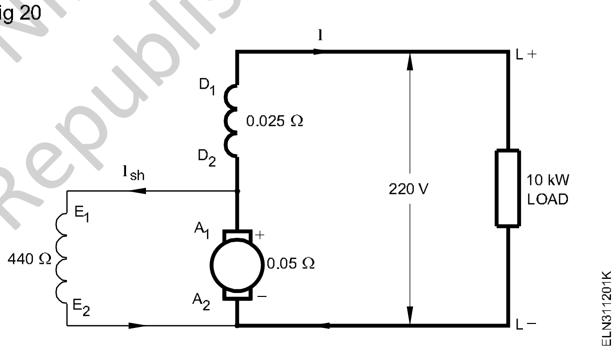
Fig 19



Example: A 10 kW compound generator works on full load with a terminal voltage of 220 V. The armature, series and shunt windings have resistances of 0.05 ohm, 0.025 ohm and 440 ohms respectively. Calculate the total emf generated in the armature when the machine is connected as short shunt.

Solution: Generator circuit is shown in Fig 20.

Fig 20



$$\text{Load current} = \frac{\text{Load in watts}}{\text{Ter min a voltage}} = \frac{10,000}{220} = 45.45\text{A}.$$

Voltage drop in series windings = 45.45 x 0.025 = 1.14 V.

Voltage across shunt winding = 220 + 1.14 = 221.14 V

I_{sh} = 221.14/440 = 0.503 A

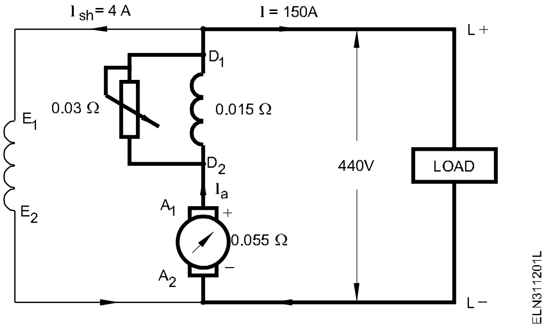
I_a = 45.45 + 0.503 = 45.953 A

$I_a R_a$ = 45.953 x 0.05 = 2.297 V.

Generator emf = Terminal voltage + voltage drop in armature + voltage drop in series field = 220 + 2.297 + 1.14 = 223.44 V.

Example: In a long-shunt compound generator, as shown in Fig 21, the terminal voltage is 440 V when the generator delivers 150 A. Determine (i) induced emf (ii) total power generated and (iii) distribution of this power given that shunt field, series field, divertor and armature resistances are 110 ohms, 0.015 ohm, 0.03 ohm and 0.055 ohm respectively.

Fig 21



Solution

I_{sh} = 440/110 = 4A;

I_a = 150 + 4 = 154 A

Since the series field resistance and divertor resistance are in parallel (Fig 14), their combined resistance is = 0.03 x 0.015/0.045 = 0.01 ohm.

Total armature circuit resistance is = 0.055 + 0.01 = 0.065 ohm.

voltage drop across the series field and armature = 154 x 0.065 = 10.01V.

(i) Voltage generated by armature E_g = 440 + 10.01 = 450.01 V, say 450 V

(ii) Total power generated by armature = $E_g I_a$ = 450 x 154 = 69,300 W.

(iii) Power lost in armature = $I_a^2 R_a$ = 154^2 x 0.055 = 1304.4 W.

Power lost in the series field and divertor = 154^2 x 0.01

= 237.2 W

Power dissipated in shunt winding = $V I_{sh}$ = 440 x 4

= 1760 W

Power delivered to load = 440 x 150

= 66000 W.

Parallel operation of DC generators

Parallel Operation of DC Generators: In a dc power plant, power is usually supplied from several generators of small ratings connected in parallel instead of from one large generator.

The necessity of parallel operation

1 **Continuity of service:** If a single large generator is used in the power plant, then in case of its breakdown, the whole plant will be shut down.

The supply can be obtained from a number of small units operating in parallel, then in case of failure of one unit, the continuity of supply can be maintained by other healthy units.

2 **Efficiency:** Generators run most efficiently when load demand on power plant decreases, one or more generators can be shut down and the remaining units can be efficiently loaded.

3 **Maintenance and repair:** If generators are operated in parallel, the routine or emergency operations can be performed by isolating the affected generator while load is being supplied by other units. This leads to both safety and economy.

4 **Increasing plant capacity:** When added capacity is required, the new unit can be simply paralleled with the old units to increase the plant capacity.

Conditions for paralleling of DC Generators

1 Output voltage must be same

2 Polarities must be same

Connecting Shunt Generators in Parallel: The generators in a power plant are connected in parallel through bus-bars. The bus-bars are heavy thick copper bars and they act as +ve and -ve terminals. The positive terminals of the generators are .connected to the +ve side of bus-bars and negative terminals to the negative side of bus-bars. Fig. 22 shows shunt generator 1 connected to the bus-bars and supplying load. When the load on the power plant increases beyond the capacity of this generator, the second shunt generator 2 is connected in parallel with the first to meet the increased load demand.

Operation of paralleling of DC Generator

1 The prime mover of generator 2 is brought up to the rated speed. Now switch S_4 in the field circuit of the generator 2 is closed.

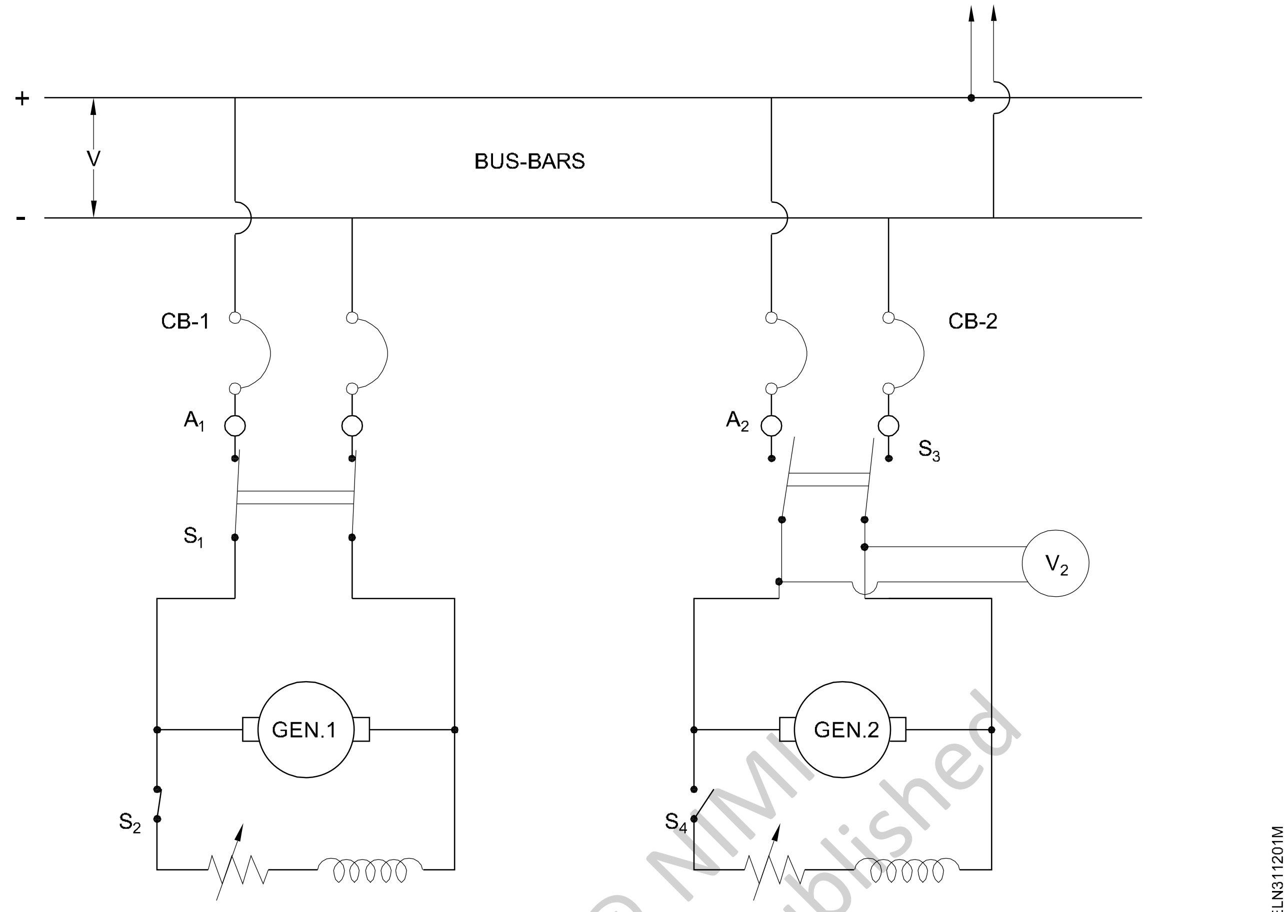
2 Next circuit breaker CB_2 is closed and the excitation of generator 2 is adjusted till it generates voltage equal to the bus-bars voltage. This is indicated by voltmeter V_2.

3 Now the generator 2 is ready to be paralleled with generator 1. The main switch S_3 is closed, thus putting generator 2 in parallel with generator 1. Note the generator 2 is not suplying any load because its generated emf is equal to bus-bars voltage. The generator is said to be "floating" (i.e. not supplying any load) on the bus-bars (Fig 22).

4 If generator 2 is to deliver any current then its generated voltage E should be greater than the bus-bars voltage V. In that case, current supplied by it I = (E-V)/Ra is the resistance of the armature circuit. By increasing the field current (and hence induced emf E), the generator 2 can be made to supply proper amount of load.

5 The load may be shifted from one shunt generator to another merely by adjusting the field excitation. Thus if generator 1 is to be shut down, the whole load can be shifted onto generator 2 provided it has the generator 1 to zero (This will be indicated by ammeter A_1) open CB_1 and then open the main switch S_1

Fig 22



Load Sharing: The load may be shifted from one generator to another merely by adjusting the field excitation. The load sharing of two generators which have unequal no-load voltages. Let E_1, E_2 = no-load voltages of the two generators R_1, R_2 = their armature resistances

Thus current output of the generators depends upon the values of E_1 and E_2. These values may be changed by field rheostats. The common terminal voltage (or bus-bars voltage) will depend upon (i) the emfs of individual generators and (ii) the total load current supplied. It is generally desired to keep the busbars voltage constant. This can be achieved by adjusting the field excitations of the generators operating in parallel.

Armature reaction

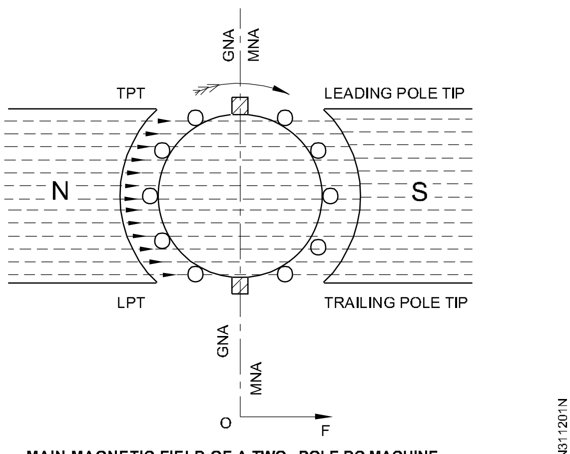
When armature conductors carry a lower load current, the mmf set up by the armature conductors interact with the main field flux in such a way that the field of the main field flux gets distorted and this is called cross-magnetizing effect.

However, the effect could be nullified by shifting the brush position of the generator by a small angle in the direction of rotation.

When the generator is loaded further, the pole tips get saturated which results in demagnetising the main field flux, thereby reducing the induced emf. This effect is called demagnetising effect, and can be explained further.

Fig 23 shows the flux distribution by the main field flux only. Since there is no current in the armature conductors, the flux is uniform. The GNA (Geometrical Neutral Axis) and MNA (Magnetic Neutral Axis) are coincident with each other.

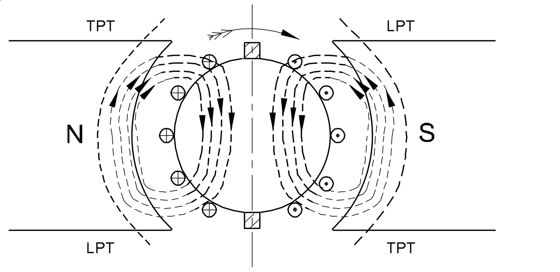
Fig 23



MAIN MAGNETIC FIELD OF A TWO - POLE DC MACHINE

Fig 24 shows the flux set up by the armature conductors alone. The current direction is marked as a plus sign(+), under the N.pole and dot (•) under the south pole as shown in the figure. The strength of this armature field (mmf) depends upon the armature current which, in turn, depends upon the load current.

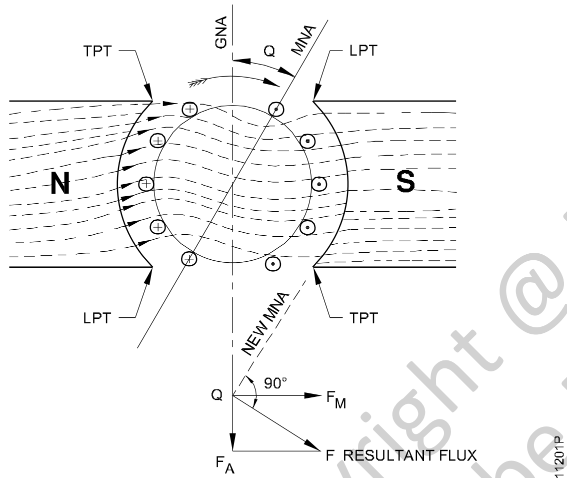
Fig 24



FLUX CREATED BY THE ARMATURE CURRENT

Cross-magnetising effect: Fig 25 shows the flux distribution by the combined effect of the main field and the armature mmf. The resulting field is found to have strengthened at the trailing pole tips and weakened at the leading pole tips. Due to this cross-magnetizing effect, the magnetic neutral axis (MNA) is shifted from the geometrical neutral axis (GNA) by an angle Q in the direction of rotation.

Fig 25



CROSS - MAGNETISING EFFECT

The effect of the main field flux (FF) and the armature flux (F_A) are shown by vectors in Fig 25. The magnetic neutral axis (MNA) should be at right angle to the resultant flux (F).

Remedy: The effect of the cross-magnetisation can be neutralized by shifting the brushes from GNA to MNA with the help of the rocker arm. Of course the amount of shifting depends upon the magnitude of the armature current. At the correct position of the brush, the induced emf will be maximum and the spark at the sides of brushes will be minimum.

Demagnetising effect: The uneven distribution of magnetic flux at heavy armature current results in a demagnetizing effect because strengthening on the trailing pole tip is only up to saturation of that tip. After saturation the flux cannot increase at the trailing tips equally with the decrease in flux at the leading pole tips which causes the demagnetising effect, and hence, the induced emf reduces under heavy load condition.

Remedy: To compensate the demagnetizing effect of the reduced induced emf, the ampere-turns are increased in the field winding itself to strengthen the main field for small machines. But, for large machines, the demagnetizing effect can be neutralized by providing compensating winding in the main pole-faces as shown in Fig 26, and connecting this compensating winding in series with armature as shown in Fig 27, which is for a compound machine.

Fig 26

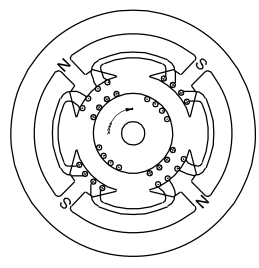
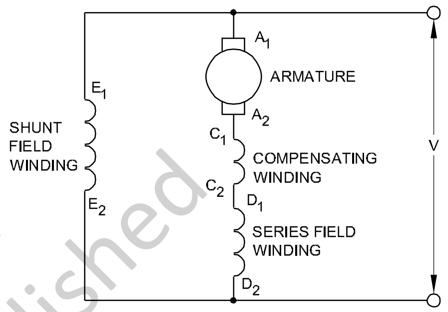


Fig 27



Compensating winding: The demagnetizing effect due to armature reaction in large machines, which are subjected to fluctuation of load, can be neutralized by this winding.

This winding carries an equal current in the opposite direction to the current in armature conductors. So the flux set up by them is also in the opposite direction and of equal magnitude to that of the armature flux. Hence they neutralize each other, and thereby, the demagnetising effect is nullified at any load, even at fluctuating loads.

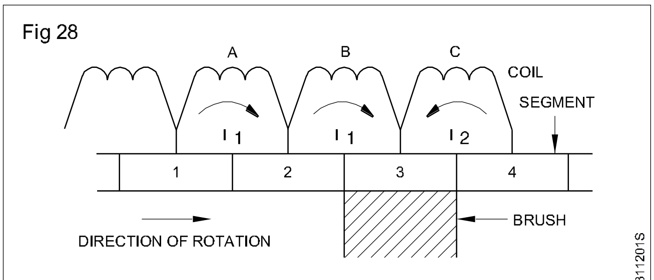
Commutation

When a DC generator is loaded, the current flows through the armature winding, commutator and brushes to the external circuit. During this process, whenever a brush spans the two commutator segments, the winding element connected to those commutator segments is short-circuited. The changes in current direction, which take place in the winding element, just before, during and after the short circuit is called commutation.

If the change in the current direction is gradual, then a smooth commutation takes place. On the other hand a sudden change in current in the winding element is called rough commutation which results in heavy sparking at the sides of brushes. If rough commutation is allowed to continue, the brushes and commutator get spoiled ultimately due to the excess heat produced by the sparks.

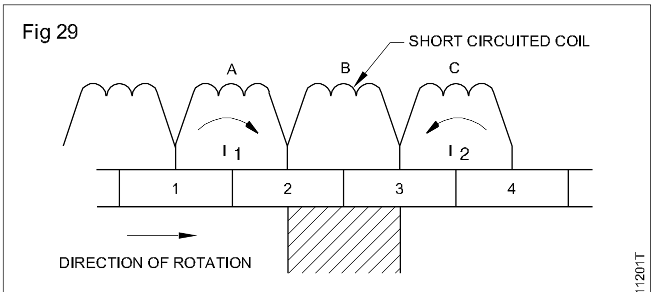
These changes in current are explained through the following figures. Fig 28 shows the current in the coil B flows in a clockwise direction, and the brush collects I_1

amps from the left side winding and I_2 amps from the right side winding.



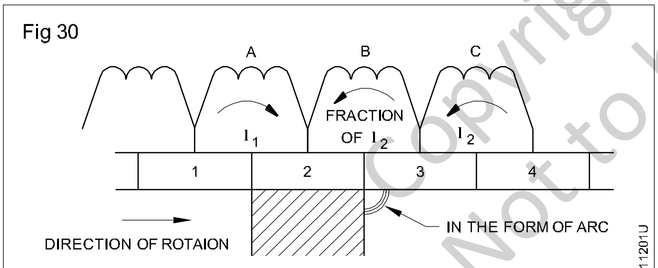
CURRENT COLLECTION - SEGMENT 3 IN CONTACT WITH THE BRUSH

Fig 29 shows that the brush short-circuits segments 2 and 3, and hence, coil B is short-circuited. Current I_1 in the left side winding passes to the brush through coil A, and the right side winding current passes through coil C. No current is in coil B as it is short-circuited.



CURRENT COLLECTION-SEGMENTS 2 & 3 ARE IN CONTACT WITH THE BRUSH

Fig 30 shows that the brush contacts segment 2 only, and the current in the left side winding passes to the brush through coil A. On the other hand the current in the right hand side (I_2) should now pass through coil B via segment 2 to the brush.



CURRENT COLLECTION - SEGMENT 2 IN CONTACT WITH THE BRUSH

At this instant, the current in coil B, has to change its direction from clockwise to anticlockwise, but even though it changes it would not attain the full value of current after the short circuit. Therefore, a major portion of current I_2 from the right side passes to the brush through an arc from segment 3. This is due to the fact that the sudden change of current direction in coil B induces a statically induced (reactance) emf equal to $\frac{\varnothing}{t}$ or $\frac{I}{t}$

where Ø is the flux created by the current I in amps, and 't' represents the time of short circuit in seconds.

Further, the induced emf can also be calculated by knowing the reactance of the coil under commutation which depends upon the self-inductance of the coil, and the mutual inductance of the neighbouring coils.

For example, a2-pole, 2-brush DC generator delivers 100 amps to a load when running at 1440 r.p.m., and has 24 segments in its commutator. Then to find the statically induced emf in the winding element soon after the short-circuit, we have the current from the left side of the brush - 50 amps and the current from the right side of the brush - 50 amps.

Hence the change of current is from 50 amps in the clockwise direction to zero, then to 50 amps in the anticlockwise direction amounting to 100 amps.

Time taken for one revolution

$$= \frac{60}{1440} = 0.04166 \text{ seconds}$$

Time taken for short circuit

$$= \frac{0.04166 \text{ seconds}}{24 \text{ segments}} = 0.001736 \text{ seconds}$$

which is equal to time reqd. to pass one segment

Hence the statically induced emf

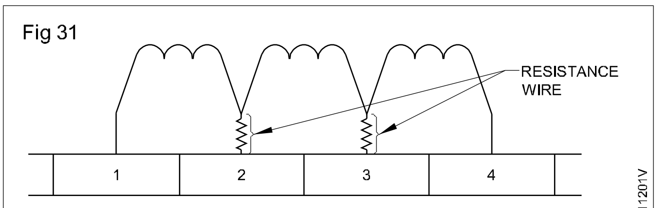
$$= \frac{I}{t} = \frac{100}{0.001730} = 57{,}603\text{V}.$$

This induced emf will obey Lenz's law, and oppose the change in the current. Hence the current from the right hand side as shown in Fig 30 would not be able to pass through coil B, and hence it jumps to the brush in the form of an arc. This is called rough commutation.

Remedies for rough commutation by providing interpoles

To avoid sparks in the brush position, the following methods are used which effectively change the rough commutation to smooth commutation.

- Resistance wires are introduced between the end connection of the coil to the commutator, as shown in Fig 31. This increased resistance helps the current to change its direction smoothly, increasing the timing and reducing the statically induced emf.

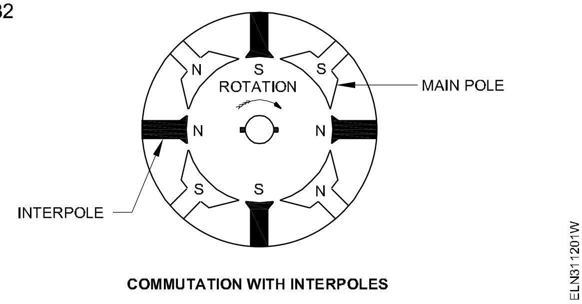


COMMUTATION WITH RESISTANCE WIRES

- High resistance brushes are used. Hence the contact resistance variation allows the current to change its direction smoothly, thereby reducing the statically induced emf.
- Small field poles called inter-poles are provided in between the main poles as shown in Fig 32. These inter-poles have their polarity the same as the next pole

ahead in the direction of rotation of the, generators. Further, their winding is connected in series with the armature so that they carry the same current as that of the armature.

Fig 32

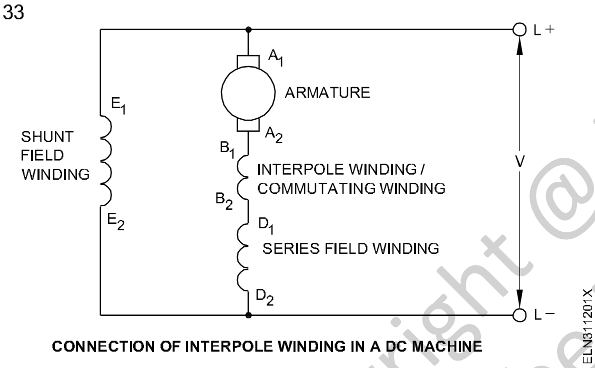


COMMUTATION WITH INTERPOLES

These inter-poles produce an emf opposite in direction to the statically induced emf, and have a magnitude depending upon the current. Thereby, the effect of statically induced emf is nullified.

These inter-poles are wound with less number of turns having thick gauge wire. Fig 33 shows the connection of inter-pole winding in a DC compound machine.

Fig 33



CONNECTION OF INTERPOLE WINDING IN A DC MACHINE

Losses and efficiency of DC machines

It is convenient to determine the efficiency of a rotating machine by determining the losses than by direct loading. Further it is not possible to arrange actual load for large and medium sized machines. By knowing the losses, the machine efficiency can be found by

$$\eta = \frac{\text{output}}{\text{output} + \text{losses}} \left(\text{For generators}\right)$$

$$\eta = \frac{\text{input - losses}}{\text{input}} \left(\text{For motors}\right)$$

In the process of energy conversion in rotating machines - current, flux and rotation are involved which cause losses in conductors, ferromagnetic materials and mechanical losses respectively. Various losses occurring in a DC machine are listed below (FIg 34 shows losses of DC machine.

Total losses can be broadly divided into two types

1 Constant losses

2 Variable losses

These losses can be further divided as

1 Constant losses - i) Core loss or iron loss

a Hysteresis loss

b Eddy current loss

ii Mechanical loss

a Windage loss

b Friction loss - brush friction loss and Bearing friction loss.

2 Variable losses - i) copper loss (I^2R)

a Armature copper loss

b Field copper loss

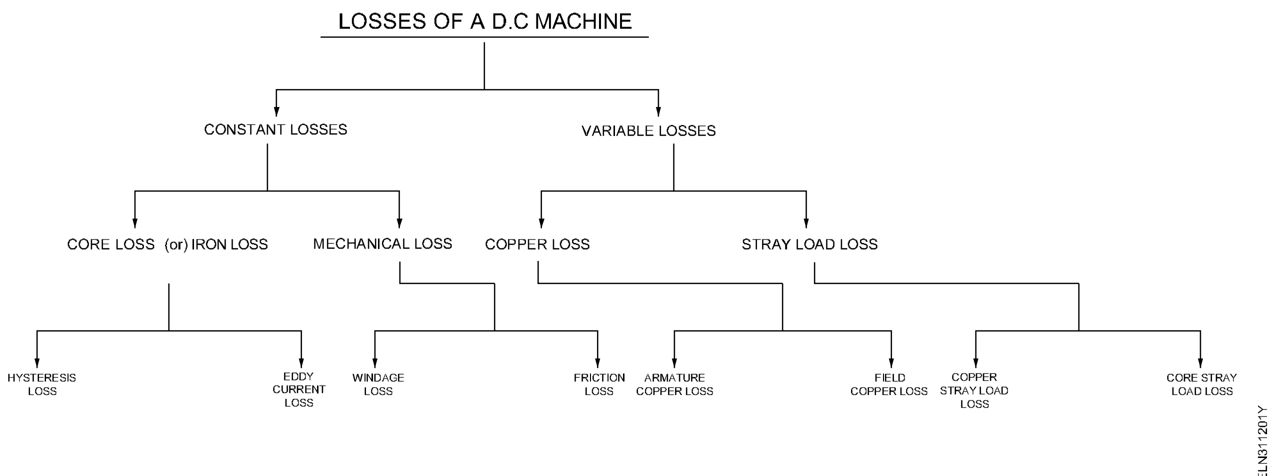
c Brush contact loss

ii Stray load loss

a Copper stray load loss

b Core stray load loss

Fig 34



Core loss or iron loss occurs in the armature core is due to the rotation of armature core in the magnetic flux produced by the field system. Iron loss consists of a) Hysteresis loss and b) Eddy current loss.

a) **Hysteresis loss:** This loss is due to the reversal of magnetization of armature core as the core passes under north and south poles alternatively. This loss depends on the volume and grade of iron, maximum value of flux density BM and frequency. Hysteresis loss W_h is given by Steinmetz formula.

$W_h = K_h B_m 1.6$ f v joule/sec. or watt

where K_h = Constant of proportionalitiy - depends on core material.

B_m = Maximum flux density in wb/m^2

F = Frequency in hertz

V = Volume of the armature core in m^3

b) Eddy Current loss: Eddy currents are the currents set up by the induced emf in the armature core when the core cuts the magnetic flux. The loss occurring due to the flow of eddy current is known as eddy current loss. To reduce this loss, the core is laminated, stacked and riveted. These laminations are insulated from each other by a thin coating of varnish. The effect of lamination is to reduce the current path because of increased resistance due to reduced cross section area of laminated core. Thus the magnitude of eddy current is reduced resulting in the reduction of eddy current loss.

Eddy Current loss W_e is given by

$W_e = K_e B^2{}_m f^2 t^2 v$ Watt

Where K_e = Constant of Proportionality

B_m = Maximum flux density in Wb/m^2

f = Frequency in Hz.

t = Thickness of the lamination in meters

v = Volume of the armature core in m^3.

ii Mechanical loss: these losses include losses due to windage, brush friction and bearing friction losses.

2) Variable losses: Variable losses consist of (i) Copper loss:

Armature copper loss ($I_a{}^2 r_a$) loss: This loss occurs in the armature windings because of the resistance of armature windings, when the current flows through them. The loss occurring is termed as copper loss or $I_a{}^2 r_a$ loss. This loss varies with the varying load.

b) Field contact drop: This is due the contact resistance between the brush and the commutator. This loss remains constant with load.

c) Brush contact drop: This is due the contact resistance between the brush and the commutator. This loss remains constant with load.

ii) Stray load loss: The additional losses which vary with the load but cannot be related to current in a simple manner are called stray load loss. Stray load losses are.

i) Copper stray load loss : The loss occuring in the conductor due to skin effect and loss due to the eddy currents in the conductor. Set up by the flux passing through them are called copper stray load loss.

ii) Core stray load loss: When the load current flows through the armature conductors, the flux density distribution gets distorted in the teeth and core. The flux density decreases at one end of the flux density wave and increases at the other. Since the core loss is proportional to the square of the flux density, the decrease in flux density will be less than the increase due to the increase in flux density, resulting in a net increase in the core loss predominantly in the teeth, known as stray load loss in the core.

Further under highly saturated conditions of teeth, flux leaks through the frame and end shields causing eddy current loss in them. This loss is a component of stray load loss. Stray load loss is difficult to calculate accurately and therefore it is taken as 1 % of the output of DC machine.

Efficiency of a DC generator

Power flow in a DC generator is shown in Figure 35.

$$= \frac{\text{output}}{\text{output} + \text{losses}} = \frac{VI}{VI + I_a^2 r_a + W_e}$$

where w_e is constant loss

Condition for maximum efficiency

Generator output = VI

Generator input = output+losses

= $VI + I^2 a R_a + W_e$

= $VI + (I + I_{sh})^2 R_a + W_e \quad \therefore I_a = (I + I_{sh})$

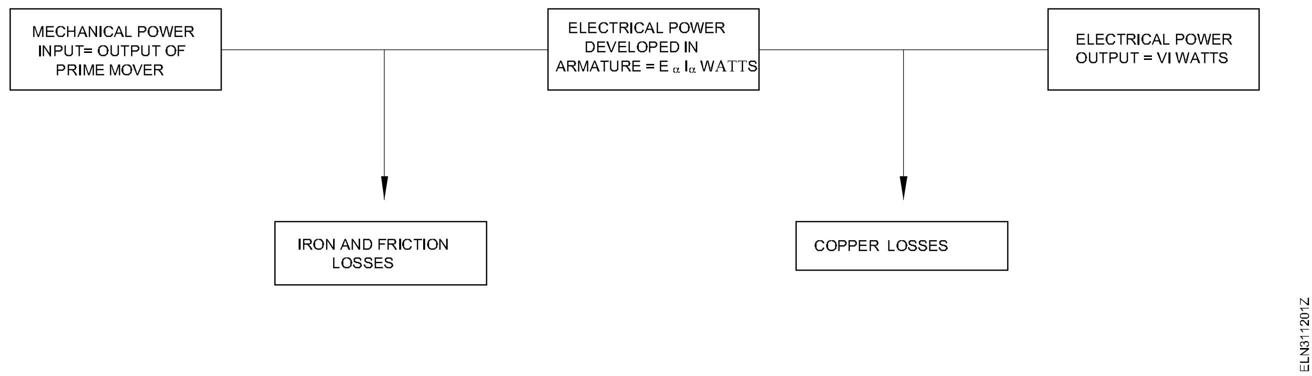
However, if I_{sh} is negligible as compared to load current I_a=I (approx.)

$$\because \eta = \frac{\text{output}}{\text{input}} = \frac{VI}{VI + I^2 a R_a + W_e} = \frac{VI}{VI + I^2 R_a + W_e}$$

Efficiency is maximum when variable loss = constant loss.

The load current corresponding to maximum efficiency is given by the relation.

Fig 35



$$I^2R_a = We$$

$$I = \sqrt{\frac{W_e}{R_a}}$$

Efficiency of DC motor

The power flow in a DC motor is shown in Figure 36

$$\text{Efficiency of a DC motor} = \frac{\text{input} - \text{losses}}{\text{input}}$$

$$= \frac{VI - I_a^2 r_a - w_c}{VI}$$

The condition for maximum power developed

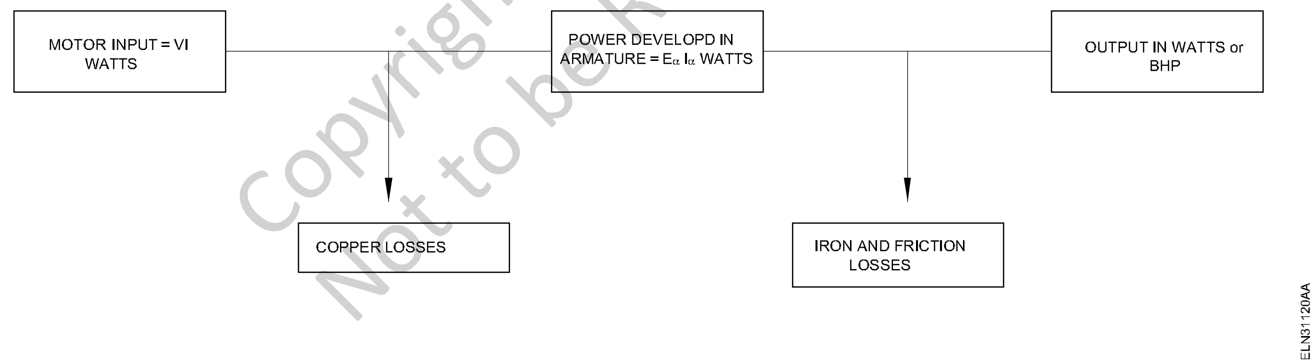
$$E_b = \frac{V}{2} = I_a r_a$$

This is shown in equation

The condition for maximum efficiency is variable loss = constant loss

$I^2 r_a = w_e$

Fig 36



Losses in a DC generator and DC motor

A DC generator converts mechanical power into electrical power and a DC motor converts electrical power into mechanical power. Thus, for a dc generator, input power is in the form of mechanical and the output power is in the form of electrical. On the other hand, for a dc motor, input power is in the form of electrical and output power is in the form of mechanical. In a practical machine, whole of the input power cannot be converted into output power as some power is lost in the conversion process. This causes the efficiency of the machine to be reduced. Efficiency is the ratio of output power to the input power. Thus, in order to design rotating dc machines (or andy electrical machine) with higher efficiency, it is important to study the losses occurring in them. Various losses in a rotating DC machine (DC generator or DC motor) can be characterised as follows:

Losses in a rotating DC machine

- **Copper losses**
  - Armature Cu loss
  - Field Cu loss
  - Loss due to brush contact resistance
- **Iron losses**
  - Hysteresis loss
  - Eddy current loss

- **Mechanical losses**
  - Friction loss
  - Windage loss

The above tree categorizes various types of losses that occur in a dc generator or a dc motor. Each of these is explained in details below.

Copper Losses

These losses occur in armature and field copper windings. Copper losses consist of Armature copper loss, Field copper loss and loss due to brush contact resistance.

Armature copper loss = $I_a^2R_a$ (where, $I_a^2R_a$ (where, I_a = Armature current and R_a = Armature resistance)

This loss contributes about 30 to 40% to full load losses. The armature copper loss is variable and depends upon the amount of loading of the machine.

Field copper loss = $\mathbf{I_f^2R_f}$ (where, I_f = field current and R_f = field resistance) In the case of a shunt wounded field, field copper loss is practically constant. It contributes about 20 to 30% to full load losses.

Brush contact resistance also contributes to the copper losses. Generally, this loss is included into armature copper loss.

Iron losses (Core losses)

As the armature core is made of iron and it rotates in a magnetic field, a small current gets induced in the core itself too. Due to this current, eddy current loss and hysteresis loss occur in the armature iron core. Iron losses are also called as Core losses or magnetic losses.

Hysteresis loss is due to the reversal of magnetization of the armature core. When the core passes under one pair of poles, it undergoes one complete cycle of magnetic reversal. The frequency of magnetic reversal is given by,

f=P.N/120 (where, P = no. of poles and N = Speed in rpm)

The loss depends upon the volume and grade of the iron, frequency of magnetic reversals and value of flux density. Hysteresis loss is given by, Steinmetz formula: $W_h=\eta B_{max}^{1.6}$ fV (watts), η = Steinmetz hysteresis constant V = volume of the core in m^3

Eddy current loss: When the armature core rotates in the magnetic field, an emf is also induced in the core (just like it induces in armature conductors), according to the Faraday's law of electromagnetic induction. Though this induced emf is small, it causes a large current to folw in the body due to the low resistance of the core. This current is known as eddy current. The powe loss due to this current is known as eddy current loss.

Mechanical losses

Mechanical losses consist of the losses due to friction in bearings and commutator. Air friction loss of rotating armature also contributes to these. These losses are about 10 to 20% of full load losses.

Stray losses

In addition to the losses stated above, there may be small losses present which are called as stray losses or miscellaneous losses. These losses are difficult to account. They are usually due to inaccuracies in the designing and modeling of the machine. Most of the times, stray losses are assumed to be 1% of the full load.

Power flow diagram

The most convenient method to understand these losses in a dc generator or a dc motor is using the power flow diagram. The diagram visualizes the amount of power that has been lost in various types of losses and the amount of power which has been actually converted into the output. Following are the typical flow diagrams for a dc generator and a dc motor. (Fig 37 & 38)

Fig 37

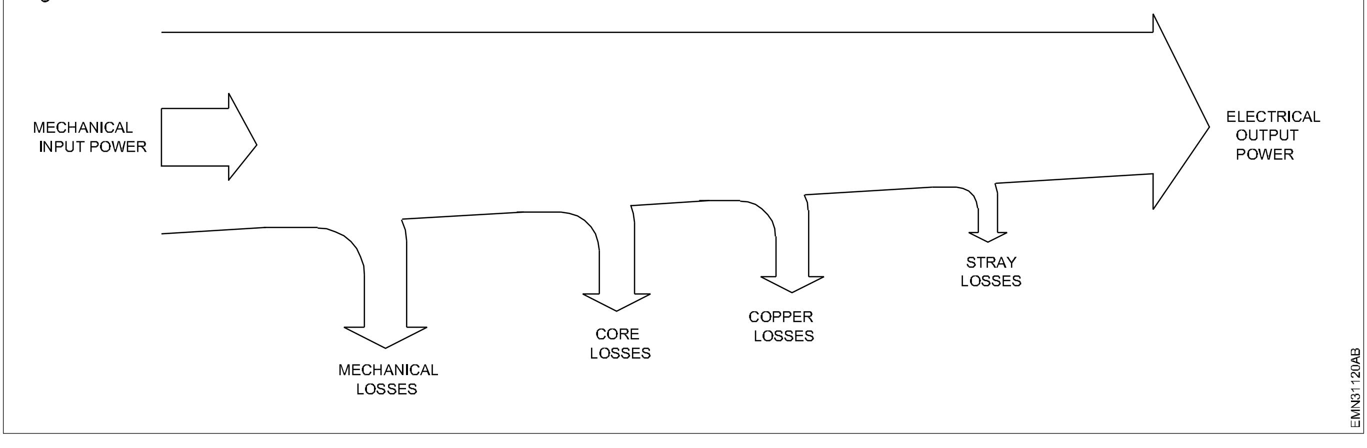
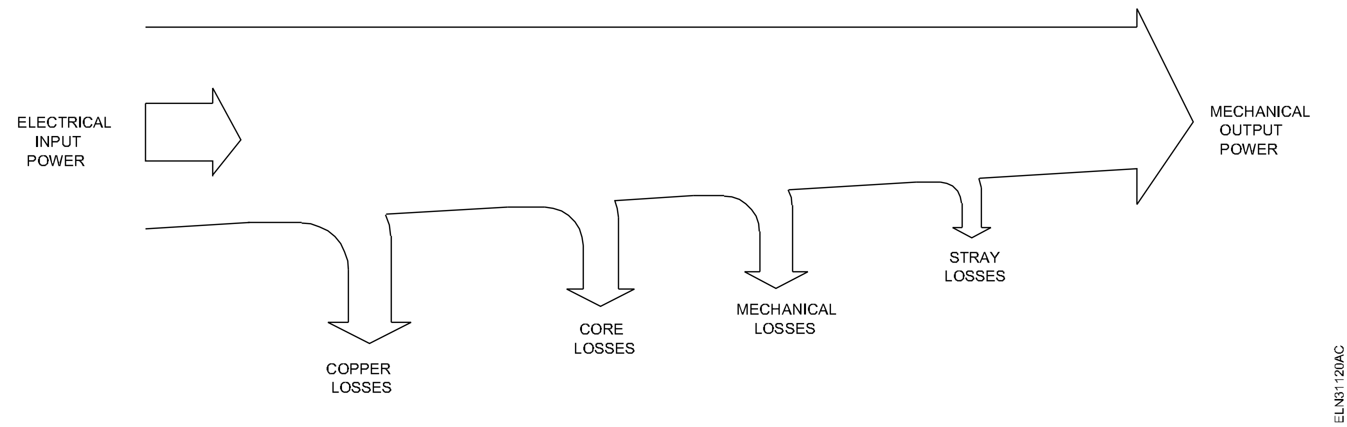


Fig 38



Efficiency of DC generator

Efficiency is simply defined as the ratio of output power to the input power. Let R = total resistance of the armature circuit (including the brush contact resistance, at series winding resistance, inter-pole winding resistance and compensating winding resistance). The efficiency of DC generator is explained in the line diagram Fig 39

I is the output current

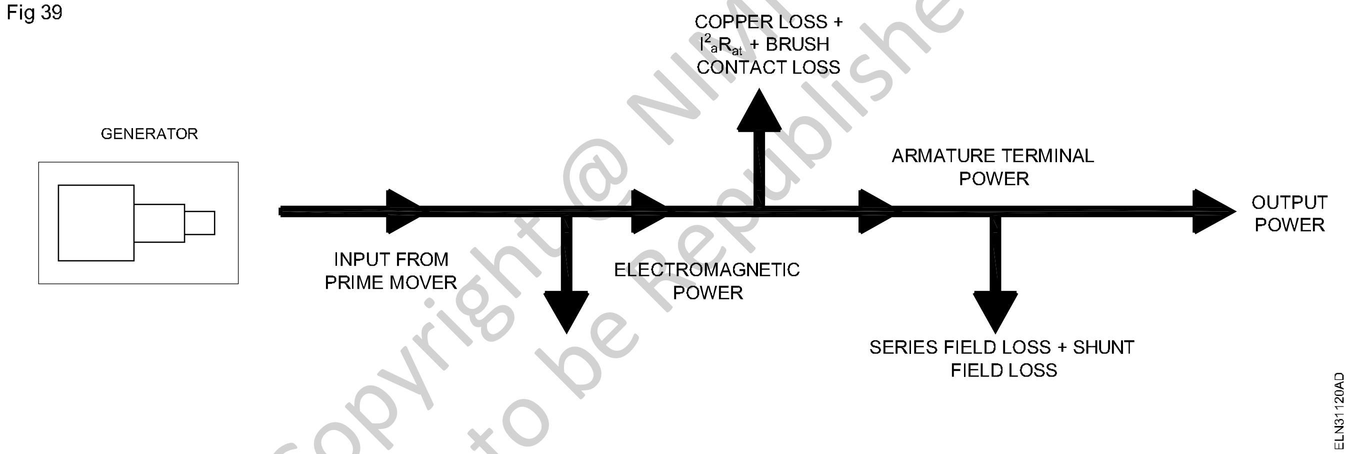
I_{sh} is the current through the shunt field

I_a is the armature current = $I + I_{sh}$

V is the terminal voltage.

Total copper loss in the armature circuit = $I_a{}^2R_{at}$

Fig 39



Power loss in the shunt circuit = V_{Ish} (this includes the loss in the shunt regulating resistance).

Mechanical losses = friction loss of bearings + friction loss at a commutator + windage loss.

Stray loss = mechanical loss + core loss

The sum of the shunt field copper loss and stray losses may be considered as a combined fixed (constant) loss that does not vary with the load current I.

Therefore, the constant losses (in shunt and compound generators) = stray loss + shunt field copper losses.

Generator efficiency is given by the equation shown below.

$$\eta_G = \frac{\text{Generator output}}{\text{Generator output} + \text{losses}}$$

$$\eta_G = \frac{VI}{VI + I_a^2 R_{at} + V_{BD}\ I_a + P_k}$$

$$I_a = I + I_{sh}$$

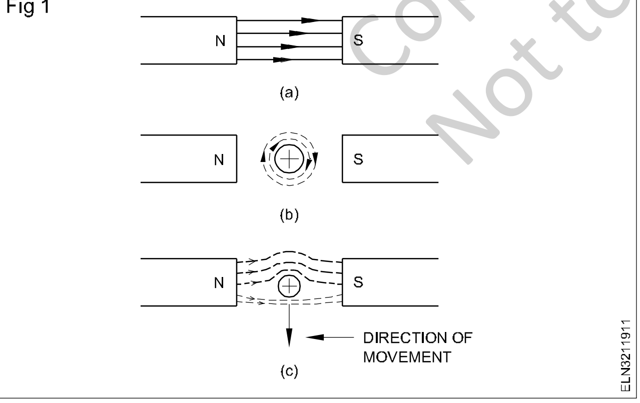
DC motor - principle and types

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of a DC motor**
- **state the different types of DC motors.**

Introduction: A DC motor is a machine which converts DC electrical energy into mechanical energy. It is similar to a DC generator in construction. Therefore, a DC machine can be used as a generator or as a motor. Even today, because of the excellent torque, speed and load characteristics of DC motors, 90% of the motors used in precision machines, wire drawing industry and traction are of this type. The DC motor needs frequent care and maintenance by qualified electricians. Hence more job opportunities exist in this area for an electrician.

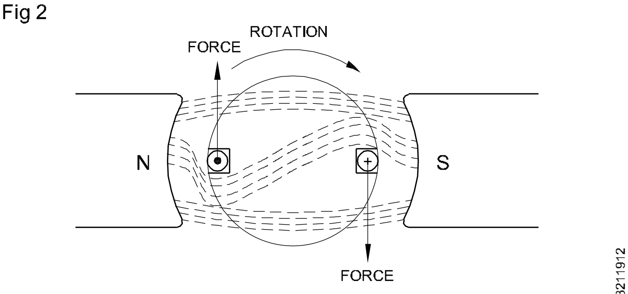
Principles of a DC motor: It works on the principle that whenever a current-carrying conductor is kept in a uniform magnetic field, a force will be set up on the conductor so as to move it at right angles to the magnetic field. It can be explained as follows. Fig 1a shows the uniform magnetic field produced by a magnet, whereas Fig 1b shows the magnetic field produced around the current-carrying conductor. Combining the effects of Fig 1a and Fig 1b in one figure, Fig 1c shows the resultant field produced by the flux of the magnet and the flux of the current-carrying conductor. Due to the interactions of these two fields, the flux above the conductor will be increased and the flux below the conductor is decreased as represented in Fig 1c. The increased flux above the conductor takes a curved path thus producing a force on the conductor to move it downwards.

Fig 1



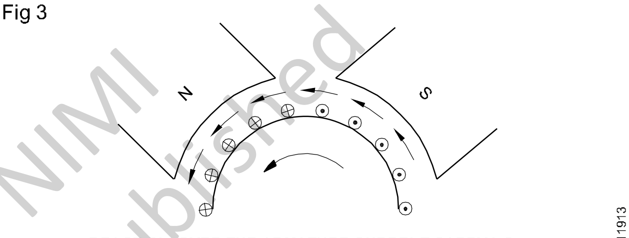
If the conductor in Fig 1 is replaced by a loop of wire as shown in Fig 2, the resultant field makes one side of the conductor move upwards and the other side move downwards. It forms a twisting torque over the conductors, and they tend to rotate, if they are free to rotate. But in a practical motor, there are a number of such conductors/ coils. Fig 3 shows the part of a motor. When its armature and field are supplied with current, the armature experiences a force tending to rotate in an anticlockwise direction as shown in Fig 3.

Fig 2



REACTION OVER A CURRENT CARRYING LOOP BY THE MAGNETIC FIELD

Fig 3



REACTION OVER THE ARMATURE CURRENT CARRYING CONDUCTORS BY THE MAGNETIC FIELD

The direction of rotation or movement can be determined by Fleming's left hand rule. Accordingly, the direction of rotation of the armature could be changed either by changing the direction of armature current or the polarity of the field.

Fleming's Left Hand Rule: The direction of force produced on a current-carrying conductor placed in a magnetic field can be determined by this rule. As shown in Fig 4a, hold the thumb, forefinger and middle finger of the left hand mutually at right angles to each other, such that the forefinger is in the direction of flux, and the middle finger is in the direction of current flow in the conductor; then the thumb indicates the direction of motion of the conductor. For example, a loop of coil carrying current, when placed under north and south poles as shown in Fig 4b, rotates in an anticlockwise direction.

Types of DC motors: As the DC motors are identical in construction to that of DC generators, they are also classified as series, shunt and compound motors, depending upon their connection of field winding with the armature and supply.

When the armature and field are connected in series, as shown in Fig 5, it is called a series motor.

When the armature and field are connected in parallel across supply, as shown in Fig 6, it is called a shunt motor.

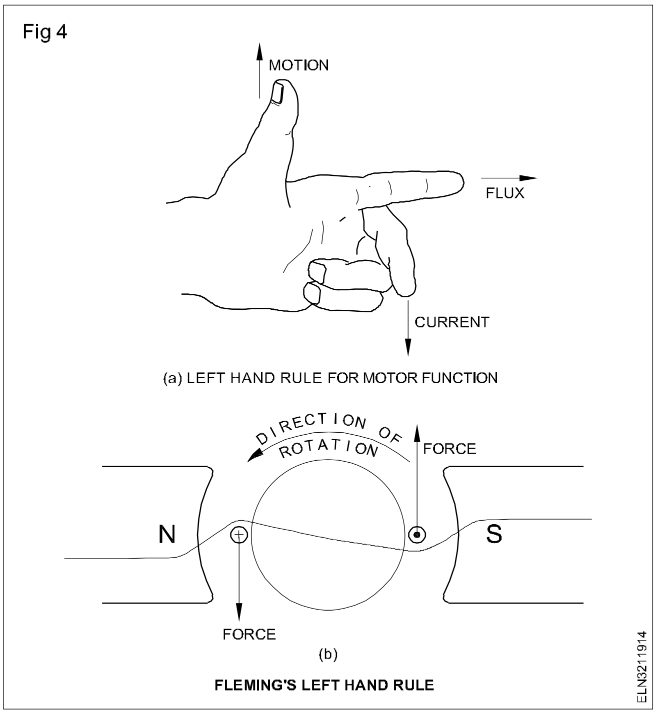


Fig 4
FLEMING'S LEFT HAND RULE

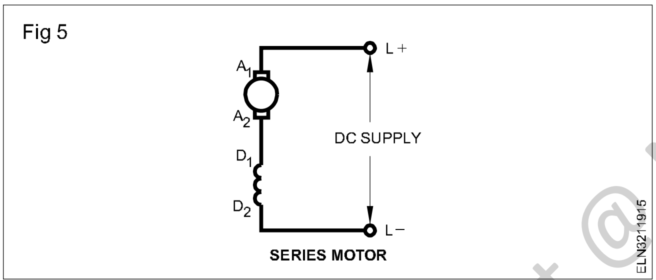


Fig 5
SERIES MOTOR

When the motor has two field coils, one in series with the armature and the other in parallel with the armature, as shown in Fig 7, it is called a compound motor.

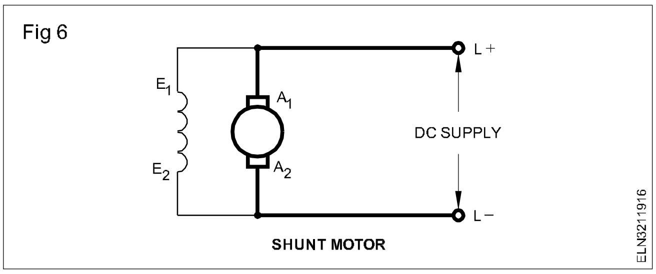


Fig 6
SHUNT MOTOR

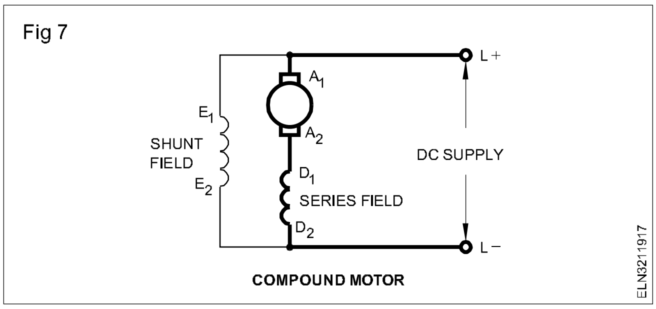


Fig 7
COMPOUND MOTOR

The relation between applied voltage, back emf, armature voltage drop, speed and flux of DC motor, method of changing direction of rotation.

The relation between applied voltage, back emf, armature voltage drop, speed and flux of DC motor - method of changing direction of rotation

Objectives: At the end of this lesson you shall be able to

- **explain the relation between applied voltage, back emf, armature voltage drop - speed - flux**
- **describe the method of changing the direction of rotation of a DC motor.**

Back emf: As the armature of a DC motor starts rotating, the armature conductors cut the magnetic flux produced by the field poles. Due to this action, an emf will be produced in these conductors. The induced emf is in such a direction as to oppose the flow of current in the armature conductor as shown in Fig 1. As it opposes the supply voltage it is called `BACK EMF' and is denoted by E_b. Its value is the same as that found in the generator. It could be written as

$$E_b = \frac{\varnothing ZNP}{60A} \text{ volts}$$

The direction of the induced (back) emf could be determined by Fleming's right hand rule.

Applied voltage: The voltage applied across the motor terminals is denoted by `V'.

Armature voltage drop: Since armature conductors have some resistance, whenever they carry current a voltage drop occurs. It is called I_aR_a drop because it is proportional to the product of the armature current I_a and armature resistance R_a. It has a definite relation with the applied voltage and back emf as shown by the formula

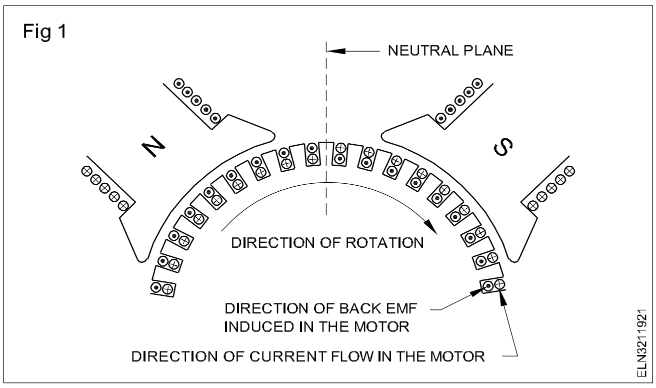


Fig 1

$V = E_b + I_aR_a$.

Alternatively, $I_aR_a = V - E_b$.

Further the back or counter emf E_b depends upon flux per pole 'Ø' and speed `N'. Therefore, the applied voltage, back emf, armature drop, flux and speed are related to one another as follows.

$$E_b = V - I_a R_a$$

$$\frac{\varnothing ZNP}{60A} = V - I_a R_a$$

$$\therefore N = \frac{(V - I_a R_a) \times 60A}{\varnothing ZP} \text{ rpm}$$

For a given motor ZPA and 60 are constants and can be denoted by a single letter K

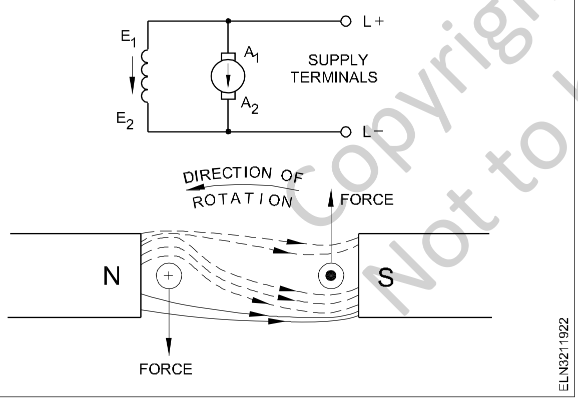
$$\text{where } K = \frac{60A}{ZP}$$

Therefore $N = K E_b/\varnothing$.

It shows that the speed of a DC motor is directly proportional to E_b and inversely proportional to the flux Ø.

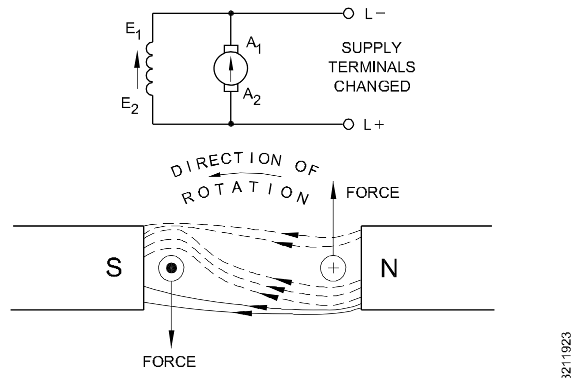
Reversing the direction of rotation of DC motors: The direction of rotation of a DC motor can be changed either by changing the direction of the armature current or by changing the direction of the field current. The direction of rotation of a DC motor cannot be changed by interchanging the supply connections because this changes the direction of the field as well as the armature current. Its effect is as shown in Figs 2 and 3.

Fig 2



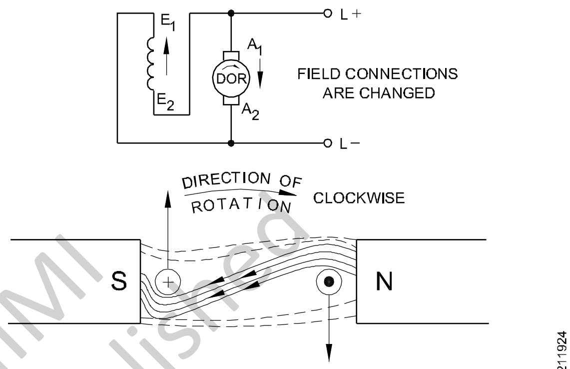
But when the field current direction alone is changed, the direction of rotation changes as shown in Fig 4. When the armature current direction alone is changed, the direction of rotation changes as shown in Fig 5.

Fig 3



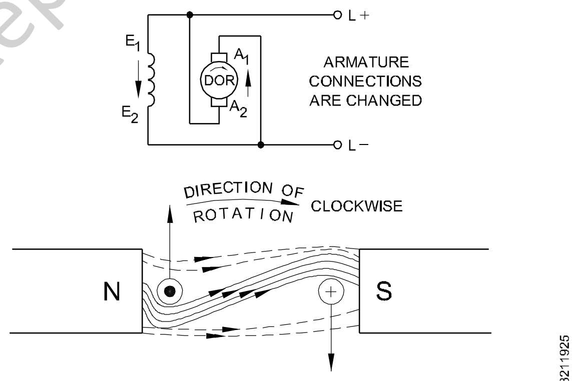
EFFECT OF CHANGING SUPPLY TERMINALS

Fig 4



EFFECT OF CHANGING THE FIELD CURRENT DIRECTION

Fig 5



EFFECT OF CHANGING THE ARMATURE CURRENT DIRECTION

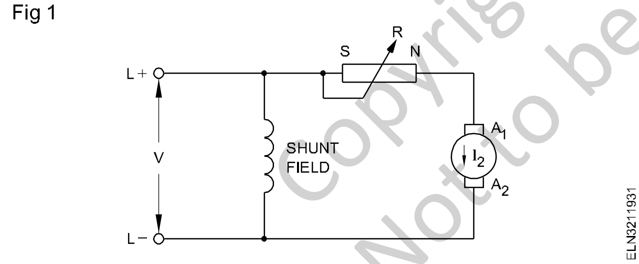
To reverse the direction of rotation of a compound motor without changing its characteristics, the best method is to change only the armature current direction. In case, changing the direction of rotation needs to be done by changing the field terminals, it is essential to change the current direction in both the shunt and series windings. Otherwise, the machine, which was running as cumulatively compounded, will change its characteristic as differentially compounded or vice versa.

DC motor starters

Objectives: At the end of this lesson you shall be able to
- **state the necessity of starter for a DC motor**
- **state the different types of starters - construction and working principle of 2-point, 3-point and 4-point starters.**

Necessity of starters: Since the armature is stationary before starting, the back emf which is proportional to speed is zero. As the armature resistance is very small, if the rated voltage is applied to the armature, it will draw many times the full load current, and thereby, there is every possibility of damaging the armature due to heavy starting current. Therefore, the starting current should be limited to a safe value. This is done by inserting a resistance in series with the armature at the time of starting for a period of 5 to 10 seconds. As the motor gains in speed, back emf is built up, and then the starting resistance could be gradually cut off. Fig 1 shows such an arrangement. Resistance R is fully included in the armature circuit by keeping the moving arm in position `S' at the time of starting, and then it is moved towards position `N' to exclude the resistance `R' when the motor has picked up its speed. But such an arrangement will be purely manual and needs constant monitoring. For example, if the motor is running, the resistance `R' will be excluded, and the moving arm position will be at position `N'. In case the supply fails, the motor will stop but the moving arm will still be in position `N'. When the supply returns, as there is no resistance included in the armature circuit through `R', the armature may draw heavy current and may get damaged. To prevent such a happening a device called starter is used in motor circuits.

Fig 1



In addition to the automatic inclusion of resistance at the time of starting, the starters may protect the motor from overload and will switch `off' the motor, when supply fails. These starters are named according to the number of connecting terminals as explained subsequently.

Types of starters: Starters used to start the DC motors are generally of three types.

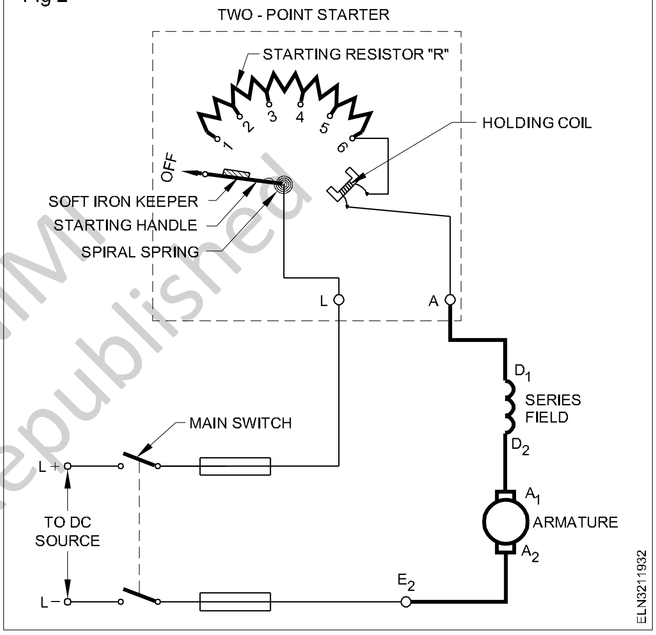
- Two-point starter
- Three-point starter
- Four-point starter

Two-point starter: This contains the following components.

- The series resistor required for starting a motor.
- The contacts (brass studs) and switching arm required to include or exclude the resistor in the armature circuit.
- A spring on the handle to bring the handle to the `OFF' position when supply fails.
- An electromagnet to hold the handle in the `ON' position.

The two-point starter is frequently used with a DC series motor. The starting resistance, electromagnet armature and the series field are all connected in series as shown in Fig 2.

Fig 2

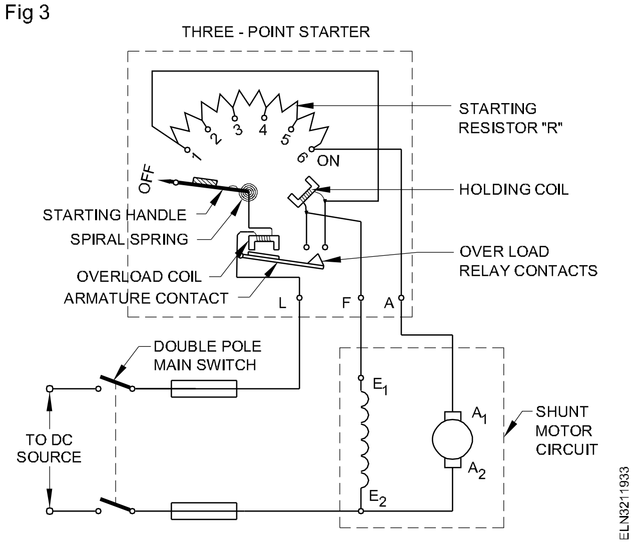


When the arm is moved to the first contact point, the circuit is completed, and the armature begins to rotate. As the armature speed increases, the arm is slowly moved towards the right side electromagnet, thereby the starter resistance is reduced. When the arm is against the electromagnet, complete starter resistance is cut off from the circuit.

The electromagnet is wound with a thick gauge wire to carry the rated armature current of the motor. This holds the handle in the `ON' position when the motor is working. The handle comes back to the `OFF' position, due to spring action when the electromagnet demagnetises due to failure of supply. This starter in general will not have protection against overloads.

Three-point starter: Fig 3 shows the internal diagram of a three(terminal) point starter connected to a DC shunt motor. The direct current supply is connected to the starter, the motor circuit through a double pole switch and suitable fuses. The starter has an insulated handle or knob for the operator's use. By moving the starter handle from the `off' position to the first brass contact (1) of the starter, the armature is connected across the line through the starting resistance. Note that the armature is in series with the total starting resistance. The shunt field, in series with the holding coil, is also connected across the line. In this mode of operation, the rush of the initial current to the armature is limited by the resistance. At the same time, the field current is at the maximum value to provide a good starting torque.

Fig 3



As the handle arm is moved to the right, the starting resistance is reduced and the motor gradually accelerates. When the last contact is reached, the armature is connected directly across the supply; thus, the motor is at full speed.

The holding coil is connected in series with the shunt field to provide a `no-field release'. If the field circuit opens by accident, the motor speed will become excessive should the armature remain connected across the line. To prevent this increase in speed, the holding coil is connected in series with the field. In case of an open circuit in the field, there will be no current through the holding coil, and hence, it will be demagnetized, and the spring action returns the arm to the `off' position.

An overload coil is provided to prevent damage to the motor from overload. Under normal load condition, the flux produced by the O/L coil will not be in a position to attract the armature contact. When the load current increases beyond a certain specified value, the flux of the O/L coil will attract the armature. The contact points of the armature then short-circuit the holding coil and demagnetize it. This enables the handle to come to the `OFF' position due to the tension of the spiral spring.

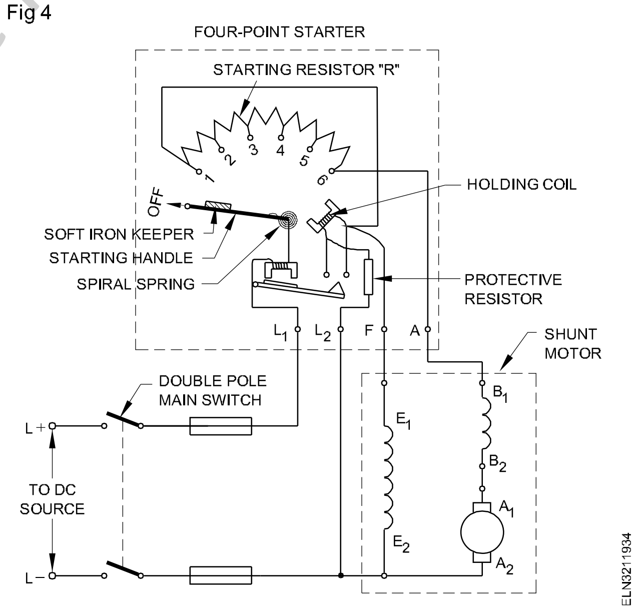
This type of starter can be used to start both shunt and compound motors.

However, a 3-point starter will be found to be tripping when the motor speed is controlled through the field regulator. The reason could be explained as stated below.

When the speed of a shunt or compound motor is to be increased beyond its rated speed, the resistance is increased in the field regulator to reduce the field current, and thereby, the field flux. While doing so, the holding coil which is in series with the field gets very low current and produces less holding force on the handle armature against the tension of the spiral spring. When the current reduces below a certain value, the handle is pulled out from the `ON' position to the `OFF' position. This is an undesirable effect. To avoid this, the 3-point starter circuit is modified, and the holding coil circuit is made independent of the field circuit. Such a starter is called a 4-point starter.

Four-point starter: In applications where many motor speeds are to be increased beyond their rated value, a four-terminal, face plate starter is used with the motor. The four(terminal) point starter, shown in Fig 4, differs from the three-point starter in that the holding coil is not connected in series with the shunt field. Instead, it is connected across the supply in series with a resistor. This resistor limits the current in the holding coil to the desired value. The holding coil serves as a no-voltage release rather than as a no-field release. If the line voltage drops below the desired value, the magnetic attraction of the holding coil is decreased, and then the spring pulls the starter handle back to the `off' position.

Fig 4



Relation between torque, flux and armature current in a DC motor

Objectives: At the end of this lesson you shall be able to

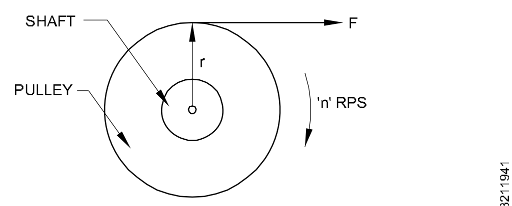
- **explain the relation between torque, flux and armature current**
- **solve problems pertaining to metric HP; load current, rated voltage, torque and speed of DC motors.**

Relation between armature current, flux and torque

Torque: The turning or twisting moment of a force about an axis is called torque. It is equal to the product of force and the radius of the pulley.

Consider a pulley of radius `r' metres acts upon by a circumferential force `F' Newton, and rotates at a speed of `n' r.p.s. as shown in Fig 1.

Fig 1



TORQUE PRODUCTION IN A MOTOR

Then torque T = F x r Newton-metres(N-m)

Work done by this force in one revolution = Force x distance

= F x $2\pi r$ joules.

Power developed in one second = F x $2\pi r$ x n joule/second or watts

= (Fxr)$2\pi n$ watts

As $2\pi N$ is angular velocity ω in radian/second and

(F x r) = Torque T

Power developed = T x ω watts

P = Tω watts.

Torque of a motor: Let T_a be the torque developed by the armature of a motor in newton-metre and `n' the speed of armature in r.p.s.

Then the power developed in the armature = $T_a 2\pi n$ watts.

As we know the electrical power is converted into mechanical power

Electrical power supplied to the armature = $E_b I_a$ where

E_b is the back emf

I_a is the armature current.

Electrical power supplied to the armature = Mechanical power developed in the armature

We get $E_b I_a = T_a 2\pi n$

Since $E_b = \frac{\varnothing ZnP}{A}$ volts (By taking `n' in r.p.s.)

$$T_a \times 2\pi n = \frac{\varnothing ZnP}{A} \times I_a$$

By cross multiplication we get

$$T_a = \frac{\varnothing ZP \times I_a}{2\pi A} \text{ Newton - metre}$$

$$\text{or } T_a = \frac{0.159\ \varnothing ZP}{A} \times I_a \text{ Newton - metre}$$

For a given motor. ZP and A are constants as they depend upon the design.

$\frac{0.159\ ZP}{A}$ can be reagrded as constant 'K'

Then $T_a = K\varnothing I_a$

where Ø is the flux pole in weber

I_a is the armature current

$$K = \frac{0.159\ ZP}{A}$$

T_a is the armature torque in newton metres.

Therefore, we can say the torque of a DC motor is directly proportional to the field flux and the armature current.

The other formula which gives torque

$$T_a \text{ is } = \frac{9.55 \times E_b I_a}{N} \text{ Newton - metre}$$

where `N' is speed in r.p.m.

Shaft torque: The complete armature torque calculated above is not available for doing useful work because of the losses in the motor.

The torque which is available for doing work is known as shaft or output torque, and it is denoted as T_{sh}.

The difference ($T_a - T_{sh}$) is known as loss of torque due to iron, friction and windage losses of motor.

$$\text{One H.P. metric} = \frac{2\pi n T_{sh}}{735.5} = \frac{2\pi N T_{sh}}{60 \times 735.5} \text{ HP}$$

where 'n' is the speed is in r.p.s., N is the speed in r.p.m.

and T_{sh} is the shaft torque in newton metre.

If the torque is given in kg. metre, it can be converted into newton metre as given below.

Newton metre = Kg. metre x 9.81

Example 1: A 250V, 4 pole, wave-wound DC series motor has 782 conductors in its armature. It has a combined armature and series field resistance of 0.75 ohms. The motor takes a current of 40 A. Estimate its speed, armature torque and H.P. if the flux per pole is 25 milli-weber.

E_b = V – $I_a R_a$

= 250 – (40 x 0.75)

= 250 – 30 = 220 volts

Therefore, $E_b = \frac{\emptyset ZnP}{A}$ volts

$$N = \frac{E_b \times 60 \times A}{\emptyset ZP} = \frac{220 \times 60 \times 2}{25 \times 10^{-3} \times 782 \times 4}$$

$$= \frac{220 \times 60 \times 2 \times 10^3}{25 \times 782 \times 4} = 338 \text{ rpm.}$$

$$T_a = \frac{9.55 \times E_b I_a}{N} = \text{Nm}$$

$$T_a = \frac{9.55 \times 220 \times 40}{338} = 248.64 \text{ Nm.}$$

Assuming armature Torque T_a = Shaft torque T_{sh}

$$\text{Metric H.P.} = \frac{2\pi N T_{sh}}{60 \times 735.5} = \frac{2 \times 22 \times 338 \times 248.64}{7 \times 60 \times 735.5}$$

= 11.97 HP metric.

Example 2: A 220V DC shunt motor runs at 500 r.p.m. when the armature current is 50A. It has an armature resistance of 0.2 ohm. Calculate the speed if the torque is doubled.

The torque is proportional to I_a and Ø. But Ø is constant for shunt motor T a I_a.

Therefore, T_{a1} a I_{a1} and T_{a2} a I_{a2}.

Therefore, $\frac{T_{a2}}{T_{a1}} = \frac{I_{a2}}{I_{a1}}$

As T_{a2} is double of T_{a1} we have $\frac{T_{a2}}{T_{a1}} = 2$

$$2 = \frac{I_{a2}}{I_{a1}} = \frac{I_{a2}}{50}$$

Therefore I_{a2} = 50 x 2 = 100 amps.

$E_{b1} = V - I_a R_a$

= 220 – (50 x .2)

= 220 – 10 = 210 volts

$E_{b2} = V - I_a R_a$

E_{b2} = 220 – (100 x .2)

= 220 – 20 = 200 volts.

$$\text{Now} = \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

$$= \frac{N_2}{500} = \frac{200}{210}$$

$$\text{Therefore, } N_2 = \frac{200 \times 500}{210} = 476 \text{ rpm.}$$

Service and maintenance of DC motor starters

Objectives: At the end of this lesson you shall be able to

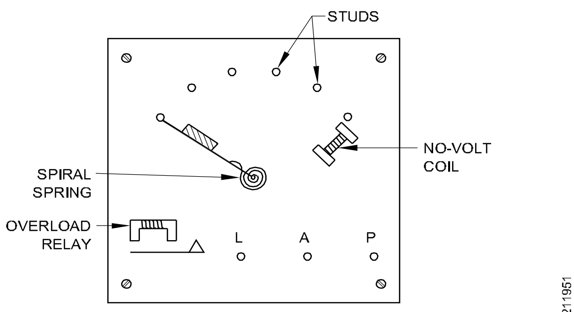
- **explain the procedure of service and troubleshoot the DC motor starter**
- **state how to check the handle for its spring tension and contact pressure against the studs**
- **state how to check the no-volt coil assembly**
- **explain the overload relay for the desired current rating.**

Servicing the starter: The starting resistance of the 3-point and 4-point starters is made up of coiled Eureka wire and it is fixed between the studs of the starter. The brass studs are arranged on the face plate of the starter in a semi- circular form as shown in Fig 1. The studs are firmly fixed on the insulated face plate. During maintenance the studs should be dressed with zero number sandpaper if the burrs are small and a smooth file should be used for pittings and big burrs, and then cleaned properly with a contact cleaner. In case the starter resistance is found open, replace it with a new resistance coil as per the original specification of the manufacturer.

Figs 2 and 3 show the schematic diagrams of 3 and 4 point starters respectively.

Handle: The handle of the face plate starter consists of a movable arm attached with a spiral spring which acts against the magnetic action of the no volt coil. In case the spring becomes weak, the arm will not come to the off position even though the supply fails.

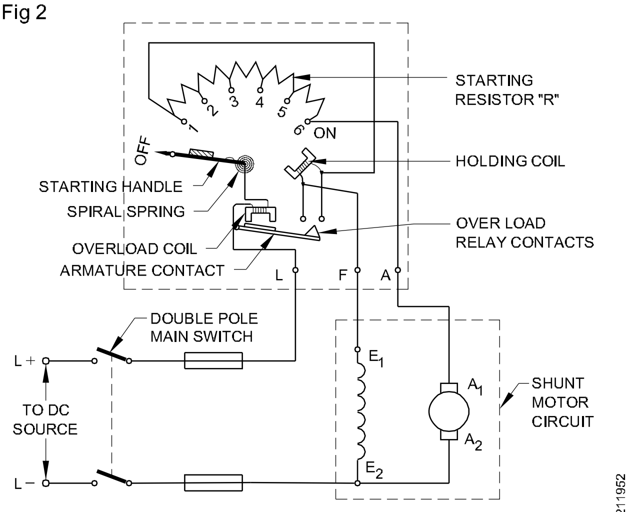
Fig 1



FACE PLATE ARRANGEMENT

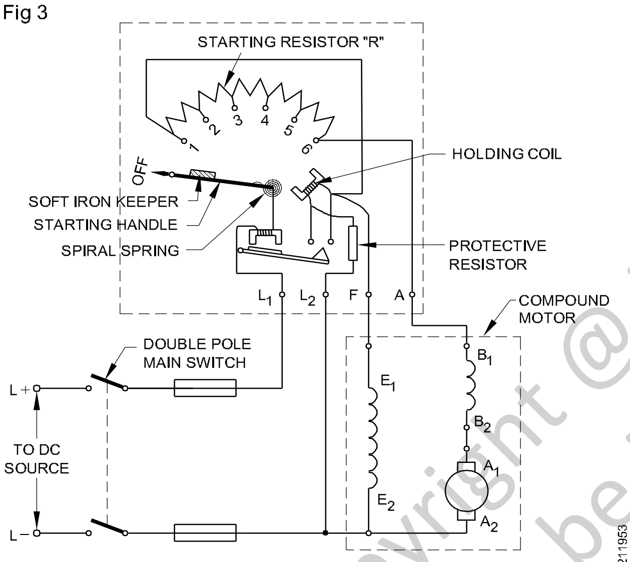
During the course of maintenance these points have to be checked. If the starter handle does not come to the off position in case of power failure, it is necessary to replace the spring as per the manufacturer specification. Also ensure during maintenance, proper pressure of the movable contact of the arm is available against the brass studs of the face place. If proper tension is not found then the starter handle is to be tightened with the help of fixing screw by adding one or two flat washers on the top of the handle as shown in Fig 4.

Fig 2



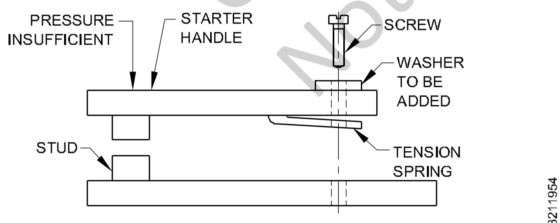
THREE - POINT STARTER

Fig 3



FOUR – POINT STARTER

Fig 4

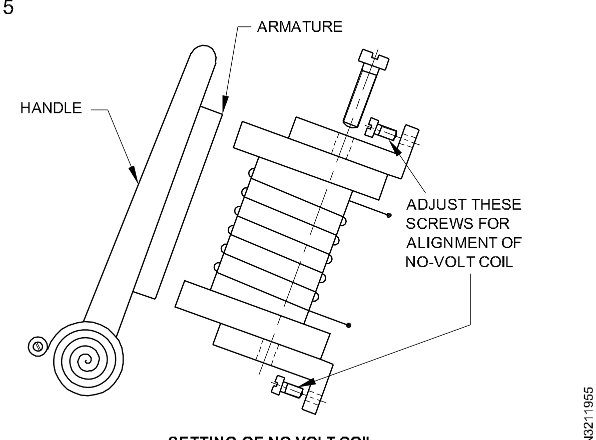


ADJUSTING THE STUD PRESSURE

Maintenance and servicing of no-volt coil assembly: The no-volt coil is connected in series with the field winding in the case of 3-point starter and in parallel with the supply through a limiting resistance in the case of 4 point starter. The no-volt coil is wound with a thin insulated wire and has a few number of turns.

When the handle of the starter is moved to the running position, the armature of the handle should be touching the core assembly of the no-volt coil. In case the core assembly is not touching properly, loosen the mounting screws of the core/coil assembly, align the core and tighten the screws. (Fig 5).

Fig 5

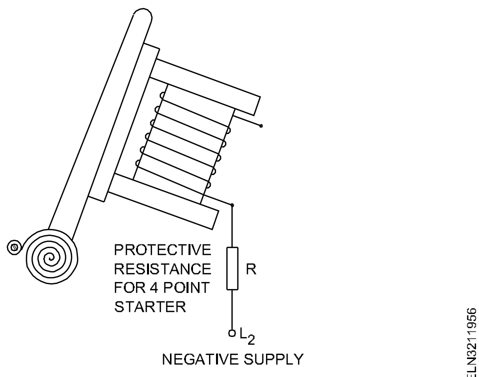


SETTING OF NO-VOLT COIL

If the NVC is not energised check visually the condition of the NVC. Measure the value and resistance of the coil as well as the insulation value and make a note of these readings. Periodically check these values and compare these with original manufacturer's data. In any case, at any time if the value falls below 80% of the normal value, then replace it with a new no-volt coil of the same specification.

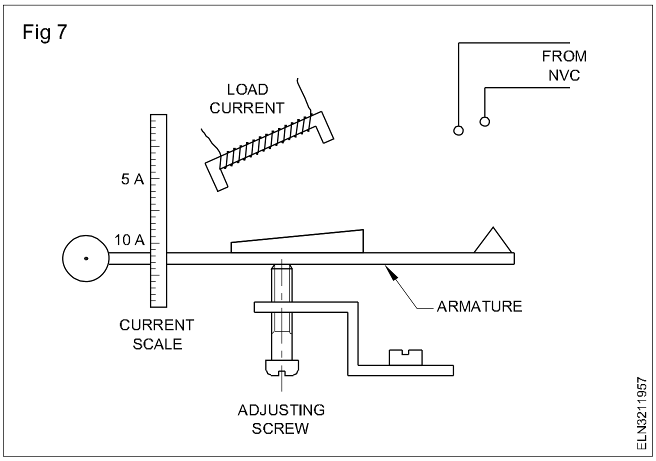
In the case of 4-point starter, the no-volt coil should be checked as mentioned above. If found OK, then the protective resistance should be checked with a multimeter. If found defective it has to be replaced with a resistance of same specification. (Fig 6.)

Fig 6



The overload relay coil is wound with thick gauge insulated wire suitable to carry the load current and has less turns. When the load current exceeds the set current, the magnetic strength of the overload coil assembly will be sufficient to attract the armature. The upward movement of the armature short-circuits the tapped contacts of the no-volt coil, thereby bypasses the current in the no-volt coil resulting in the demagnetisation of the no volt coil and releasing the handle to off position.

Maintenance of overload relay (Fig 7)**:** A magnetic overload relay is provided near the handle on the left side of the starter face plate; underneath the overload relay an armature is provided and it is adjusted as per the load current of the motor.



To test the overload relay the motor has to be loaded and the tripping of the overload relay to be observed. In case the overload relay trips at a lower current or higher current value when compared to set current value the current scale has to be recalibrated.

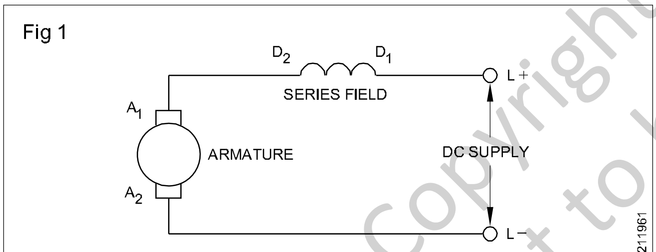
In the case of chattering noise observed at the no-volt coil the surfaces of the core assembly and armature need to be cleaned.

For the troubleshooting procedure follow the chart given in the trade practical exercise.

Characteristics and applications of a DC series motor

Objectives: At the end of this lesson you shall be able to
- **explain the characteristics of a series motor**
  - **torque versus load**
  - **speed versus load**
  - **speed versus torque**
- **state the uses of a DC series motor**
- **explain the method of changing the direction of rotation of a DC series motor**
- **state the method of loading the motor and explain the brake test.**

DC series motors: The DC series motor, like the DC series generator, has its field connected in series with the armature as shown in Fig 1. Due to this mode of connection, all the current that flows through the armature must also flow through the field, and hence, the field strength varies with the change in the load.

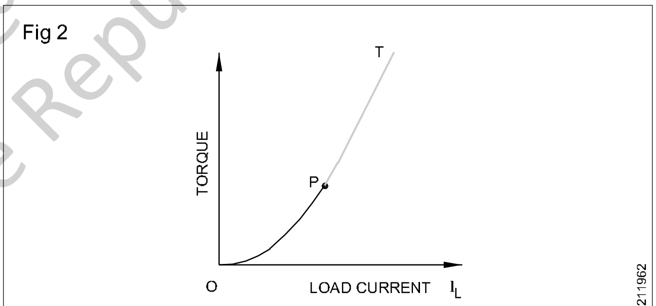


DC SERIES MOTOR CONNECTION

A DC series motor has a very high starting torque. In some motors, it may be as high as five times the full load torque. Further, the speed of the DC series motor also varies with the load.

Characteristics of DC series motors: The torque `T' in a DC motor is proportional to the flux `Ø' and the armature current `I_a'. The speed is inversely proportional to the flux. The relation between these factors i.e. torque vs load, speed V_s load and torque V_s speed are plotted on a graph, and are known as characteristic curves of motors. The study of these characteristics enables us to understand the behaviour of the motors under different conditions.

Torque load characteristics of the DC series motor: Fig 2 shows the torque load characteristic curve of a DC series motor. At low or light load, the torque is low due to the low armature current and low field flux. But as the load increases, the torque also increases proportionate to the square of the armature current up to the point `P' of the curve. This could be illustrated by the formula T proportional to armature current and field flux. T a I_a Øse as $Ø_{se}$ is proportional to I_{se} and, further, I_{se} is proportional to the armature current. We have



TORQUE-LOAD CHARACTERISTIC

T a $I_a I_{se}$

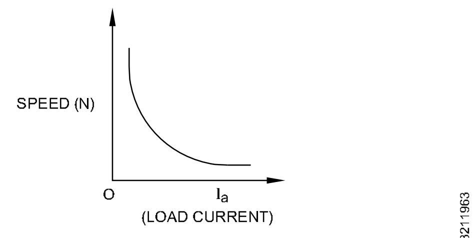
T a $I_a I_a$

T a I_a^2.

Beyond this point 'P' the curve becomes a straight line, and indicates the torque is proportional to the armature current only as the field cores are saturated. This curve shows that the torque is low at light loads and increases at heavy loads. Further the starting current of a DC series motor is about 1.5 times the full load current and the torque is about 2.25 times (1.5^2) the full load torque assuming the poles are not saturated.

Speed Vs load characteristics: Fig 3 shows the speed load characteristic curve of a DC series motor. From the curve it is clear that when the load is small the speed is high, and as the load increases the speed decreases. As the curve shown is parallel to the `Y' axis at low load currents, it can be inferred that the speed attains a dangerous value. Therefore, the DC series motors are seldom used without load. Care should be taken while using belt drives where the load can be `OFF' if the belt breaks or slips out. To avoid this, usually the load is connected directly or through gears to a DC series motor.

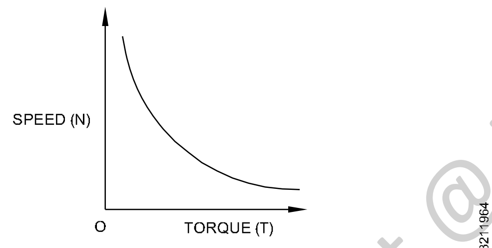
Fig 3



SPEED-LOAD CHARACTERISTIC

Speed-torque characteristics: Fig 4 shows the speed-torque characteristic of a DC motor. It shows that when the torque is low, the speed is high. This is due to the low field flux (N a 1/Ø). As the torque increases the motor draws more current and causes the speed to reduce. This is due to the increased field flux by increased load current in the DC series field.

Fig 4



SPEED-TORQUE CHARACTERISTIC

Uses of a DC series motor: The DC series motor is used in applications where torque and speed requirements vary substantially, and in jobs that require a heavy starting torque and a high rate of acceleration as in traction, hoists, cranes, and heavy construction trucks.

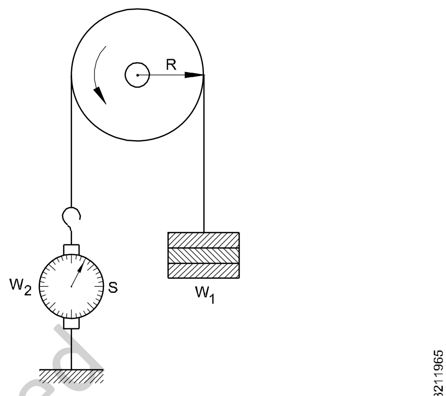
Method of changing the direction of rotation of a DC series motor: We know that by applying Fleming's left hand rule, the direction of rotation of the armature in a DC motor could be determined. According to Fleming's left hand rule, either by changing the polarity of the field or by changing the direction of current in the armature, the direction of rotation could be changed. However, if the polarity of the supply is changed, as both the polarity of field and the direction of current in the armature change, the direction of rotation will remain unchanged. Therefore, the direction of rotation of a DC series motor can be changed by changing either the field or the armature connection.

Method of loading a DC series motor: A DC series motor should never be operated without load. To keep the speed of the DC series motor within safe limits, we have to maintain a certain load on the shaft. This could be done by connecting the DC series motor to a direct-coupled load or by mounting a gear-coupled load.

The method of loading a DC series motor of small capacity for testing in a laboratory is by the brake test which is explained below.

Brake test (Method I): It is a direct method and consists of applying a brake through a special (camel hair) belt to a water-cooled drum mounted on the motor shaft as shown in Fig 5. One end of the belt is fixed to the ground via a spring balance S, and the other end is connected to a suspended weight W_1. The motor is run and the load on the motor is adjusted till it carries its full load current.

Fig 5



BRAKE TEST

Let W_1 – suspended weight in kg.

W_2 – reading on spring balance in kg.wt.

The net pull on the belt due to friction at the pulley is

$(W_1 – W_2)$ kg. wt. or 9.81 $(W_1 – W_2)$ newton. If R-radius of the pulley is in metre then, the shaft torque T_{sh} developed by the motor

$= (W_1 – W_2)R$ kg.m

$= 9.81(W_1 – W_2)R$ N–m

If n – motor or drum speed in r.p.s.

Motor output power $= T_{sh} \times 2\pi n$ watt

$= 2\pi \times 9.81\, n\, (W_1 – W_2)R$ watt

$= 61.68\, n\, (W_1 – W_2)R$ watt.

Let, V = supply voltage;

I = load current taken by the motor.

Then, input power = VI watt.

$$\text{Therefore, efficiency} = \frac{\text{output}}{\text{input}} = \frac{61.68n(W_1 - W_2)R}{VI}$$

Further the metric horsepower developed by the motor can be calculated by the formula

$$\text{HP metric} = \frac{2\pi n T_{sh}}{735.6}$$

where 'n' is the speed in r.p.s.

T_{sh} is the shaft torque in newton metres.

The power rating given in the name-plate of the motor indicates the horsepower which is developed at the shaft.

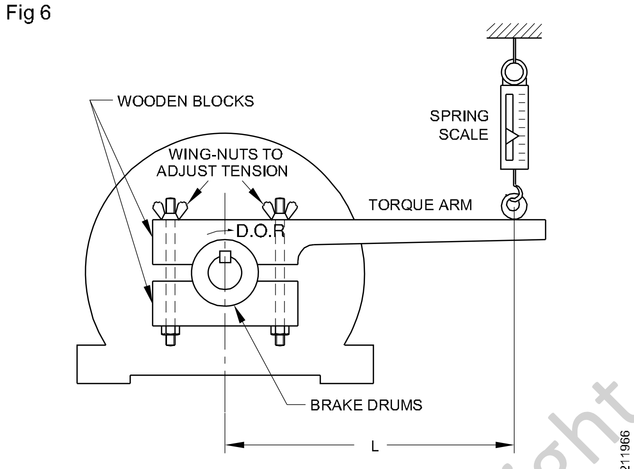
The simple brake test described above can be used for small motors only, because in the case of larger motors, it is difficult to dissipate the large amount of heat generated at the brake.

It is most important to remember that a series motor should never be operated without a load.

The field is very weak at no load. Operating the motor without a load will allow the motor to reach such high speeds that the centrifugal force will cause the windings to tear free.

Brake test (Method II): The torque developed by a motor may be measured alternatively by a device called a prony brake as shown in Fig 6.

Fig 6



PRONY BRAKE USED FOR MEASURING TORQUE DEVELOPED BY A MOTOR

There are various prony brake designs available. In Fig 6, the brake drum is encased in split wooden blocks. By tightening the wing-nuts, the pressure of the wooden blocks on the brake drum can be varied, and thereby, the load can be adjusted to the desired value. The brake drum has an extension torque arm that is fastened to a spring scale which measures the force developed on the brake drum in newtons. The torque developed is the product of the net force on the scale (in newtons) X the effective length (L) of the torque arm in metres.

Torque = force x distance

= spring balance reading in Kg.wt x 'L' in metres.

The efficiency and the output of the motor in metric horsepower could be calculated as explained in the above paragraphs.

Example 1: A prony brake arm is 0.4 m in length. The wing-nuts on the brake are tightened on the motor pulley, creating a force of 50 Kg.wt. What is the torque that is being developed by the motor?

1 Kg.wt = 9.8 newtons

Torque = force x length(distance)

= 50 x 9.81 x 0.4

= 196.2 newton metres.

Example 2: In the above case calculate the metric horsepower developed by the motor when the shaft speed is 1500 r.p.m.

$$\text{HP metric} = \frac{2\pi n T_{sh}}{735.6}$$

$$n = \frac{1500}{60} = 25 \text{ r.p.s. } (n = \text{r.p.s})$$

$$T_{sh} = 196.2 \text{ N.m}$$

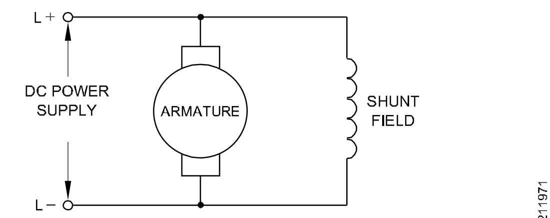
$$\text{HP (metric)} = \frac{2\pi \times 25 \times 196.2}{735.5} = 41.9 \text{ HP (metric)}$$

Characteristic and applications of a DC shunt motor

Objectives: At the end of this lesson you shall be able to
- **describe the characteristics of a DC shunt motor**
  - **– speed vs load characteristics**
  - **– torque vs load characteristics**
  - **– torque vs speed characteristics**
- **state the applications of a DC shunt motor.**

Shunt motor: As shown in Fig 1, in a shunt motor, the field is connected directly across the armature and the supply. The field current, and hence, the field flux are constant. When operating without a load, the torque requirement is small, since it is only needed to overcome windage and friction losses. Because of the constant field flux, the armature will develop a back emf that will limit the current to the value needed to develop only the required torque.

Fig 1



DC SHUNT MOTOR

Speed load characteristic of the DC shunt motor: Shunt motors are classified as constant speed motors. In other words, there is very little variation in the speed of the shunt motor from no load to full load. Equation 1 may be used to determine the speed of the DC motor at various loads.

$$N = \frac{V - I_a R_a}{K_1 \varnothing} = \frac{E_b}{K_1 \varnothing} \text{ (Eqn.1)}$$

where

N - speed of the armature in r.p.m.

V - applied voltage

I_a - armature current at a specific load

R_a - armature resistance

Ø - flux per pole

K_1 - a constant value for the specific motor

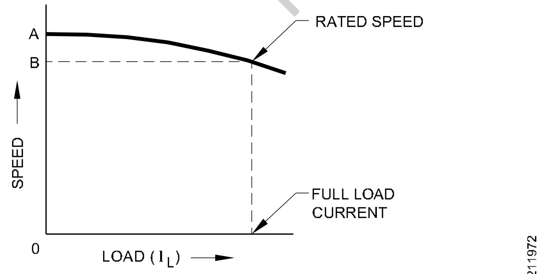
E_b - the back emf

In a shunt motor, V,R_a,K_1 and Ø are practically constant values, and the armature current is the only variable. At no load the value of `I_a' is small, leading to the maximum speed. At full load, $I_a R_a$ is generally about 5 percent of V. The actual value depends upon the size and design of the motor. Consequently, at full load, the speed is about 95 percent of the no-load value.

However the speed will drop slightly to reduce the back emf such that the armature can draw more current to develop an increased torque from no load to full load.

Fig 2 shows the speed-load characteristic of a DC shunt motor. From the curve it is observed that the speed slightly drops from its no-load speed OA to OB when the motor delivers full load. This is due to the increased $I_a R_a$ drop in armature. As the drop is small, the DC shunt motor is regarded as a practically constant speed motor.

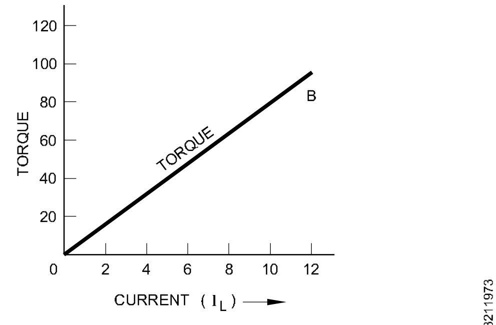
Fig 2



LOAD VERSUS SPEED CHARACTERISTIC OF DC SHUNT MOTOR

Torque vs load characteristics of the DC shunt motor: Motor torque is proportional to the product of the field flux and the armature current. As the field flux is constant, the torque varies as the load current varies. Fig 3 shows the torque vs load curve of a DC shunt motor. From this it is clear that the torque is directly proportional to load or armature current I_a.

Fig 3

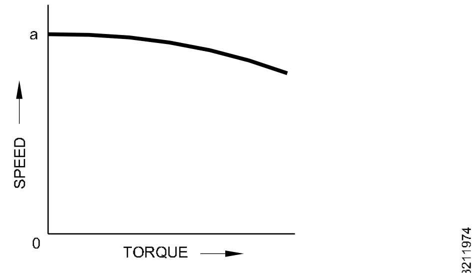


TORQUE VERSUS LOAD CHARACTERISTIC CURVE

The starting torque of a shunt motor is about 1.5 times the full load torque indicating that the shunt motor does not have as high a starting torque as the series motor, but it has much better speed regulation.

Torque Vs speed characteristics: Fig 4 shows the torque speed characteristic of a DC shunt motor. From the curve it is observed that the increase in torque has negligible effect on the speed. The speed slightly drops as the torque increases.

Fig 4



SPEED VERSUS TORQUE CHARACTERISTIC OF DC SHUNT MOTOR

Application of DC shunt motor: A DC shunt motor is best suited for constant speed drives. It meets the requirements of many industrial applications. Some specific applications are machine tools, wood planers, circular saws, grinders, polishers, printing processes, blowers and motor generator sets.

When working with a shunt motor, never open the field circuit when it is in operation. If this happens, as the flux is only due to the residual field, the motor speed increases to a dangerous magnitude. At light loads this speed could become dangerously high, and the armature may fly off.

DC compound motor - load characteristics

Objectives: At the end of this lesson you shall be able to
- **state the types, applications of DC motors**
- **state the characteristic of a DC compound motor**
- **state the precautions to be observed while starting a differential compound motor.**

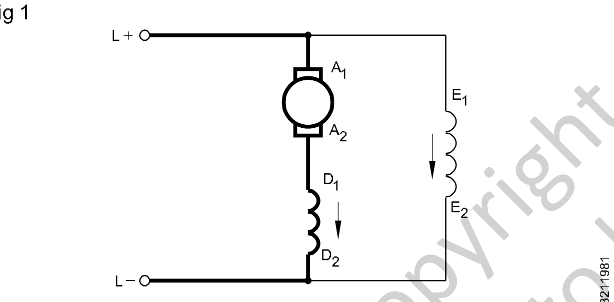
DC compound motor: A DC compound motor has both shunt and series fields for producing the required main flux in the poles. A DC compound machine can be used as a motor or generator. It can be classified as indicated below.

Compound motor
- Cumulative compound
  - Long shunt
  - Short shunt
- Differential compound
  - Long shunt
  - Short shunt

Cumulative compound motor: When the series field of the DC compound motor is connected in such a way that its flux aids the flux produced by the shunt field, as shown in Fig 1, then it is called a cumulative compound motor.

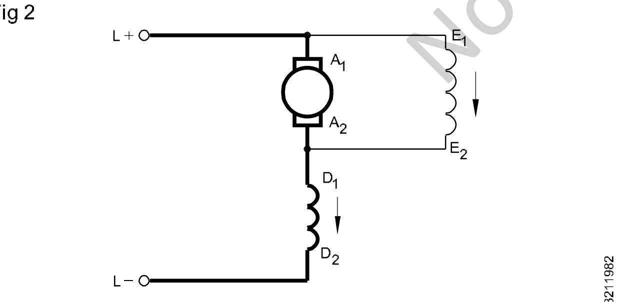
Depending on the shunt field connection, it is further sub-divided as the long shunt, (Fig 1) the short shunt (Fig 2) cumulative compound motor.

Fig 1



CUMULATIVE COMPOUND MOTOR (LONG SHUNT)

Fig 2

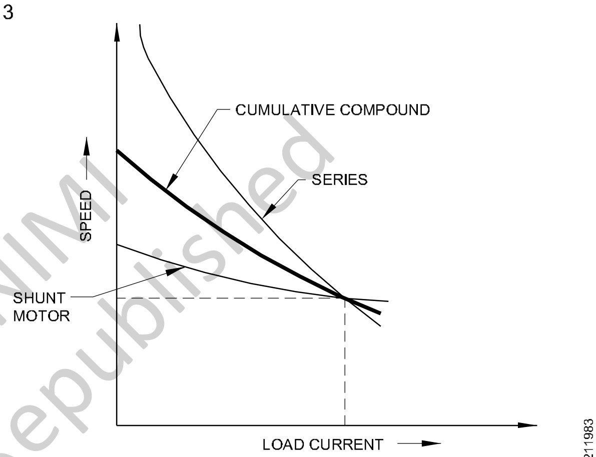


CUMULATIVE COMPOUND MOTOR (SHORT SHUNT)

As this motor has both shunt and series fields, it has the combined behaviour of the shunt and series motor, depending on the magnitude of the fluxes due to these two fields. If the series ampere-turns are more predominant than the shunt ampere-turns at full load, then it has a higher starting torque than the shunt motor, and its speed falls more than that of the shunt motor. If the shunt ampere-turns are more predominant than the series ampere-turns at full load, the motor acts almost like a shunt motor but its speed drops a little more than that of a shunt motor.

Speed-load characteristic: Fig 3 shows the speed-load characteristic of the cumulative compound motor, and also of the series and shunt motors for comparison. The speed of this motor falls more than the shunt motor but falls less than the series motor. As the speed load curve starts from Y-axis, unlike in a DC series motor, the cumulative compound motor can also run on no-load at a specified speed.

Fig 3

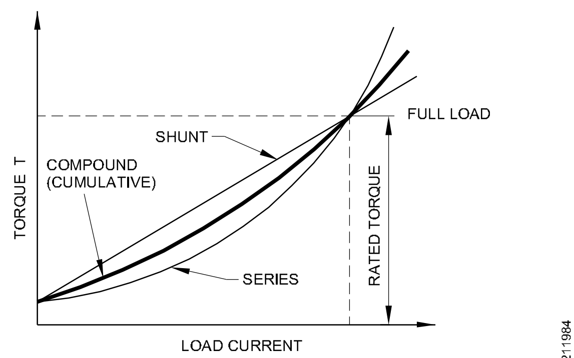


SPEED-LOAD CHARACTERISTIC OF CUMULATIVE COMPOUND MOTOR

The increased drop in speed at load is due to the combined drop of the voltage due to armature and series field resistances.

Torque-load characteristic: Fig 4 shows the torque-load characteristic of the cumulative compound motor, and also that of the series and shunt motors for comparison. Up to full load, the torque developed in a cumulative compound motor is less than that in the shunt motor but more than in the series motor.

Fig 4

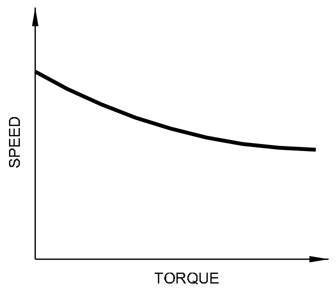


TORQUE-LOAD CHARACTERISTIC OF COMPOUND MOTOR (CUMULATIVE)

However, at the time of starting, the starting current is about 1.5 times the full load current, and hence, the cumulative compound motor produces a high torque, which is better than that of the shunt motor during starting.

Torque-speed characteristic: Fig 5 shows the torque-speed characteristic of the cumulatively compound motor. As the total flux of the motor increases with load, the speed decreases but the torque increases. As the output power is proportional to the product of speed and torque, the cumulative compound motor will not be overloaded in case of sudden appearance of load as in rolling mills.

Fig 5



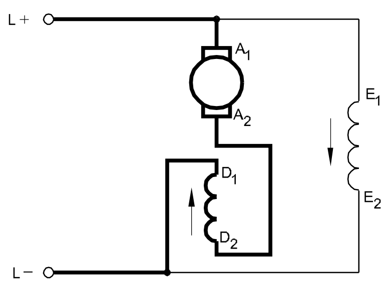
TORQUE SPEED CHARACTERISTIC OF A CUMULATIVE COMPOUND MOTOR

Application of cumulative compound motors: Compound motors are used to drive machines that require a relatively constant speed under varying loads. They are frequently used on machines that require sudden application of heavy loads, such as presses, shears, compressors, reciprocating tools, steel rolling machinery and elevators. Compound motors are also used when it is desired to protect the motor by causing it to decrease the speed under heavy loads. However, using a flywheel along the motor facilitates almost constant speed by converting the stored energy in the flywheel to be utilised during heavy loads. During light loads the kinetic energy is stored in the flywheel.

Never open the shunt field of a compound motor when the motor is operating at high load.

Differential compound motor: When the series field of the DC compound motor is connected in such a way that its flux opposes (bucks) the flux produced by the shunt field as shown in Fig 6, it is called a differential compound motor.

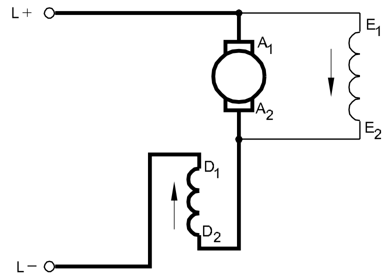
Fig 6



DIFFERENTIAL COMPOUND MOTOR (LONG SHUNT)

Depending upon the shunt field connection, the compound motor is further subdivided as long shunt (Fig 6) and short shunt (Fig 7) differential compound motor.

Fig 7

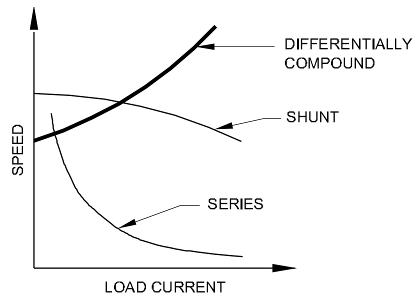


DIFFERENTIAL COMPOUND MOTOR (SHORT SHUNT)

As the series field flux is in the opposite direction to the shunt field flux, there is some inherent problem at the time of starting. At the time of starting, the shunt field takes some time to build up, whereas a heavy rush of current will be through the series field and armature. The motor will, therefore, tend to start up the wrong way. When the shunt field is fully established, the total flux, which is the difference of series and shunt field fluxes, may be so small that the motor may not produce sufficient torque to run the motor. Hence it is advisable to short-circuit the series field of the differential compound motor at the time of starting, and then put the series field in the circuit when the motor is running.

Characteristics of a differential compound motor: The speed-load characteristic of the differential compound motor, shown in Fig 8, indicates that the motor speed increases with the increase in load due to the fact that the total flux decreases at the increased load.

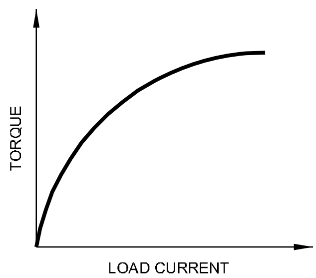
Fig 8



SPEED - LOAD CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

The torque-load characteristic of the DC differential compound motor shown in Fig 9, indicates that the torque increases with the increased load.

Fig 9

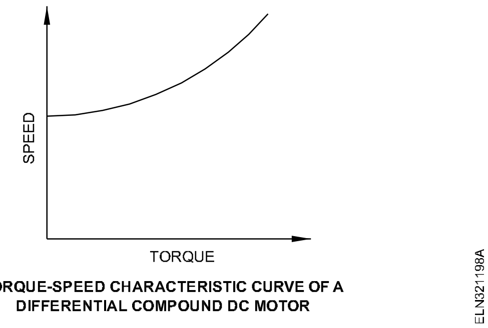


TORQUE - LOAD CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

Fig 10 shows the torque-speed characteristic indicating that both speed and torque increase in the machine, resulting in the overloading of the machine initially, and thereby, reaching an unstable state.

Application of DC differential compound motor: This motor is not in common use due to its unstable behaviour at overloads. This motor is dangerous to use unless there is no possibility of the load exceeding the normal full load value as it is designed to work within full load limits.

Fig 10



TORQUE-SPEED CHARACTERISTIC CURVE OF A DIFFERENTIAL COMPOUND DC MOTOR

Speed control methods of a DC motor and their applications

Objective: At the end of this lesson you shall be able to
- **explain the principle and the methods of controlling the speed of a DC motor.**

Principle of speed control in DC motors: In certain industrial applications, the variation of speed is a necessity. In DC motors the speed can be changed to any specified value easily. This is the main reason for certain industries to prefer DC motors for drives rather than AC motors. The speed of a DC motor can be varied, based on the following simple relationship.

It is known that the applied voltage = back e m f + armature resistance voltage drop

$V = E_b + I_aR_a$.

Hence $E_b = V - I_aR_a$ and also

the back emf $E_b = \frac{P\varnothing N}{60} \times \frac{Z}{A} = K\varnothing N$

where K is a constant.

Therefore $N = \frac{E_b}{k\varnothing} = \frac{V - I_aR_a}{k\varnothing}$ Eqn.1

From the above expression, it is clear that the speed of a DC motor is directly proportional to the back emf E_b, and inversely proportional to flux (Ø). Thus the speed of the DC motor can be varied by changing either the back emf E_b or the flux Øor both. In fact, if the back emf is decreased across the armature, the speed decreases, and if the flux is decreased the speed increases. The following are the most common methods of controlling the speed of DC motors based on the above principle.

Methods of speed control in DC shunt motors and compound motors

Armature control method: This method works on the principle that the speed of the DC motor could be varied by varying the back emf. As the back emf = $V - I_aR_a$, by varying the armature resistance we can obtain various speeds. A variable resistance called controller is connected in series with the armature as shown in Fig 1. The controller should be selected to carry the armature current for a longer period.

Let the initial and final speeds of the motor be N_1 and N_2, and the back emf be E_{b1} and E_{b2} respectively,

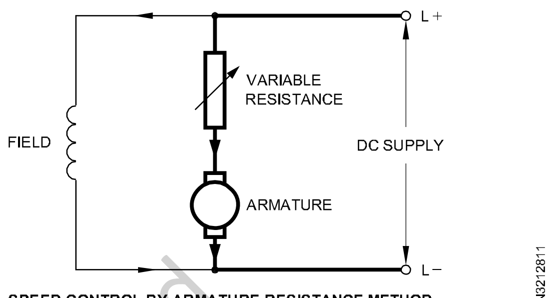
Then $N1 = \frac{E_{b1}}{k}$ .....Eqn.2.

$N2 = \frac{E_{b2}}{k}$ .....Eqn.3.

By dividing Eqn.3 by Eqn.2 we have

$N_2 = \frac{E_{b2}N_1}{E_{b1}}$.

Fig 1



SPEED CONTROL BY ARMATURE RESISTANCE METHOD

By varying the controller resistance value in the armature circuit, the back emf can be varied from E_{b1} to E_{b2}, thereby, the speed can be varied from N_1 to N_2.

Advantages

This method is suitable for constant load drives where speed variations from low speed up to normal speed are only required.

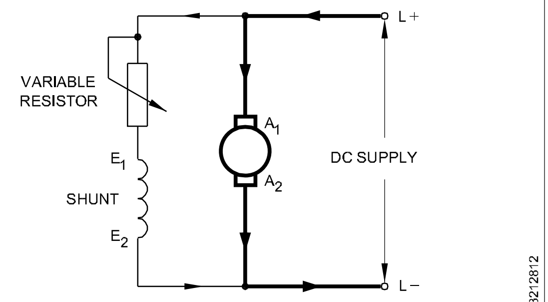
Disadvantages

- Speeds below normal can only be obtained.
- After setting the required speed, it changes with the change in the load because of speed variations not only due to control resistance but also due to load. Hence a stable speed cannot be maintained when the load changes.
- Power loss in the control resistance is high due to the higher current rating, leading to low efficiency of the motor.
- Cost of control resistance is high due to the fact it has to be designed to carry the armature current.
- Requires expensive arrangement to dissipate the heat developed in the control resistance.

Application of the armature control method: Suitable for DC shunt and compound motors used in printing machines, cranes and hoists where the duration of low speed operation is minimum.

The shunt field control method: This method works on the principle that the speed of the DC motor could be varied by varying the field flux. For this, a variable resistance (rheostat) is connected in series with the shunt winding as shown in Fig 2.

Fig 2



SHUNT FIELD CONTROL CIRCUIT

When the resistance is increased in the field circuit, the field current and the flux are reduced. Due to the reduction of flux, the speed is increased.

Advantages

- Higher speeds i.e. above normal speed only can be obtained which will be stable from no load to full load.
- As the magnitude of the field current is low, the power loss in the field rheostat is minimum.
- Control is easy, economical and efficient.

Disadvantages

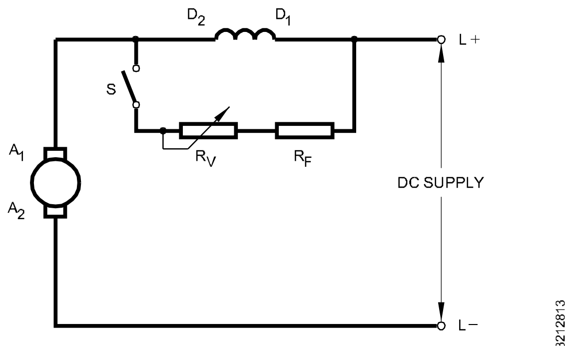
- Owing to the very weak field, a reduced torque is obtained at top speeds.
- The operation at high speeds with a weak field leads to commutation difficulties unless inter-poles are used.

Application of shunt field control: This method is the most widely used speed control method where speeds above normal are required, and at the same time, the load applied to the motor changes often.

Method of speed control in DC series motors

Field diverter method: A variable resistance, called a diverter, is connected in parallel with the field winding as in Fig 3. R_V represents the variable portion of the divertor and R_F the fixed portion. The function of R_F is to prevent the series winding being short-circuited, when the diverter is operated.

Fig 3



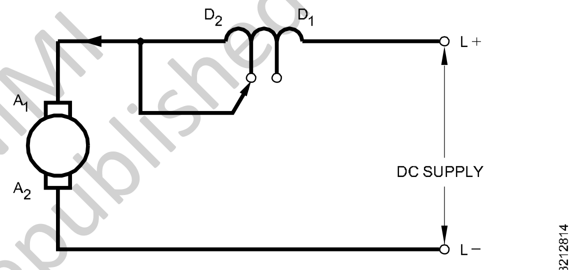
FIELD DIVERTER CONTROL CIRCUIT

The smaller the value of $R_V + R_F$, the greater is the current diverted from the series winding, and, higher the speed of the motor. The minimum speed for a given input current is obtained by opening the switch `S', thereby breaking the circuit through the diverter.

Application of the series field diverter method: This method is mainly used in the speed control of electric trains. By this method, speeds above normal only could be obtained, and the power loss in the diverter is quite considerable.

Field tapping method: A tap changing arrangement is made on the series field winding as shown in Fig 4. By varying the number of effective turns of the field winding, the speed can be controlled. The motor circuit should be started with all the winding included, and the speed can be changed then, by setting at a suitable tapping. This provision should be incorporated in the switch gear. Otherwise, if the tapping is kept at a lower setting and the motor is started, the motor races to a high speed at the time of starting itself, which is undesirable.

Fig 4



FIELD TAPPING CONTROL CIRCUIT

Application of series field tapping method: This method is used in small motors like food mixers, fans etc.

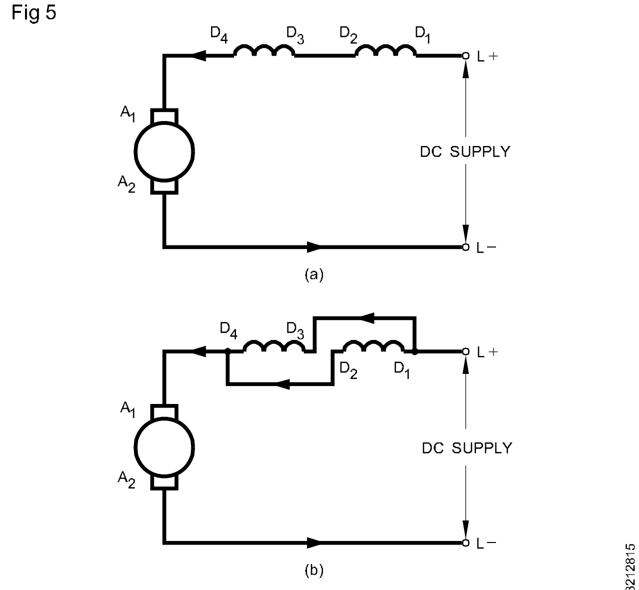
Series parallel method: Fig 5(a) shows a series motor with two halves of the field winding connected in series. If the two halves of the field winding are connected in parallel as in Fig 5(b), then for a given current 'I' taken from the supply, the current in each field coil is reduced to half and the flux is, therefore, reduced and the speed increased.

Application of series parallel method: This is the simplest method though only two speeds are possible. This method is often used for controlling the speed of fan motors.

Supply voltage control method: A controller (variable resistance) is connected in series with the motor as shown in Fig 6. This method can be used to control the speed from zero up to full normal speed.

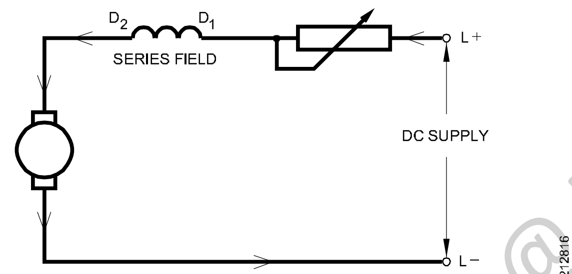
The disadvantage in this method is that there is loss of energy in the control resistance in the form of heat. But with the introduction of SCR based control circuit, obtaining a variable supply voltage to motor is achieved with the least power loss. This method is widely used in larger modern machines where power loss is a major concern.

Fig 5



SERIES-PARALLEL METHOD OF CONTROL

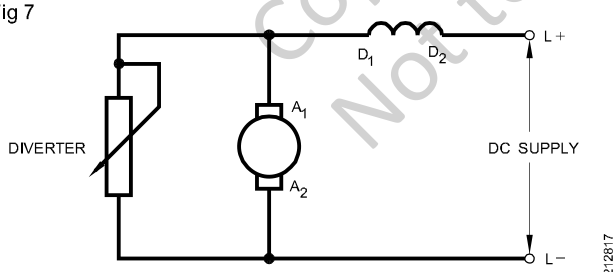
Fig 6



VOLTAGE CONTROL CIRCUIT

Armature diverter method: In this method, a variable resistor called a diverter is connected across the armature as shown in Fig 7. By this method, the armature current is controlled to vary the speed below the rated value for series motors.

Fig 7



ARMATURE DIVERTER CONTROL CIRCUIT

For a motor running at constant load torque, if the armature current is reduced by the armature diverter, the line current increases to meet the torque, thereby, the series field current increases. This increased field current reduces the speed.

This method is wasteful, costly and unsuitable for changing loads.

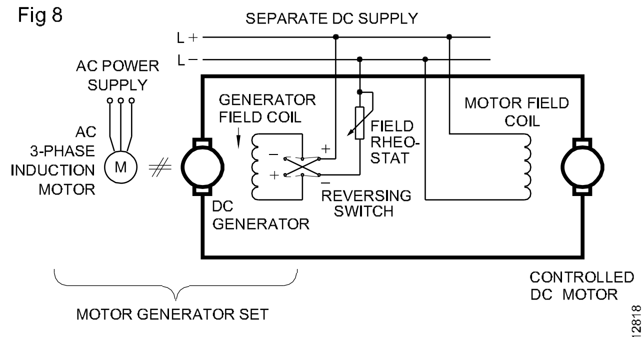
The speed control methods illustrated for DCseries motor cannot be used for compound motors as these adjustments would radically change the performance characteristics of the compound motor.

Ward-Leonard system of speed control: In all the methods explained so far, it is clear that the speed cannot be varied from zero to above normal by any one method and atleast two methods are required to be combined to do so. Further, the efficiency of the above mentioned controls is much less, due to power loss and instability due to load variation.

A smooth variation of speed from zero to above normal with inherent stability of speed at all loads is achieved through an adjustable voltage system of speed control called Ward-Leonard system of speed control.

In this system, a DC generator is mechanically coupled to a constant speed DC motor or an AC 3-phase induction motor as shown in Fig 8. The generated supply from the DC generator is fed directly to the armature of the controlled DC motor. The fields of both the DC generator and the controlled DC motor are separately excited from a suitable DC supply. The field of the DC generator is controlled through a field rheostat and a change-over switch to vary the generated voltage and to change the polarity respectively. This enables the supply to the controlled DC motor to vary at a wide range and also makes it possible to reverse the supply voltage polarity. This, in turn, changes the speed of the controlled DC motor to vary from zero to above normal speed as well as change the direction of rotation, if necessary. The controlled DC motor speed can be brought down to zero by reducing the supply voltage of the generator to a suitable level.

Fig 8



WARD-LEONARD SYSTEM OF SPEED CONTROL

Advantages

- By this system, a speed as low as zero and as high as two times the normal speed could be achieved.
- The direction of rotation of the controlled DC motor can be changed simply by reversing the controller in the field circuit of the generator.
- As there is not much power loss in the field rheostat, the speed variations are achieved at higher efficiency.
- The speed of the controlled DC motor is independent of the load.

Disadvantage

This method requires high initial cost and low overall efficiency due to three machines in operation.

Application of the Ward-Leonard speed control method: This system is used in steel rolling mills and paper mill drives, hoists, elevators etc. where a precise control of speed over a wide range is required. Even today DC motors are used in India as electrical drives in modern steel rolling mills, heavy industries like BHEL, HMT etc. Due to modernization, these DC motors are incorporated with solid state control devices like transistors, diodes, thyristors and microprocessors to eliminate human errors of operation and to maintain trouble-free service though the basic principles for the speed control, remain, as already stated, valid.

Method of calculation of control resistance and new speed

Objective: At the end of this lesson you shall be able to

- **explain the method of calculating the value of control resistance when full load current of the motor, armature resistance and applied voltages are known.**

We know from the earlier discussions that the speed of a DC motor.

$$N = \frac{V - I_a R_a}{K\varnothing} = \frac{E_b}{K\varnothing}$$

where

V = rated voltage of motor

I_a = armature current

R_a = armature circuit resistance

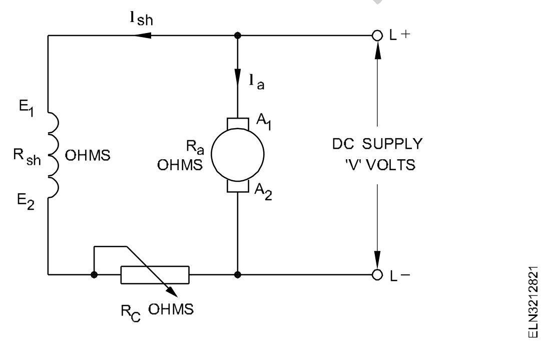
K is a constant for a particular motor

Ø is the flux in webers per pole of the motor

N is the speed in r.p.m.

The various methods of speed control discussed in the earlier chapter were based on this formula. From these we know that the speed of the motor can be controlled by either changing the flux Ø or by changing the back emf $E_b = (V - I_a R_a)$. To obtain these, we found that control resistance is connected either in field or in armature circuits. When control resistance is added, the speed will change. An electrician should be in a position to determine the value of the control resistance to be connected in the circuit to obtain a designated speed. The value of control resistance to be used to obtain a new speed can be calculated based on the following information (Fig 1).

Fig 1



Method of calculating control resistance in series with the shunt field

Let

E_{b1} = back emf at speed N1

E_{b2} = back emf at speed N2

N_1 = speed at which it is running

N_2 = new speed/speed to which it changes

I_{F1} = field current at N1

I_{F2} = field current at N2

R_t = total shunt field circuit resistance

R_{sh} = shunt field resistance

R_c = value of control resistance in series with shunt field.

Then $\frac{E_{b1}}{E_{b2}} = \frac{k\,\varnothing_1 N_1}{k\,\varnothing_2 N_2}$

As Ø is proportional to the field current I_F.

Therefore, we have $\frac{E_{b1}}{E_{b2}} = \frac{kI_{F1}N_1}{kI_{F2}N_2}$

Therefore the new speed $N_2 = \frac{E_{b2}I_{F1}N_1}{E_{b1}I_{F2}}$

Further $I_{F2} = \frac{\text{Applied voltage}}{\text{shunt field circuit resistance}} = \frac{V}{R_{sh} + R_c}$

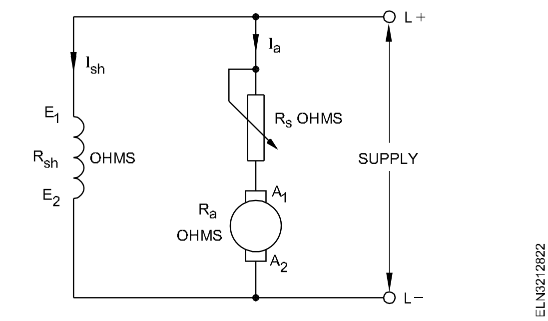
$$R_c = \frac{V}{I_{F2}} - R_{sh}$$

$$= R_t - R_{sh}.$$

Method of calculating the control resistance in series with the armature

Referring to Fig 2 we have

Fig 2



I_{a1} = armature current at N_1

I_{a2} = armature current at N_2

If $I_{a1} = I_{a2}$, then the load is of constant torque

N_1 = initial speed

N_2 = new or final speed

V = supply voltage

R_t = total armature circuit resistance

R_s = control resistance

R = control resistance in series with armatures

$$N_1 = \frac{E_{b1}}{k\varnothing} \text{ and } N_2 = \frac{E_{b2}}{k\varnothing}$$

$$N_2 = \frac{N_1 E_{b2}}{E_{b1}} = \frac{N_1(V - I_{a1}R_t)}{(V - I_{a2}R_a)}$$

where $R_t = R_s + R_a$.

Example 1 : A 230 volts DC shunt motor runs at 1000 r.p.m. and takes an armature current of 20A. Find the resistance to be added to the field to increase speed to 1200 r.p.m. at an armature current of 30 amps, if R_a = 0.25 ohms, R_{sh} = 230 ohms.

As the armature current varies from 20 to 30 amps, we get two variables E_{b1} and E_{b2}. Further the speed has to be increased by adding resistance in the shunt field. As such the field current changes from I_{F1} to I_{F2}.

$E_{b1} = V - I_{a1}R_a$ = 230 – (20 x 0.25) = 230 - 5 = 225 V

$E_{b2} = V - I_{a2}R_a$ = 230 – (30 x 0.25) = 230 - 7.5 = 222.5 volts

$$I_{F1} = \frac{230}{230} = 1 \text{ amp.}$$

$$\frac{E_{b1}}{E_{b2}} = \frac{I_{F1}N_1}{I_{F2}N_2}$$

$$I_{F2} = \frac{E_{b2} \times I_{F1} \times N_1}{E_{b1}N_2}$$

$$= \frac{222.5 \times 1 \times 1000}{225 \times 1200}$$

$$= 0.824 \text{ amp}$$

$$R_t = \frac{230}{I_{F2}} = \frac{239}{0.824} = 279.12 \text{ ohms.}$$

Therefore, $R_c = R_t$ - 230 = 279.12 - 230 = 49.12 ohms.

Example 2 : A DC shunt motor operates on 230V takes an armature current of 20A at 1000 r.p.m.. Its armature resistance is 1 ohm. Calculate the value of resistance to be added to the series with armature to reduce its speed to 800 r.p.m..

$E_{b1} = V - I_aR_a$ = 230 – (20 x 1) = 230 – 20 = 210 volts

$$\frac{E_{b1}}{E_{b2}} = \frac{N_1}{N_2}$$

Therefore, $E_{b2} = \frac{E_{b1} \times N_2}{N_1}$

$$= \frac{210 \times 800}{1000} = 168 \text{ volts.}$$

$E_{b2} = V - I_a R_t$.

Therefore $I_aR_t = V - E_{b2}$

= 230-168 =62 volts.

Therefore R_t = 62/20 = 3.1 ohms

$R_s = R_t - R_a$

= 3.1–1 = 2.1 ohms.

Example 3 : A 240 volts series motor takes 10 amps when giving its rated output at 2000 r.p.m.. Its resistance is 0.5 ohm. Find what resistance must be added to obtain the same torque at 1500 rpm. Calculate the power loss in control. (As torque is the same the current taken by the motor should be same.)

$E_{b1} = V - I_aR_a$ = 240 – (10 x 0.5) = 240-5 = 235 volts

$$E_{b2} = \frac{E_{b1}N_2}{N_1} = \frac{235 \times 1500}{2000} = 176.3 \text{ volts.}$$

$I_aR_t = V - E_{b2}$ = 240-176.3 = 63.7 volts

Therefore, $R_t = \frac{I_aR_t}{I_a} = \frac{63.7}{10}$ = 6.37 ohms.

Therefore, $R_s = R_t - R_a$ = 6.37 - 0.5

Series control resistance = 5.87 ohms

Power loss in control resistance $I_a^2Rs = 10^2 \times 5.87$ = 587 watts.

Troubleshooting in DC machines

Objective: At the end of this lesson you shall be able to
- **use the trouble shooting chart to rectify defects in i) DC machines in general ii) DC motors iii) DC generators.**

DC machines have electrical problems which are not normally found in AC machines. DC motors and generators have commutators and brushes, which cause special problems. If the commutator is properly maintained, it will give many years of useful service.

Troubleshooting in DC machines in general is discussed in Chart 1 where as Chart 2 deals with DC motors and Chart 3 is for DC generator.

Chart 1

Troubleshooting chart for DC machines

Symptoms	Cause	Remedies
Very rapid wearing out of the brushes	a) Insufficient brush tension.	a) Test brush tension.
or over heating of pig tails	b) Brushes not fully bedded.	b) Inspect the brush faces and the brushes.
or heavy sparking at the commutator	c) Incorrect size of grade of replaced brushes	c) Use correct grade of brush for replacement.
	d) Overloading.	d) Reduce the load.
or over heating of commutator.	e) Excessive brush pressure.	e) Adjust the brush tension to lower value
	f) Insufficient or unequal brush pressure due to brushes sticking in holder.	f) Check the free movement of brushes in holder.
	g) Short circuit in commutator segment.	g) Clean the commutator and test for shorts. Rectify the defect. Inspect the commutator surface.
	h) Uneven commutator surface.	h) Under cut the mica and skin the commutator if necessary.
	i) Brushes may not be in magnetic magnetic neutral plane.	i) Adjust the rocker arm to neutral plane.
	j) Dirty oily or tarnished commutator surface.	j) Clean and polish the commutator.
	k) Incorrect direction of rotation.	k) Check the direction of rotation and rectify the defect.
Brush chatter or hissing noise	a) Excessive clearance of brush holders.	a) Adjust holders.
	b) Incorrect angle of brush.	b) Adjust to correct angle.
	c) Incorrect brushes for the service.	c) Get manufacturer's recommendation.
	d) High mica.	d) Undercut mica.
	e) Incorrect brush spring pressure.	e) Adjust to correct value.
Selective commutation (one brush takes more load than it should)	a) Insufficeint brush spring pressure. b) Unbalanced circuits in armature.	a) Adjust the correct pressure making sure brushes ride free in holders.

Symptoms	Cause	Remedies
		b) Eliminate high resistance in defective joints by checking armature or equalizer circuit or commutator risers. Check for poor contacts between bus and bus rings.
Sparking at light loads	a) Paint spray, chemicals, oil or grease or other foreign material on commutator.	a) Use motor designed for application Clean commutator, and provide protection against foreign matter. Install an enclosed motor designed for the application.
Overheating of field coils	a) Short circuit between turns or layers	a) Replace defective coil or rewind the coil.
Overheating of armature	a) More voltage across the armature. may be high or in the case of motor the applied voltage.	a) In the case of generator the speed may be high measure and reduce it.
	b) More current in armature.	b) Reduce the overload.
	c) Armature winding shorted.	c) Check the commutator and remove any metallic particles in between segments. Test the machine for shorts and rectify the defect.
	d) Insufficient air circulation around machine	d) Allow good ventilation around the machine by providing fan etc.
Machine operates but overheats	a) Overloading.	a) Reduce load.
	b) Worn out bearing.	b) Replace bearing.
	c) Tight bearing.	c) Grease it.
	d) Shorted or earthed winding.	d) Test the winding.
	e) Wrong alignment of pulley.	e) Align properly.
Vibration while running	a) Loose foundation bolts.	a) Tighten them.
	b) Loose coupling pulleys.	b) Tighten them.
	c) Wrong alignment.	c) Align properly
	d) Loose internal parts.	d) Tighten them.
	e) Bent shaft.	e) True the shaft in a lathe
	f) Unbalanced armature.	f) Balance it.
	g) Damaged bearing.	g) Inspect the bearing and replace it if necessary.
Mechanical noise	a) Foreign matter in air gap.	a) Clean the machine.
	b) Defective alignment.	b) Align the machine.
	c) Defective bearing.	c) Replace the bearing.
Bearing overheating	a) Incorrect grade or quantity of grease (roller type).	a) Remove incorrect grade or surplus grease and replenish withcorrect quantity of recommended grease

Chart 2

Troubleshooting chart for DC motors

Symptoms	Cause	Remedies
Motor will not start	a) Open circuit in starter.	a) Check for open startingresistor,
	b) Low or no terminal voltage.	b) Check the incoming voltage with name-plate rating and correct the supply voltage.
	c) Bearing frozen.	c) Recondition the shaft and replace the bearing.
	d) Overload.	d) Reduce the load.
	e) Excessive friction.	e) Check the bearing lubrication to make sure that the oil is sufficient quantity and of good quality. Disconnect motor from driven machine and turn motor by hand to see if trouble is in motor. Strip and reassemble motor; then check part by part for proper location and fit.Straighten or replace bent shaft.
Motor stops after running short time	a) Motor is not getting power.	a) Check voltage in the motor terminals: also fuses and overload relay. Rectify the defect.
	b) Motor is started with weak or no field.	b) If adjustable-speed motor, check the rheostat for correct setting. If correct, check the condition of rheostat. Check the field coils for open winding. Check the wiring for loose or broken condition
	c) Motor torque insufficient to drive load.	c) Check the line voltage with name plate rating. Use larger motor or one with suitable characteristic to match the load.
Motor runs too slow under load.	a) Line voltage too low.	a) Rectify the supply voltage or under load check and remove any excess resistance in supply line, connections or controller.
	b) Brushes ahead of neutral plane.	b) Set brushes on neutral plane.
	c) Overload.	c) Check to see that load does not exceed allowable load on motor.
Motor runs too fast under load.	a) Weak field.	a) Check for resistance in shunt-under load field circuits. Check for grounds.
	b) Line voltage too high.	b) Correct high voltage condition.
	c) Brushes are out of neutral plane.	c) Set brushes on neutral plane.

Chart 3

Troubleshooting chart for DC Generators

Symptoms	Cause	Remedies
Generator fails to build up voltage	a) The direction of rotation must have been reversed.	a) Change the direction of rotation
	b) Brushes not resting on the commutator.	b) Brushes to be set over the commutator in correct position.
	c) Residual magnetism is completely lost.	c) Run the generator as a DC motor or sometime (few seconds) or connect the field circuit to a battery or DC voltage to reestablish the residual magnetism.
	d) Generator speed is too low.	d) Generator speed should be restored to normal speed by increasing the prime mover speed.
	e) Short circuit in the armature.	e) Rectify the short circuit in the armature.
	f) Open circuit in the armature.	f) Test and rectify the open circuit.
	g) Short circuit in the field circuit.	g) Test and rectify the short circuit which may be in the coil. Faulty coil will show much less resistance than a good coil.
	h) Open circuit in field winding.	h) Check the continuity of the circuit and rectify the defect.

Maintenance procedure for DC machines

Objectives: At the end of this lesson you shall be able to
- **state what is meant by preventive maintenance and its importance**
- **describe the recommended maintenance schedule for DC motors**
- **explain how to maintain the maintenance record.**

Preventive maintenance: Preventive maintenance of electrical machines consists of routinely scheduled periodical inspections, tests, planned minor maintenance repairs and a system of maintaining inspection records for future reference. Preventive maintenance is a combination of routine and planned operations.

Routine operations: Routine operations are those which follow fixed schedules to maintain electrical motors at daily, weekly or at other fixed intervals.

Planned operation: By contrast, planned operation consists of additional work which is performed at irregular frequencies, and is determined by inspection and previous operating experience or the details of defects found in the maintenance records.

Necessity of preventive maintenance: By carrying out an effective preventive maintenance programme on electrical machines, we can eliminate major failures of the machines, accidents, heavy repair costs and loss of production time. Proper preventive maintenance will lead to economy of operation, less down-time, dependable machine operation, longer machine life and lower overall cost of maintenance and repair.

Scheduling of preventive maintenance: Routine periodical inspection and tests may be scheduled to be carried out daily, weekly, monthly, half-yearly and annualy depending upon the following factors.

- The importance of the motor/generator in the production
- The duty cycle of the machine
- The age of the machine
- The earlier history of the machine
- The environment in which the machine operates
- The recommendations of the manufacturer.

Recommended maintenance schedule for machines: While carrying out routine periodical maintenance, an electrician will make full use of his senses to diagnose and locate problems in electrical machines. The sense of smell directs attention to burning insulation: the sense of feel detects excessive heating in winding or bearing; the sense of hearing detects excessive noise, speed or vibration and the sense of sight detects excessive sparking and many other mechanical faults.

Sensory impressions must also be supplemented by various testing procedures to localize the trouble. A thorough understanding of electrical principles and the efficient use of test equipment are important to an electrician during this phase of operation.

Machine details		Page 1
Manufacturer, Trade Mark ________		
Type, Model or List number ________		
Type of current ________		
Function ________ Generator/Motor		
Fabrication or serial number ________		
Type of connection ________ Sep/Shunt/Series/Compound		
Rated voltage ________ volts	Rated current ________ amps	
Rated power ________ K.W.	Rated speed ________ r.p.m.	
Rated exc. voltage ________ volts	Rated exc. current ________ amps	
Rating class ________	Directon of rotation ________	
Insulation class ________	Protection class ________	

The following maintenance schedule is recommended for DC machines.

1 Daily maintenance

- Examine visually earth connections and machine leads.
- Check the sparking at the commutator.
- Check the motor windings for overheating. (The permissible maximum temperature is near about that which can be comfortably felt by hand.)
- Examine the control equipment.
- In the case of oil-ring lubricated machines
  a) examine the bearings to see that the oil rings are working
  b) note the temperature of the bearings
  c) add oil, if necessary
  d) check end play.
- Check for unusual noise at the machine while running.

2 Weekly maintenance

- Examine the commutator and brushes.
- Check belt tension. In cases where this is excessive it should immediately be reduced. In the case of sleeve-bearing machines, the air gap between the rotor and stator should be checked.
- Blow out air through the windings of protected type machines situated in dusty locations.
- Examine the starting equipment for burnt contacts where machine is started and stopped frequently.
- Examine oil in the case of oil-ring lubricated bearings for contamination by dust, grit, etc.(This can be roughly judged from the colour of the oil.)
- Check foundation bolts and other fasteners.

3 Monthly maintenance

- Overhaul controllers.
- Inspect and clean the oil circuit breakers.
- Renew the oil in high- speed bearings which are in damp and dusty locations.
- Wipe the brush-holders and check the bedding of brushes of DC machines.
- Test the insulation of windings.

4 Half-yearly maintenance

- Check the brushes and replace, if necessary.
- Check the windings of machines subjected to corrosive and other elements. If necessary, bake the windings and varnish.
- Check the brush tension and adjust, if necessary.
- Check the grease in the ball and roller bearings, and make it up, where necessary, taking care to avoid overfilling.
- Check the current input to the motor or the output of the generator and compare it with normal values.
- Drain all the oil bearings, wash with petrol to which a few drops of oil have been added; flush with lubricating oil and refill with clean oil.

5 Annual maintenance

- Check all the high speed bearings, and renew, if necessary.

- Blow out all the machine winding thoroughly with clean dry air. Make sure that the pressure is not that high as to damage the insulation.
- Clean and varnish the oily windings.
- Overhaul the motors which have been subjected to severe operating conditions.
- Renew the switch and fuse contacts, if damaged.
- Check the oil in the starter and the grease/oil in the bearings.
- Renew the oil in the starters subjected to damp or corrosive elements.
- Check the switch conditions, resistance to earth between motor/generator windings, control gear and wiring.
- Check the resistance of earth connections.
- Check the air gaps in between the armature and field.
- Test the insulation of windings before and after overhauling the motors/generators.

6 Records

- Maintain a register giving one or more pages for each machine, and record therein all important inspections and maintenance works carried out from time to time. These records should show past performance, normal insulation level, air gap measurements, nature of repairs and interval between previous repairs and other important information which would be of help for good performance and maintenance.

While routine maintenance could be done either during the working of the machine or during short interval `down' periods, the planned maintenance requires to be done during holidays or by taking shut-downs of small duration.

Planned maintenance schedule needs to be decided, based on the routine maintenance reports entered in the maintenance card.

Details of inner parts	Page 1
Bearing	**Particulars of supply order**
Sleeve ball roller	Supply order No: ______
Front end No. ______	Year of purchase ______
Pulley end No. ______	Date of first inspection and test ______
Grease type ______	Date of installation ______
Coupling type ______	Location ______
Brush grade ______	
Brush No. as per manufacturer ______	

Initial test results	Page 1
Resistance value of shunt winding ______	
Resistance value of series winding ______	
Resistance value of armature ______	
Insulation resistance value between	
armature and shunt field ______	
armature and series field ______	
series field and shunt field ______	
armature and frame ______	
shunt field and frame ______	
series field and frame ______	

The 2nd page gives the record of maintenance carried out, and, in particular the defects noted therein.

Maintenance record

Maintaining a system of inspection records is a must in preventive maintenance schedule. This system uses a register as stated above or cards as shown below which are kept in the master file. By referring to these maintenance cards, the foreman can schedule the planned maintenance.

Maintenance card: The 1st page gives the details of name-plate, location, year of purchase, initial test results etc pertaining to the machine.

A careful study of the maintenance card helps the foreman to plan the shut-down date to facilitate early overhauling or planned maintenance schedule to prevent a major breakdown.

Method of maintenance: During the routine maintenance inspection, the investigations and adjustment to be carried out for the parts and accessories of the motors/generators are given below to improve the efficiency of preventive maintenance.

- Clean daily the motor/generator, switch gear and associated cables free from dirt, dust and grease. Use dry compressed air to drive away the dust from the machines.
- Check the bearing daily for excessive noise and temperature. If required, re-grease or re-oil the bearing with the same grade of grease/oil as in original. Do not mix different grades of grease together as it may result in forming sludge or acids, and spoil the bearings.
- Check the machine daily against strains of water or oil or grease which may leak from the surroundings. Take the necessary protective steps to prevent the leakage.
- Check daily the belts, gears and coupling for looseness, vibration and noise. Adjust/replace the parts, if found defective.
- Check weekly the brushes and the commutator for sparking and wear.
- Check weekly the bearing for proper lubrication.
- Check weekly the terminals and switch contacts.
- Inspect the brushes and the commutator once in a month for excessive wear, chatter and sparking. Worn-out brushes need to be replaced with the same grade brushes. Check spring tension on the brushes, and adjust, if necessary. Badly worn-out commutators need to be turned in a lathe or be replaced.
- Check monthly the brushes for proper seating. If necessary, reshape the brushes to proper curvature to suit the commutator surface.
- Check monthly the end plates and the shaft for excessive end play.
- Check monthly the main and auxiliary contact points of the switch gear for wear, pitting and burns. Badly worn out contact point needs replacement. Check the connection terminals for loose connection and scales or burning. Rectify the defects.
- Test monthly once the field windings and armature for insulation and ground faults. Low reading of insulation below 1 megohm indicates weak insulation. Dry out the winding, and re-varnish, if necessary.
- Check monthly once the foundation bolt and other fasteners for tightness.
- Once a year undercut the mica in between the commutator bars. Test the commutator and armature for shorts, open and ground faults.

Maintenance card

Report on routine maintenance **Page 2**

Date of maintenance	Scheduled maintenance carried out	Defects noted	Attended by (Signature)	Reported to (Signature)	Remarks

The 3rd page gives the details of the test carried out in the motor at intervals with corresponding readings

Maintenance card

Report on test details **Page 3**

Date of Test	Schedule	Test particulars	Test results	Tested by (Signature)	Reported to (Signature)	Remarks

From the above it is clear that atleast once in a year, the motor/generator needs a thorough overhauling in addition to frequent routine maintenance.

The 4th page gives the details of the defects,causes and repair carried out

Motor service card **Page 4**

Date of repair	Repair and parts replaced	Cause	Repaired by (Signature)	Supervised by (Signature)	Remarks

DC motor control system (drives) AC-DC and DC-AC control

Objectives: At the end of this lesson you shall be able to
- **state the importance of AC to DC drive control**
- **list the advantages and applications of AC to DC drives**
- **explain the DC-DC drive control system (chopper)**
- **list the advantages and application of DC-DC drive.**

AC to DC drive control

AC/DC drive in an electronic device which converts a fixed frequency and voltage to an adjustable frequency and AC voltage source. It controls

- the speed
- the torque
- the horse power
- the directions of AC motor

These drives are also known as "Adjustable Speed Drives (ASD)" or "Variable Frequency Drives (VFD)"

It becomes more popularity due to energy saving.

The AC/DC converter is an SCR bridge, which receives AC power from the output wire and provides adjustable voltage DC power to DC bus, by using inverter.

The voltage regulator is required to preset the DC bus voltage level required for the output voltage amplitude to the motor

The frequency is adjusted by the frequency control device which is cause to control the speed of the motor.

Advances in technology have made the size, cost, reliability and performance of AC drives very appealing as Industrial "Variable Speed Applications"

Advantages

- Precise speed control
- Energy saving
- Simple operation
- No external control
- Good reliability
- Lighter and smaller in size
- It is preferable method of speed control

Application

Fans, Blowers, Compressors, Pumps, Lathes, Stamping presses, Etc.

DC - DC drive control (Chopper)

DC - DC converter (chopper) drives are widely used in traction application all over the world. A DC - DC Converter is connected between a fixed voltage DC source and a DC motor to vary the armature voltage. In addition to armature voltage control a DC - DC converter can provide regenerative braking of the motors and can return energy back to the supply. It operates at high frequency.

DC-DC converter drives are also used in battery electric vehicle (BEVs). There are few control methods in DC-DC converter drive such as

- Power (or) acceleration control
- Regenerative brake control
- Rheostatic brake control
- Combined regenerative and rheostatic brake control

Advantages

It provides high starting torque. It is also possible to obtain speed control over a wide range. The methods of speed control are normally simpler and less expensive than those of AC drives.

Applications

- Servo applications
- Robotics

Materials used for winding - field coil winding

Objectives: At the end of this lesson you shall be able to
- **classify different types of insulating materials used for winding according to their ability to withstand temperature**
- **list out the insulating materials used for winding and their applications.**

Insulating materials : In winding work, proper selection of insulating materials is an important criterion. The ageing factor of the insulation of electrical equipment and apparatus depends upon many factors, such as temperature, electrical and mechanical stress, vibration, moisture, dirt and chemical reaction.

Classification of insulating materials used for winding: The temperature encountered in electrical equipment and apparatus very often decides the ageing factor of insulating materials of the system. Certain basic thermal classifications have proved useful and have been accepted throughout the world. Hence the insulating materials used for winding are classified according to their ability to withstand a particular range of temperatures.

Each class of insulation is associated (according to BIS 1271-1985) with a particular temperature. When this temperature is not exceeded, it will ensure an economic life for the insulation of an equipment under usual conditions of service. One must also take into account other factors like vibration, dirty conditions, the presence of chemicals, etc. since these factors may cause early breakdown of an insulation material.

The recognised classes of the most commonly used insulating materials and the temperatures assigned to them are given in Table 1.

The temperature quoted in Table 1 is the actual temperature of the insulation and not the rise in temperature of the electrical equipment.

Table 1

Classification of insulations
(as per BIS:1271-1958/1985)

Sl. No.	Class	Max. safe temp.	Description of insulation material
(1)	(2)	(3)	(4)
1	Y	90°C	Cotton, silk, paper without impregnation,
2	A	105°C	Cotton,silk, paper immersed in oil.
3	E	120°C	Leatheroid paper, empire cloth., fibre.
4	B	130°C	Mica, glass fibre, asbestos.
5	F	155°C	The insulation of this class consists of materials of a better quality than class B insulation. Glass fibre, mica,asbestos etc.
6	H	180°C	Silicon elastomer and combinations of materials such as mica, glass fibre, asbestos etc.
7	200 220 250	200°C 220°C 250°C	This class consists of materials such as mica, porcelain, glass, quartz, etc.

Materials: The following are the common insulating materials used for winding purposes.

Insulation paper sheets: They are generally used for insulating slots and other metal parts from the live wire in a winding system.

Leatheroid paper: It is a special paper having better ageing and dielectric strength. It is available in colours of dark grey and bottle green. It is used for Class A insulation scheme.

Pressphan paper: It consists of highly glazed and pressed paper, having good dielectric strength. Normally, it is available in yellow colour. Used for Class A insulation scheme.

Triplex paper: In this a layer of polyester film is deposited on the surface/surfaces of leatheroid or pressphan paper or elephantide paper to make it non-hygroscopic. Normally one side of this paper is glazed and colours may be brown, green, grey or yellow depending upon the papers used. This paper is used for Class E insulation schemes.

Millinex paper: This is a synthetic paper, milky white in colour. It is highly non-hygroscopic and possesses good electrical and mechanical strength. Used for class E and B insulation schemes.

Micanite paper (mica folium) and micanite cloth: It consists of soft mica, bonded with paper or cloth base. This can withstand higher temperatures. Normally it is white in colour with the mica visible. Used for Class E and B insulation schemes.

Empire cloth: It is an impregnated cloth and is highly flexible. Generally it is available in black or yellow colour, depending upon the colour of the varnishes used. It is recommended for Class A insulation scheme.

Glass fibre cloth: It is a cloth made of glass wool. It has high dielectric strength and can withstand high temperature. It is highly flexible. When not impregnated, the colour is white. Impregnated fibre glass cloth is normally used in winding, and the colour will be golden yellow or black. Used for Class E and B insulation schemes.

The above insulating sheets are available in thicknesses of 2 mil, 5 mil, 7 mil, 10 mil & 15 mil, having a width of one metre. They are generally sold in kilograms.

For Classes `F' and `H', special type of insulation sheets are used. Some of the brand names are `Hypotherm and Nomex'.

TAPES**:** These are used for wrapping the conductor or groups of conductors in the winding process.

Cotton tape: Generally it is not impregnated and is available with cross and straight woven fabric. It is white in colour. Used for Class A and E insulation schemes.

Empire tape: It is an impregnated cloth tape. The colour of the tape will be the colour of the impregnating varnish used, i.e. yellow or black. Used for class A insulation scheme.

Fibre glass tape: It is available as either impregnated or non-impregnated types. It has got high dielectric strength and can withstand high temperature. It is generally used for Class E, B and F insulation schemes.

The above mentioned tapes are available in sizes 2,5, 7 and 10 mils thick, 12mm, 19mm and 25 mm wide-in rolls of 25, 50 and 100 metres.

For class `F' and `H' insulation schemes, special types of silicon based tapes are used. For example, SILICON-ELASTOMER which is a brand name.

SLEEVES : Sleeves are used to insulate winding lead connections and terminations.

Cotton sleeves: These are made of cotton fabric, generally not varnished. They are used for class A insulation scheme.

Empire sleeves: These are impregnated cotton sleeves and are used for class A insulation scheme.

Fibre glass sleeves : These are impregnated fibre glass, woven fabric sleeves. Generally, they are yellow and black in colour. Used for class E, B & F insulation schemes.

PVC sleeves: These are made up of polyvinyl chloride sheets and are available in different colours. They are highly non-hygroscopic. Due to their deterioration at rise in temperature, they are not used for winding purposes. They may be used for insulating exposed lead terminations.

The above mentioned sleeves are available in sizes 1mm, 2mm, 3mm, 4mm up to 12 mm in dia. and generally one metre long. Sometimes they may be rolled into 25, 50 and 100 metre rolls.

Other insulating materials

Fibre: Generally fabric-based fibre is used in insulation. It is used for wedges and packing purposes. It is somewhat reddish in colour and is available in sheets with a thickness of 1 mm to 12 mm, and is sold by weight in kgs. It is used for Class A,E & B insulation schemes.

Bamboo: Well seasoned bamboos are used as wedges in the winding process. Readymade cut pieces of suitable sizes are available in shops. It is used for Class A & E insulation schemes.

Hemp thread: It is used for binding the coils and overhangs. It is available in different thicknesses and in rolls. Used for Class A insulation scheme.

Terylene thread: It is made up of terylene material and is used for binding the coils and overhangs. It is available in different thicknesses and in rolls. It is suitable for Class E & B insulation schemes.

Varnish: It is a liquid insulating material which is used for increasing the insulating property of some of the materials used in the winding process. Two types of varnishes are available for winding purposes.

- Air-drying insulating varnish
- Baking insulation varnish

These varnishes are available in two colours, golden yellow and black. They are available in tins of 1 to 5 litres normally.

More particulars about varnish and varnishing processes are discussed in Ex. 3.2.130.

Winding wires

Objectives: At the end of this lesson you shall be able to
- **refer to a winding-wire table having particulars like gauge number, diameter, area of cross-section, weight per km, accommodation of turns per square cm and their current-carrying capacity etc.**
- **state the scheme of insulation of a field coil**
- **explain the method of winding field coils**
- **explain the method of connecting the field coils,and the method of testing.**

Winding wires : The annealed copper conductors, normally in round shape, are used for winding small and medium capacity electrical machines and equipments. These copper wires are provided with a variety of insulation as stated below.

- Super-enamelled copper wire (S.E.)
- Single cotton-covered copper wire (S.C.C.)
- Double cotton-covered copper wire (D.C.C.)
- Single silk-covered copper wire (S.S.C.)
- Double silk-covered copper wire (D.S.C.)
- PVC-covered copper winding wire

Generally super-enamelled copper winding wire with medium covering is used for most of the winding applications, whereas for some special applications super-enamelled copper wire with thick covering may be used.

Field coils and armature of certain DC machines might be wound with super-enamelled, DCC or DSC copper winding wires.

PVC covered copper winding wire is mainly used for submersible pumps.

The winding wires are available in different sizes and grades of insulation.

All the required particulars for SE copper wire having medium covering are given in Table 1.

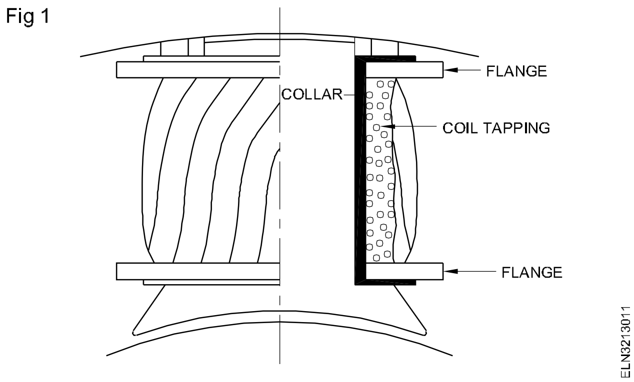
Such tables are published by all leading manufacturers of winding wires to help the winder in his task. The current-carrying capacity of the conductor shown in Table 1 is at 2.3A/mm². In general usage, a rating nearly 3 to 4 times higher in value, is used depending upon the insulation and temperature grade of the machinery.

Winding of field coils: In rewinding a field coil, special attention shall be given for selection of proper winding wire - its insulation, correct size of coil and the insulation scheme involved in different stages so as to satisfy the original condition, unless otherwise warranted by necessity.

Insulation details for a field coil : The field coil shall be well insulated from the frame, field pole and pole shoes.

Collar : The insulation used around the field pole, called a collar, is shown in Fig 1.

Fig 1



Flanges: The insulation used on either side of the coil i.e. to insulate it from the frame and pole shoes is called flanges. (Fig 1)

Table 1

(Data for super - enamelled copper wire)

Size	Dia-meter inches	Dia-meter mm	Area sq. mm	Turns per square cm.	Curr-ent in am-pere	Per 1000 metre in Kg.
14	.080	2.03	3.244	22	7.5	28.18
15	.072	1.82	2.63	27	6.1	22.84
16	.064	1.62	2.1	33	4.8	18.06
17	.056	1.42	1.59	42	3.7	13.85
18	.048	1.21	1.167	58	2.7	11.05
19	.040	1.01	0.811	87	1.9	7.08
20	.036	.91	0.636	105	1.5	5.75
21	.032	.81	0.52	134	1.2	4.55
22	.028	.71	0.4	172	.92	3.58
23	.024	.60	0.29	234	.68	2.56
24	.022	.55	0.25	275	.57	2.24
25	.020	.50	0.202	329	.4	1.78
26	.018	.45	0.162	397	.38	1.45
27	.0164	.41	0.137	484	.32	1.29
28	.0148	.37	0.111	583	.26	1.01
29	.0136	.34	0.094	680	.22	0.804
30	.0124	.31	0.078	834	.18	0.712
31	.0116	.29	0.070	939	.158	0.646
32	.0108	.27	0.06	1,068	.137	0.505

Size	Dia-meter inches	Dia-meter mm	Area sq. mm	Turns per square cm.	Curr-ent in am-pere	Per 1000 metre in Kg.
33	.0100	.26	0.055	1,070	.118	0.45
34	.0092	.23	0.043	1,490	.100	0.362
35	.0084	.21	0.036	1,744	.083	0.324
36	.0076	.19	0.029	2,085	.068	0.261
37	.0068	.17	0.023	2,542	.054	0.209
38	.0060	.15	0.018	3,162	.042	0.164
39	.0052	.13	0.014	4,379	.032	0.127
40	.0048	.12	0.0117	5,030	.027	0.114
41	.0044	.11	0.0098	6,060	.028	0.09
42	.0040	.10	0.0078	7,692	.018	0.073
43	.0036	.09	0.0064	9,375	.015	0.06
44	.0032	.08	0.005	12,000	.012	0.047
45	.0028	.07	0.0039	15,384	.009	0.037
46	.0024	.06	0.0028	21,428	.006	0.026
47	.0020	.05	0.00196	30,612	.005	0.015
48	.0016	.04	0.00126	47,619	.003	0.012
* **Current carrying capacity taken as 2.3 ampere per sq. mm.**						

Coil wrapping or coil taping : The insulation used around the coil is called coil wrapping or coil taping.

For example, the following are the details of insulation for a typical field coil.

- Conductor - super-enamelled copper wire with medium covering.
- Collar - 10 mils single, leatheroid.
- Flanges - 15 mils single, leatheroid.
- Coil wrapping - two layers of 7 mils, 19 mm wide cotton tape.
- Coil lead covering - empire sleeves.
- Varnish - air-dry, golden yellow, Class E. varnish.

Preparation of a field coil : Field coils are wound with insulated copper wire whose diameter and number of turns depend on the exciting voltage and machine capacity. While rewinding, it is essential to follow the same size of winding wire,coil and insulation scheme as that of the original. The wire can be wound on a wooden former that consists of a centre-piece (cut to the size of the inner dimensions of the coil) and two side pieces to hold the coil in place. The construction of the former is given in Fig 2. The centre-piece (winding frame) is slightly tapered to one side to facilitate removal of the coil from the former. Proper shape of the coil could be retained during its removal from the former after completion of the winding, if strips of tape or cord are placed on the centre-piece (winding frame) before starting the winding of the coil as shown in Fig 3. These tapes or cords can then be tied up easily after completion of winding as shown in Fig 4. The former is placed in a lathe chuck or in a coil-winding machine or in a hand winder to wind the coil, with the same size wire and the same number of turns as those of the original coil. The collar and flange insulation papers should be of the same type, grade,thickness and size as those of the original.

Fig 2

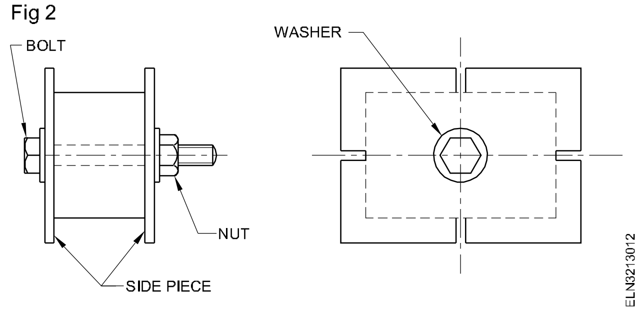


Fig 3

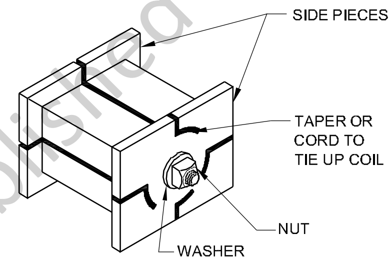
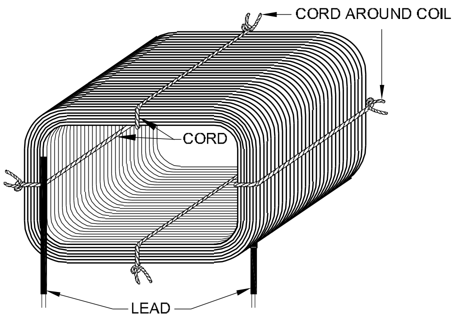
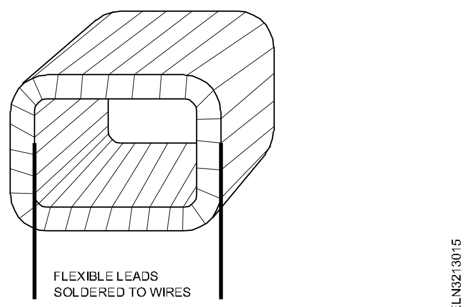


Fig 4



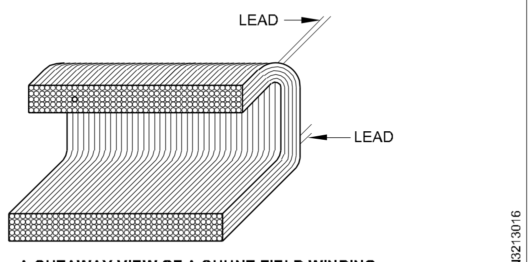
The size of the former may be obtained from the original coil or by measuring the dimensions of the field pole and allowing for the thickness of the tape. (Fig 5 shows the coil taped with cotton tape.)

Fig 5



When a field coil consists of many turns of fine wire arranged as shown in the cut-away view of shunt field winding (Fig 6), there may be thousands of turns. It is not advisable to try to rewind this type of coil by counting the number of turns. The usual method is to weigh the old coil and to wind the new coil with the same wire size having the same weight.

Fig 6



A CUTAWAY VIEW OF A SHUNT-FIELD WINDING

However, Table 1 could be used to check whether the coil, when wound, will be having the same size as that of the original so that it could be accommodated without difficulty.

Often in such trials it is found that the coil after completion is found to be larger in size and has to be modified by reducing some of the turns.

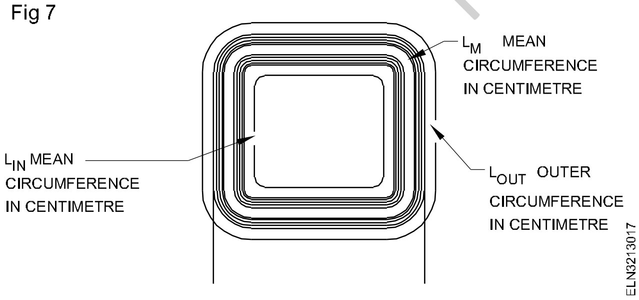
Reasons for such problems can be as follows.

- Slight change in diameter of the selected winding wire.
- Extra thick coating of insulation.
- Loose winding.
- Slight change in thickness of the insulation paper used in between the layers.

Procedure to find the size of the coil before actual winding: Weigh the coil without taped insulation and refer to the last column of Table 1 and determine the length of the winding wire in metres. From the original coil determine the average length of a turn.

Suppose, referring to Fig 7, we have

Fig 7



inner circumference of the coil = L_{IN} cm.

outer circumference of the coil = L_{OUT} cm.

mean circumference of the coil

$$L_M = \frac{L_{IN} + L_{OUT}}{2}$$

The mean circumference of the coil could be taken as length of one turn.

$$\text{No. of turns of the coil} = \frac{\text{Total length of winding wire}}{\text{Length of the turn}}$$

After determining the number of turns, refer to the column under `Turns per square cm' against the chosen winding wire.

Using the following formula, the cross-section of the proposed coil in sq cm could be found.

$$\text{Cross - section of the coil in sq.cm.} = \frac{\text{Total number of turns}}{\text{Turns per sq.cm.}}$$

Check the available space with respect to the calculated cross-section of the coil. You may multiply the cross-section of the coil by a factor of 1.25 to allow for the additional area required for insulation.

Termination of field coil leads: While winding, see that the ends of the coil are taken to the coil sides. Insulate the end leads with the proper size of cotton/empire/fibre glass sleeving and terminate the same. In the case of fine super-enamelled copper wires used for coil winding, use insulated flexible cord for lead connections. (Fig 5)

Solder the flexible cord with the enamelled copper wire. At the end, the soldered joints should be insulated properly with empire/fibre glass tapes.

Taping the field coil : When required, tape the coil with a suitable size of cotton/empire/fibre glass tape. Before starting for taping, tie down the end leads of the coil to prevent them from being cut or damaged. Tape the coil tightly and uniformly. The tape of the coil must not tear or slip off while it is being placed on the pole.

Some field coils may not be taped. But they are definitely insulated from the body and pole using insulating paper flanges and collars.

Grounding of a field coil may be caused by careless insulation work at this stage.

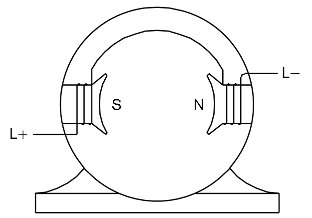
Varnishing the field coil : After preparing the field coil, preheat the coil in an oven at about 90°C for 3 to 4 hours to drive the moisture out from the field coil. Cool the coil to 60°C and dip the coil in baking varnish for 5 to 10 minutes, till the air bubbles ceases in the varnish tank. Drain the varnish and bake in the oven at 120°C for 6 to 8 hours.

After the varnishing is over, assemble the field coils on the field poles. While laying the field coils, observe the lead end position for the right connection.

Connecting field coils : In DC machines, the field coils are connected so that alternate polarity is formed in the machine.

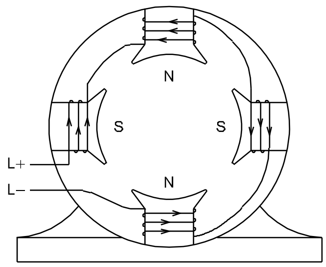
Thus, in a two-pole DC machine as shown in Fig 8, one of the poles is north and the other one is south. In a four-pole DC machine the poles must be alternately north and south as shown in Fig 9.

Fig 8



IN A TWO-POLE MOTOR, THE FILEDS ARE CONNECTED TO FORM A NORTH AND SOUTH PLOE

Fig 9



NORTH AND SOUTH POLES IN A FOUR-POLE MOTOR

The field coils are connected in series except in very large DC machines and in machines that have been reconnected from a higher to a lower voltage, in such cases they are connected in parallel with reverse polarity for alternate poles.

To form alternate polarity in the field coils, which are wound in a similar direction, the current should flow through the first pole coil - say in a clockwise direction, through the second pole coil in a counter-clockwise direction and through the third pole coil in a clockwise direction and the fourth pole coil in an anticlockwise direction and so on. It is extremely difficult to determine this direction once the field coils are taped, as the direction of the winding turns is not visible.

Testing of field coil connections : There are two methods to test the correct field coil polarity.

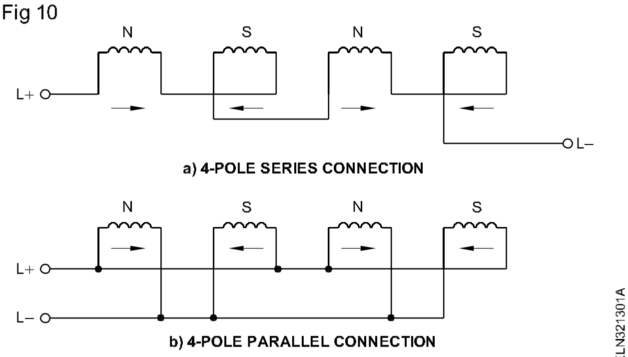
– Compass method

– Iron rod method

Compass method : The compass method may be used on any number of poles. (If it is a compound motor, test one field winding - either shunt or series at a time.) For testing the field coils of a four-pole motor, the four field coils are connected in series, as shown in Fig 9.

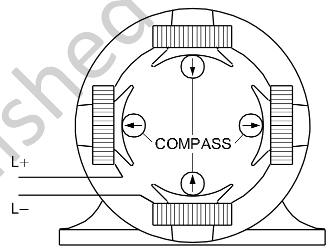
Fig.10 shows series and parallel connection of field coils to create alternate poles

Fig 10



Then a low DC voltage, say 10 to 20% of the rated voltage, is applied to the field circuit. A compass is placed near a pole either inside of the machine or alongside the field coil as shown in Fig 11. A notation is made as to the end of the needle which points to the pole. When the compass is moved to the next pole, the other end of the needle should be attracted. Thus the poles should be of alternate polarity. If not, interchange the lead connection of the particular field coil.

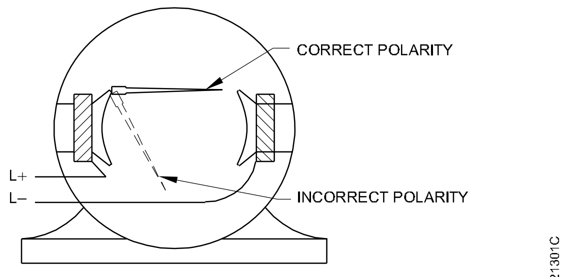
Fig 11



ON A 4-POLE MOTOR, ADJACENT POLES MUST HAVE OPPOSITE POLARITY

Iron rod method : In this method, the rated DC voltage is applied to the field circuit. The head of an iron nail is placed against one pole, as shown in Fig 12. If the polarities are correct, the other end of the nail will be attracted to the next pole; if incorrect, it will be repulsed.

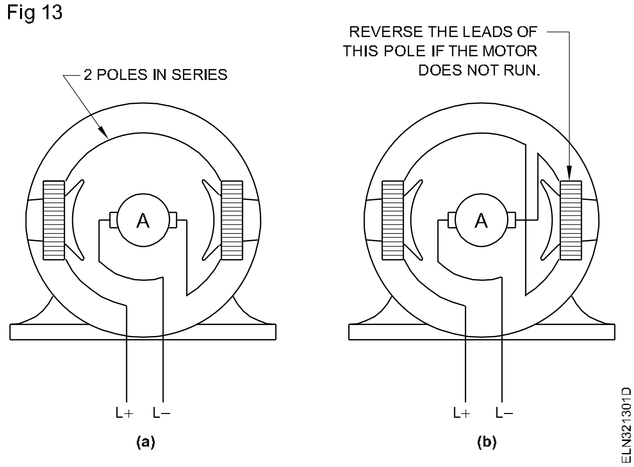
Fig 12



TESTING POLARITY OF THE FIELD COILS WITH A NAIL

In the case of a small two-pole DC motor, the trial and error method is used. Initially two field coils and armature are connected in series as shown in Fig 13a. If the motor runs, the polarities of the connected field poles are correct. If the motor does not rotate, interchange the field coil connection as in Fig 13b. If the motor runs, it is assumed the field and armature are in good condition and properly connected.

Fig 13



Armature winding - terms - types - rewinding of mixer/liquidizer

Objectives: At the end of this lesson you shall be able to
- **define the general terms used in DC armature winding**
- **explain the different types of DC armature winding.**

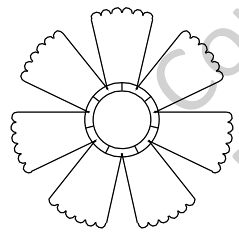
Winding : Winding is an orderly arrangement of insulated conductors in the slots of armature/stator cores with their end connection in a specified sequence.

Winding is mainly classified as:

- closed coil winding
- open coil winding.

Closed coil winding : It is also called DC armature winding. In closed coil winding, the end of the coil, after connecting through the other coils in the armature, finds itself connected to the commencement end of the starting coil as shown in Fig 1.

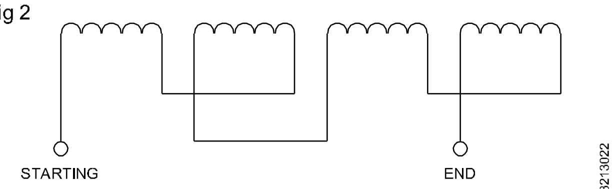
Fig 1



CLOSED COIL WINDING

Open coil winding : It is also called AC stator winding. In open coil winding, the end of the coil after connecting through other coils in the stator, is terminated as end lead, i.e. the starting end of the coil and the finishing end of the coil are kept open as shown in Fig 2.

Fig 2



OPEN COIL WINDING

DC armature winding : It is a closed coil winding, wherein the coil ends are connected through the commutator segments to form the closed circuit.

Terms used in DC armature winding

Coil or winding element : Length of a wire lying in the magnetic field and in which an emf is induced is called an active conductor.

Referring to Fig 3, we find the two active conductors AB and CD along with their end connections constitute one coil or winding element of the armature winding. The coil may consist of a single turn only as shown in Fig 3 or multi-turns as shown in Fig 4. A single-turn coil or winding element will have two conductors only. But a multi-turn coil may have many conductors per coil side. In Fig 4 for example, each coil side has 3 conductors. The group of conductors constituting a coil side of a multi-turn coil is tied together with a tape as a unit (Fig 5) and is placed in the armature slot. It may be noted that each winding element has two connecting leads and each commutator bar has two connecting leads brought from the winding. As such there are as many commutator bars as the number of winding elements.

Fig 3

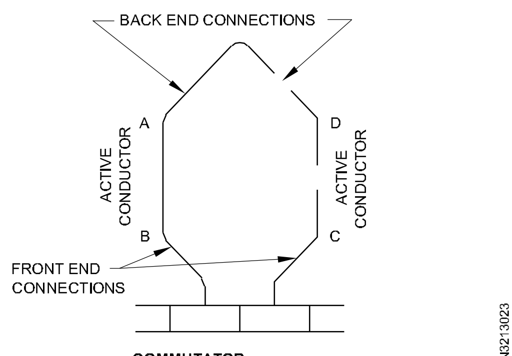
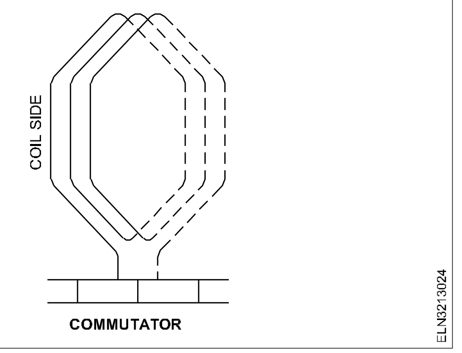
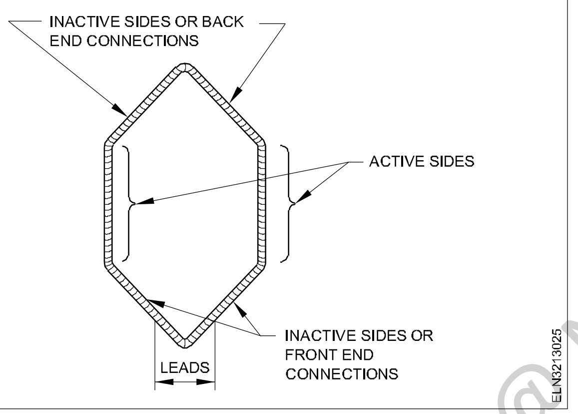


Fig 4



Active sides : These are the sides which lie within the slots. They are also known as coil sides. The induction takes place only in the active sides of the coil while they move in the magnetic field. (Fig 5)

Fig 5



In winding calculation these active sides are considered as conductors. The coil has got two conductors irrespective of the number of turns.

Inactive sides : That part of a coil which does not lie in the slot is known as the inactive side of a coil. No induction takes place in the inactive sides.

Example: Back and front end connections. (Fig 5)

Leads of coil : The ends coming out from a coil are known as leads of a coil. Every coil has got two leads.

Pole-pitch(Y_p) : It may be variously defined as:

- the periphery of the armature divided by the number of poles of the machine i.e. the distance between two adjacent poles.It is denoted by Y_p.
- it is equal to the number of armature conductors (or armature slots) per pole. For example, if there are 48 conductors, 24 coils, 24 slots and 4 poles, then the pole pitch is

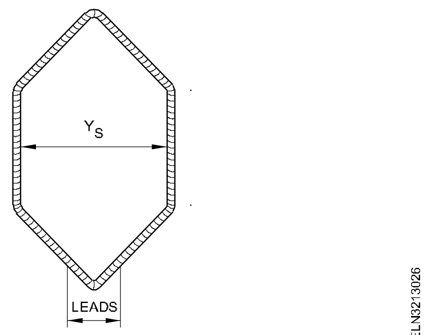
$$Y_P = \frac{\text{Number of slots}}{\text{Number of poles}} = \frac{24}{4} = 6 \text{ in terms of slots}$$

or

$$Y_P = \frac{\text{No. of conductors}}{\text{No. of poles}} = \frac{48}{4} = 12 \text{ in terms of conductors}$$

Coil-span or coil-pitch(Y_S) : The coil-span or coil-pitch is the distance, measured in terms of armature slots or armature conductors between two sides of a coil. It is in fact the periphery of the armature measured in terms of slots or conductors spanned by the two sides of the coil. It is denoted by Y_S as shown in Fig 6.

Fig 6



Coil-pitch Y_S is calculated in the same way as is done for Pole pitch.

Hence the modified calculation will be

$$Y_S = \frac{\text{No. of slots}}{\text{No. of poles}} - K = \frac{S}{P} - K \text{ (in terms of slots)}$$

$$= \frac{\text{No. of conductors}}{\text{No. of poles}} - K = \frac{C}{P} - K \text{ (in terms of conductors)}$$

where K = any part of S/P or C/P that is subtracted to make Y_s an integer.

Back pitch (Y_B) : The distance measured in terms of the armature conductors which a coil advances on the back of the armature is called back pitch and is denoted by Y_B. This is illustrated in Figs 7 and 8. The back pitch is also equal to the coil-pitch.

Fig 7

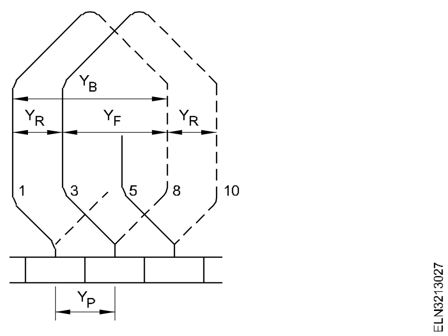
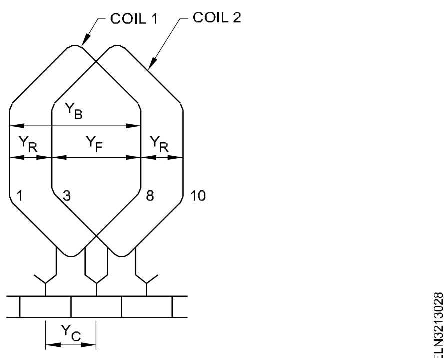
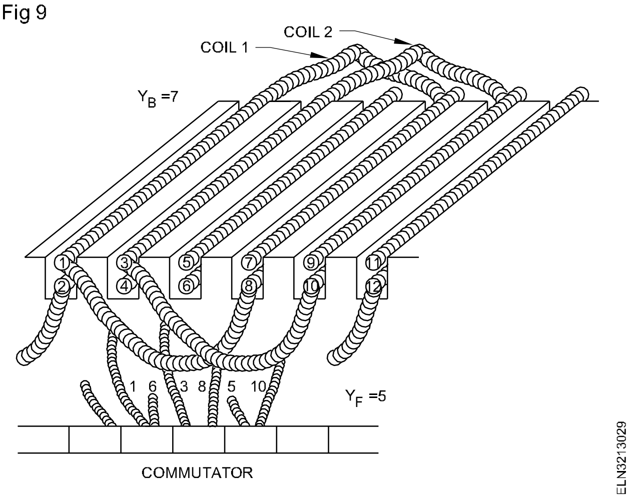


Fig 8



As shown in Fig 9, coil side 1 is connected on the back of armature to coil side 8 (same coil). Hence $Y_B = 8 - 1 = 7$ conductors.

Fig 9



Front pitch(Y_F) : The number of armature conductors or elements spanned by a coil on the front (commutator end of an armature) is called the front pitch and is designated by Y_F. This is shown in Figs 7,8 and 9. Coil side 8 is connected to coil side 3 (second coil) through the commutator segment. Hence $Y_F = 8 - 3 = 5$ conductors.

Average pitch (Y_A) : The average of the front pitch Y_F and the back pitch Y_B is called average pitch. Y_A

$$\text{i.e., } Y_A = \frac{Y_B + Y_F}{2}$$

It is expressed in number of conductors.

Resultant pitch (Y_R) : In general, it may be defined as the distance between the beginning of one coil and the beginning of the next coil to which it is connected or it is the distance between the beginnings of two consecutive coil sides as shown in Figs 7 and 8 and denoted by letter Y_R. As in Fig 9, $Y_R = Y_B - Y_F$, i.e. $Y_R = 7 - 5 = 2$ conductors. The resultant pitch Y_R depends upon the type of winding like lap or wave, as well as simplex or multiplex.

Commutator pitch(Y_c) : It is the distance (measured in commutator bars or segments) between the segments to which the two ends of a coil are connected. It is denoted by Y_c. From the figures 7, 8 and 9, it is clear the commutator pitch $Y_c = 1$ segment.

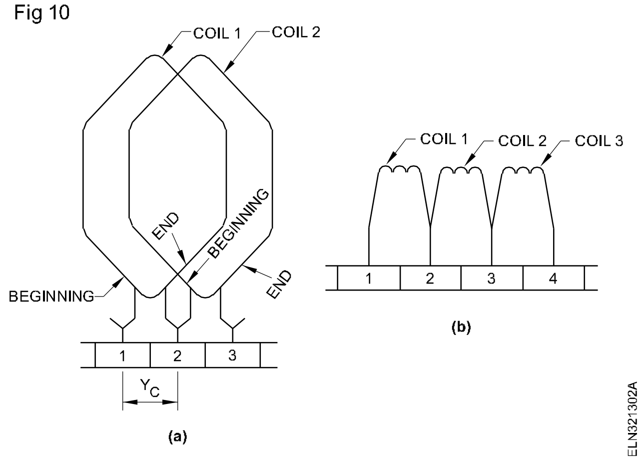
The commutator pitch Y_c varies with the type of winding, like lap or wave as well as simplex or multiplex.

Types of DC armature windings

Lap and wave winding : The DC armature windings are classified into two main groups, lap and wave windings. The difference between them is the manner in which, the leads are connected to the commutator segments.

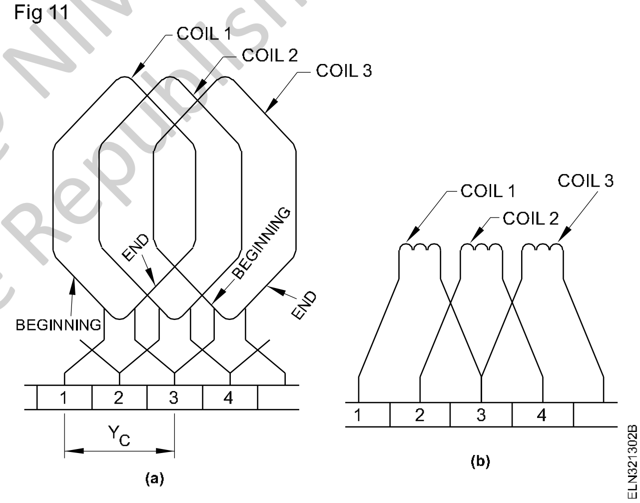
Simplex lap winding : In a simplex lap winding, the end lead of coil 1 is connected to the beginning lead of the adjacent coil(coil 2) through the commutator segments. The commutator pitch of one segment is maintained. Fig 10 shows the lead connection of a simplex lap winding.

Fig 10



Duplex lap winding : In duplex lap winding, the end lead of coil 1 is connected to the beginning lead of coil 3, through commutator segments. The commutator pitch of two segments is maintained as shown in Figs 11a and b.

Fig 11



In triplex lap and quadruplex lap windings, the end leads of coil 1 are connected to the beginning leads of coil 4 and coil 5 respectively through commutator segments. In general commutator pitches

Y_c = 1 segment for simplex lap winding

Y_c = 2 segments for duplex lap winding

Y_c = 3 segments for triplex lap winding

Y_c = 4 segments for quadruplex lap winding.

Simplex wave winding : In simplex wave winding, the end lead of the coil 1 is connected to the beginning of a coil placed at a distance equal to one pole pitch. (Fig 12)

Duplex wave winding : In duplex wave winding there is parallel combination of two simplex wave windings as shown in Fig 13.

Fig 12

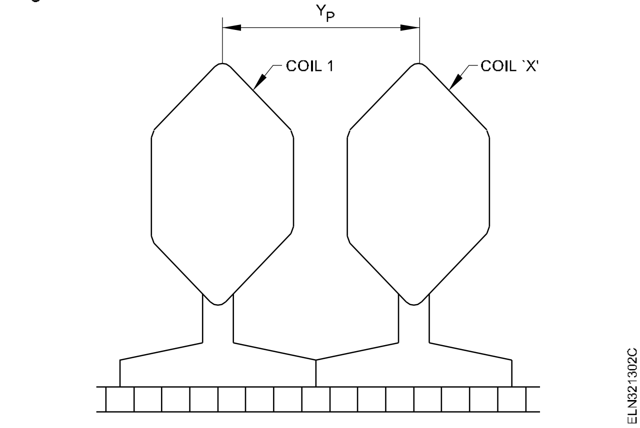
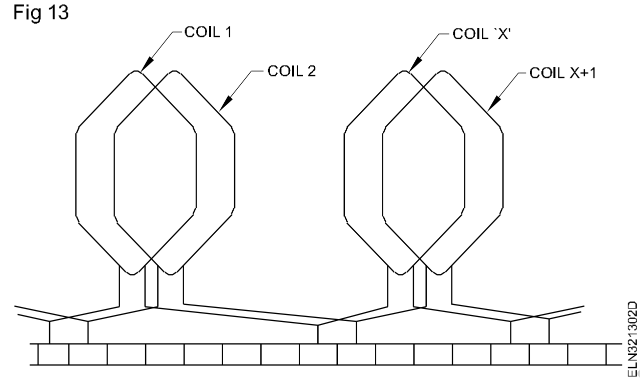


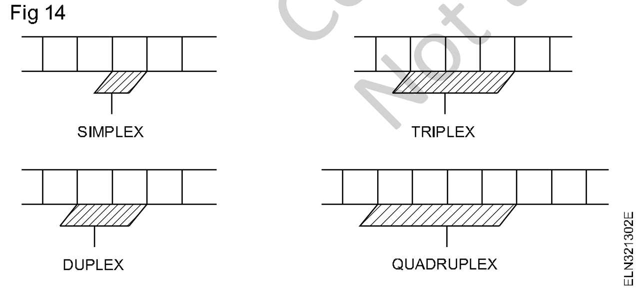
Fig 13



Triplex wave winding : Triplex wave winding will have a parallel combination of three simplex wave windings, and so on.

> **The width of the brush will be such that in simplex lap or wave winding, the brush will make contact with only one segment. The brush will contact two segments in duplex, three in triplex and four in quadruplex. (Refer to Fig 14)**

Fig 14



Progressive lap or wave winding : In progressive lap or wave winding, the front pitch Y_F will be less than the back pitch Y_B, i.e. as you lay the coils clock-wise, the connections to the commutator segments will also proceed clockwise as in Figs 15a and b. In progressive winding, Y_c is referred to as +1.

Retrogressive lap or wave winding: In retrogressive lap or wave winding, the front pitch Y_F will be greater than the back pitch Y_B, i.e. as you lay the coils clockwise, the connection to the commutator segments will proceed anticlockwise as shown in Figs 16 a & b. In retrogressive winding Y_c is represented as -1.

Fig 15

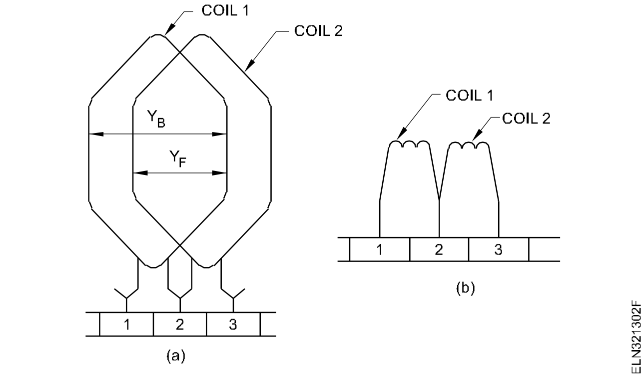
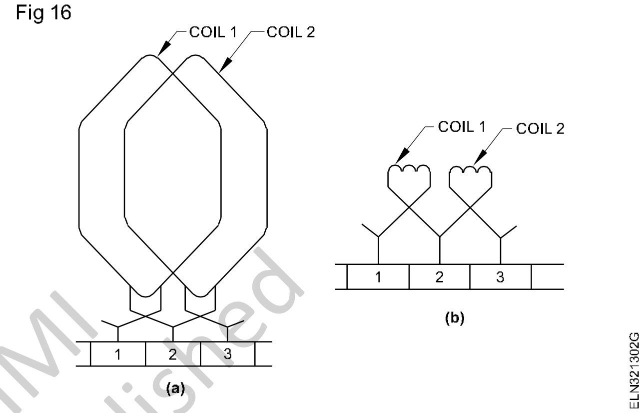
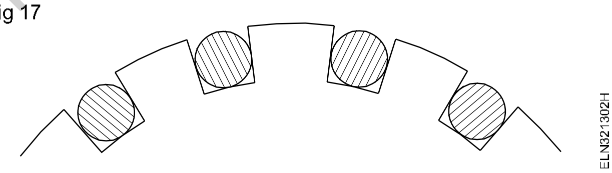


Fig 16



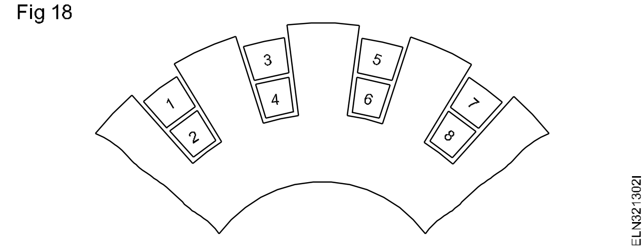
Single layer winding : A single layer winding is one in which only one coil side is placed in each armature slot, as shown in Fig 17. Such a winding is not used much.

Fig 17



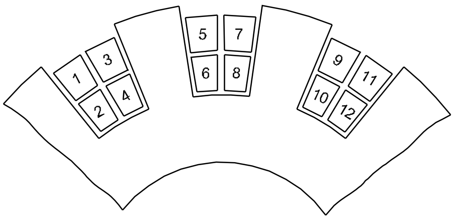
Two-layer winding : In this type of winding, there are two conductors or coil sides per slot arranged in two layers as shown in Fig 18. Usually, one side of every coil lies in the upper half of one slot and the other side of the same coil lies in the lower half of some other slot at a distance of one coil pitch away.

Fig 18



Multi-coil winding : Sometimes 4 or 6 or 8 coil sides are used in each slot in several layers because it is not practicable to have too many slots.(Fig 19) The coil sides lying at the upper half of the slots are numbered odd, i.e. 1,3,5,7 etc. while those at the lower half are numbered even, i.e. 2,4,6,8 etc.

Fig 19



Simplex lap and wave winding - developed diagram

Objectives: At the end of this lesson you shall be able to
- **state the conditions for Lap winding and wave winding**
- **calculate and draw the developed ring diagram for simplex lap and wave winding.**

Development winding diagram : To draw the development winding diagram, the winding particulars like number of conductors, number of poles, pitches, types of windings etc. are required. For any DC armature winding, there shall be as many coils as the number of commutator segments. Further, the number of coils will be the multiple of the number of slots, i.e. for a single layer, there will be double the number of slots as that of the commutator segments and for a double layer there will as many slots as the commutator segments.

Lap winding

Conditions for lap winding : For lap winding the following terms and conditions are to be fulfilled.

- The front pitch Y_F and the back pitch Y_B should be approximately equal to the pole-pitch Y_P.
- Both the front pitch Y_F and the back pitch Y_B should be an odd number.
- The back pitch Y_B and the front pitch Y_F should differ by 2 conductors, for simplex lap winding. In the case of multiplex winding, it is equal to 2 x No. of `plex'.

Ex. For duplex 2x2 = 4 conductors.

For triplex 2x3 = 6 conductors and so on.

The average pitch should be as given by the formula

Commutator pitch should be

Y_C = ± 1 for simplex

= ± 2 for duplex

= ± 3 for triplex and so on.

- The number of parallel paths `A' in the armature will be the multiple of the number of poles. A = P, in the case of simplex lap winding, i.e 2-pole armature winding will have 2 parallel paths, 4-pole armature winding will have 4 parallel paths and so on. However, the number of parallel paths for multiplex winding will be equal to A = P x No. of `plex'.
- There must be as many brushes as there are poles.
- The brushes must be wide enough to cover atleast *m* segments, where '*m* ' is the 'plex' (multiplicity) of the winding.

Progressive winding

$$\text{Back pitch}\, Y_B = \frac{Z}{P} + 1$$

Front pitch $Y_F = Y_B - 2$ x plex

Reprogressive winding

$$\text{Front pitch}\, Y_F = \frac{Z}{P} + 1 \qquad \text{Back pitch}\quad Y_B = Y_F - 2 \text{ x plex}$$

> **To make the winding possible as lap-winding, Z/P must be an even number.**
>
> **Considering the above points, only the armature having the designated slots can be wound for lap winding.**

Calculations : The following calculations are made for finding out winding pitches and coil connections with commutator segments for simplex lap winding.

Example

No. of commutator segments	6
No. of slots	6
No. of poles	2
Type of winding	simple lap.

As pointed out earlier the winding should be in double layer only.

Solution

No. of coils = No. of commutator segments = 6 coils

No. of conductors or coil sides = No. of coils x 2
= 6 x 2 = 12 conductors.

$$\text{Pole pitch}\, Y_P = \frac{\text{No. of slots}}{\text{No. of poles}} = 6/2 = 3 \text{ slots}$$

Also Y_P in terms of conductors $= \frac{\text{No. of conductors}}{\text{No. of poles}}$

$= 12/2 = 6$ conductors

No. of conductors/slot = 12/6 = 2 conductors/slots.

Hence the winding is double layer winding.

Back pitch $Y_B = \frac{Z}{P} + 1 = 12/2 + 1 = 6 + 1 = 7$

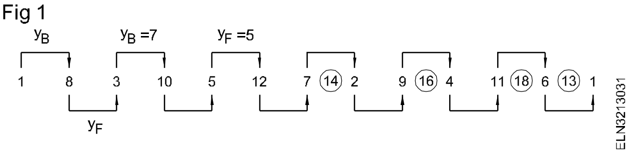
Front pitch $Y_F = Y_B - 2 \times \text{Plex} = 7 - 2 = 5$

$Y_B = 7$ and $Y_F = 5$ for progressive winding

$Y_B = 5$ and $Y_F = 7$ for retrogressive winding

The winding sequence of conductors for progressive lap winding is shown in Fig 1.

Fig 1



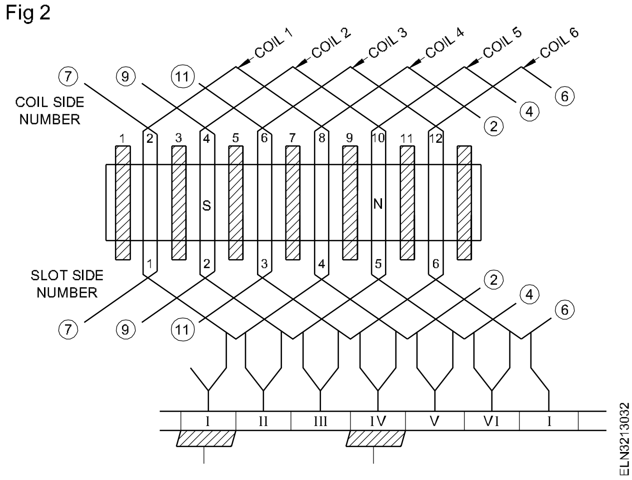
Winding Table

Coil	Conductor		Slot		Commutator segments	
	From	To	From	To	From	To
1	1	8	1	4	I	II
2	3	10	2	5	II	III
3	5	12	3	6	III	IV
4	7	2	4	1	IV	V
5	9	4	5	2	V	VI
6	11	6	6	3	VI	I

Development winding diagram for 12 conductors, 2 poles, 6 slots, 6 segments, simplex double layer lap winding

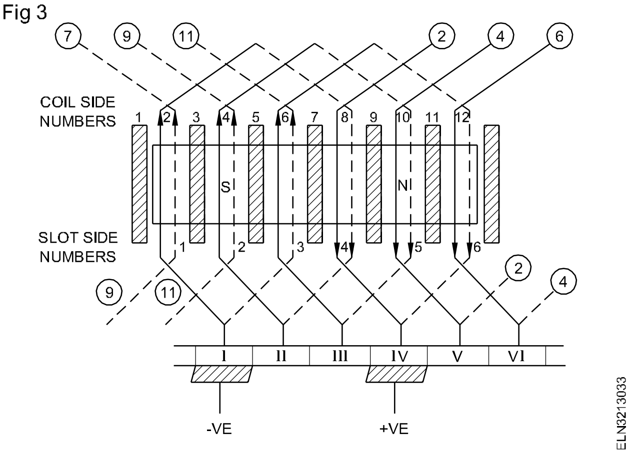
Fig 2 shows the arrangement of coils in the respective slots and the connection of the coils with the segments.

Fig 2



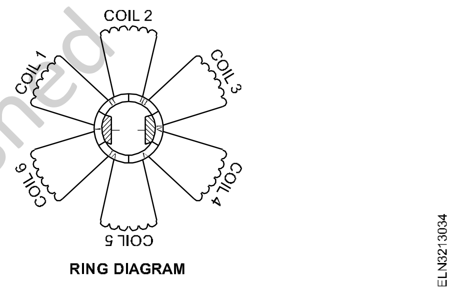
Development diagram with conductors : Fig 3 shows the arrangement of armature conductors in the slots and connections to commutator segments.

Fig 3



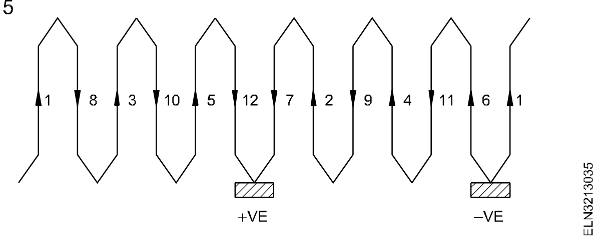
Ring diagram : Fig 4 shows the connection of 6 coils with the commutator segments in the form of a ring diagram.

Fig 4



Sequence diagram : This diagram is mainly used to trace the direction of current in the coil sides (conductors). With the help of this diagram the brush position can be located. (Fig 5)

Fig 5



Wave winding

Conditions for wave winding : For wave winding, the following terms and conditions should be fulfilled.

- The front pitch Y_F and back pitch Y_B should be approximately equal to the pole pitch Y_P.
- Both the front pitch Y_F and the back pitch Y_B should be an odd number.
- The back pitch Y_B and the front pitch Y_F may be of the same value or may differ by 2 conductors, in the case of simplex, and the same or 2 or 4 conductors for multiplex wave winding, depending upon the condition

$Y_A = \frac{Y_B + Y_F}{2}$ approximately

- The average pitch should be as given by the formula

$Y_A = \frac{Y_B + Y_F}{2}$ (or)

$$Y_A = \frac{\text{No.of conductors} \pm 2 \text{ x plex}}{\text{No. of poles}}$$

$Y_A = \frac{Z \pm 2}{P}$ for simplex wave winding

$= \frac{Z + 2}{P}$ for progressive simplex wave winding

$= \frac{Z - 2}{P}$ for retrogressive simplex wave winding

$Y_A = \frac{Z \pm 4}{P}$ for duplex wave winding

$Y_A = \frac{Z \pm 6}{P}$ for triplex wave winding and so on

- $Y_C = \frac{\text{No.of commutator segments} \pm m}{\text{Pairs of poles}} = \frac{C \pm m}{p/2}$

where Y_c is the commutator pitch

C = total number of commutator segments

p = number of poles

m = the plex of the winding.

The commutator pitch Y_c shall be equal to the average pitch Y_A. $Y_c = Y_A$

The resultant pitch is the sum of the front and back pitches. $Y_R = Y_B + Y_F$

- The number of coil sides must satisfy the following relations.

  Z = P x Y_A ± 2 where P is the number of poles.

- In the case of simplex wave winding the number of parallel paths `A' is equal to 2 only, irrespective of the number of poles. However the number of parallel paths increases in multiples of the plex of the windings.

  Eg. A = 2 x plex.

Considering the above points, only an armature having designated slots can be wound for wave winding.

- Two brushes are necessary, but as many brushes as there are poles may be used, and they must be set so that they short-circuit only the coils cutting no flux.

- The brushes must be wide enough to cover atleast `m' segments where 'm' is the 'plex' of the winding.

Calculations : The following calculations are made for finding out winding pitches and coil connections with commutator segments for simplex wave winding.

Example

Number of commutator segments	7 Nos.
Number of slots	7 Nos.
Number of poles	2 Nos.
Type of winding	Wave.

Winding table

1 The number of coils = Number of commutator segments = 7 coils.

2 The number of conductors or No. of coil sides = No. of coils x 2 = 7 x 2 = 14 conductors.

3 Pole pitch $Y_P = \frac{\text{No.of slots}}{\text{No. of poles}} = 7/2 = 3.5$ slots, say 3 slots

Also, $Y_P = \frac{\text{No.of conductors}}{\text{No. of poles}} = 14/2 = 7$ conductors

4 No. of conductors/slot = 14/7 = 2 conductors/slot. Hence, the winding is double layer.

5 Average pitch $Y_A = \frac{Z \pm 2}{P}$

$= \frac{14 + 2}{2} = 16/2 = 8$ (for progressive winding).

$= \frac{14 - 2}{2} = 12/2 = 6$ (for retrogressive winding).

Hence $Y_A = Y_C = 8$ or 6.

6 Taking $Y_A = 8$ for progressive winding we have

$2Y_A$ = 2 x 8 = 16 = $Y_B + Y_F$

$Y_B - Y_F$ = 2

$Y_B + Y_F$ = 16.

Hence back pitch $Y_B = 9$ and front pitch $Y_F = 7$.

Taking $Y_A = 6$ for retrogressive winding we have

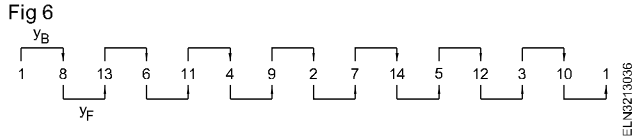
$2Y_A$ = 2 x 6 = 12 = $Y_B + Y_F$

$Y_B - Y_F = 12$.

Hence, back pitch $Y_B = 7$ and front pitch $Y_F = 5$ for retrogressive wave winding.

The winding sequence of conductors for retrogressive wave winding is shown in Fig 6.

Fig 6



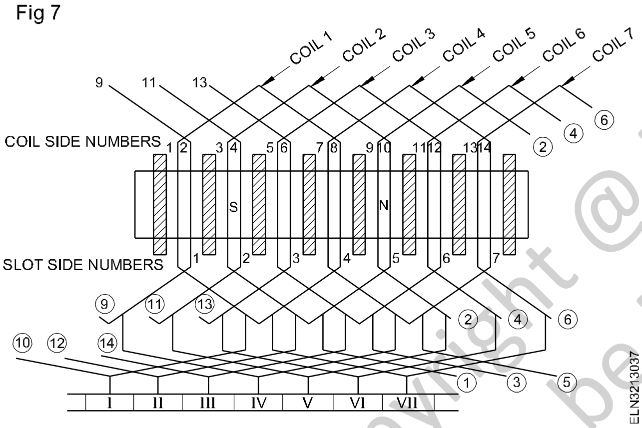
$Y_B = 7$, $Y_F = 5$.

Winding Table

Coil	Conductor		Slot		Commutator segments	
	From	To	From	To	From	To
1	1	8	1	4	I	VII
2	13	6	7	3	VII	VI
3	11	4	6	2	VI	V
4	9	2	5	1	V	IV
5	7	14	4	7	IV	III
6	5	12	3	6	III	II
7	3	10	2	5	II	I
Development winding diagram for 14 conductors, 2 poles, 7 slots, 7 segments, simplex, double layer wave winding						

Development diagram with coil connection : Fig 7 shows the arrangement of coils in their respective slots and their connection to the segments.

Fig 7



Development diagram with conductors : Fig 8 shows the arrangement of armature conductors in the slots and the connection to commutator segments.

Ring diagram : The ring diagram of wave winding in the case of a 2-pole armature will appear similar to that of lap winding, but the coil ends will be connected as shown in Fig 9.

Fig 8

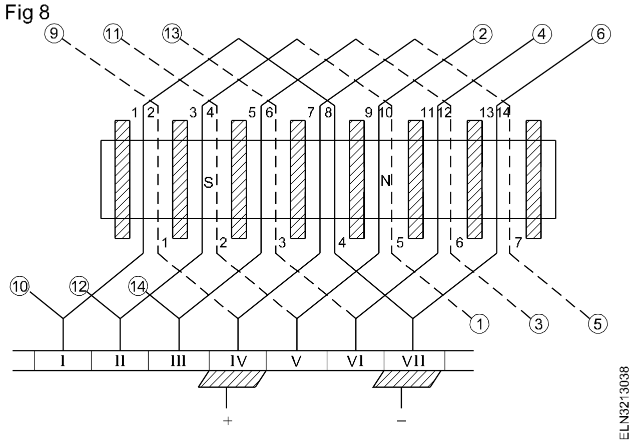
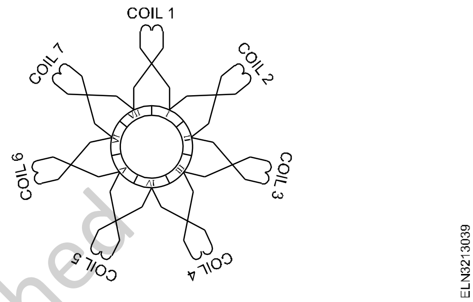
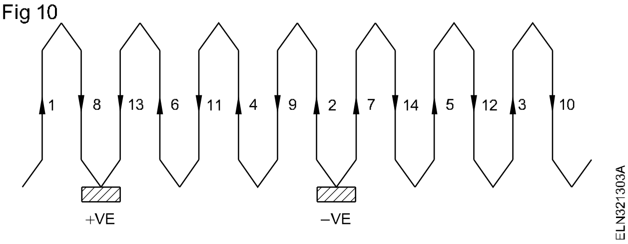


Fig 9



Sequence diagram : This diagram (Fig 10) is mainly used to trace the current direction of the coil sides (conductors) and, thereby, locate the brush position. Please note the brush is placed at a distance of 3 commutator segments i.e. less than 180° geometrical (app.155°).

Fig 10



Preparation of armature for rewinding

Objectives: At the end of this lesson you shall be able to

- **explain the types of slots and their relative advantages, and the place of their use**
- **state the scheme of insulation of armature**
- **state the necessity and the method of testing a commutator before rewinding.**

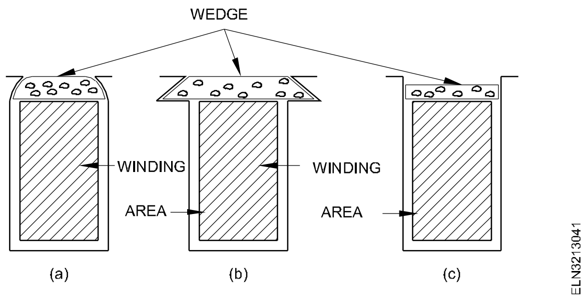
Slots : Slots are provided in the armature laminated core, to house the armature conductors in position.

Types of slots: Generally the following three types of slots are provided in armature cores.

- Open type
- Semi-enclosed type
- Closed type

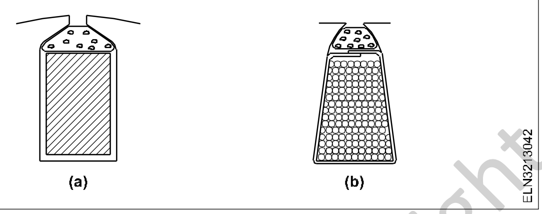
Open type slots : Open type slots are used for medium and high voltage machines. The slots are tapered a little or dovetailed on the top to receive the wedges after rewinding, as shown in Figs1 a, b & c. Former wound coils after being properly insulated are housed in the slots. To prevent the coils from coming out of the slots, banding is done with steel wire on the shallow channel over the circumference of the armature. In such types of armatures, better cooling facilities are provided by keeping ventilating ducts below the slots.

Fig 1



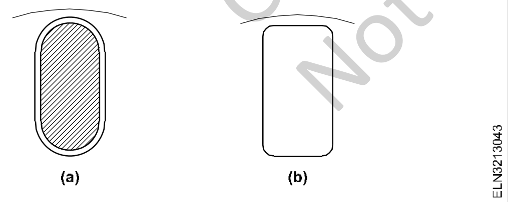
Semi-enclosed type slots : Semi-enclosed types of slots are used for low and medium voltage machines. The slots in this type of armature are tapered towards the periphery, i.e. openings towards the teeth are smaller as compared to the base, as shown in Figs 2 a & b. So reluctance is less than in open type slots. Moreover, the coils cannot come out easily because of the provision of small wedges on the teeth. The conductors are placed in the slots one by one, and not the complete coil at the same time during the winding process. In the case of bar or strip winding, they are pushed through sideways and bent to shape to form the overhangs required.

Fig 2



Closed type slots: Closed type of slots are used in rotors of AC machines and high speed alternators. The slots in this type of armature are totally closed as shown in Figs 3 a & b.

Fig 3



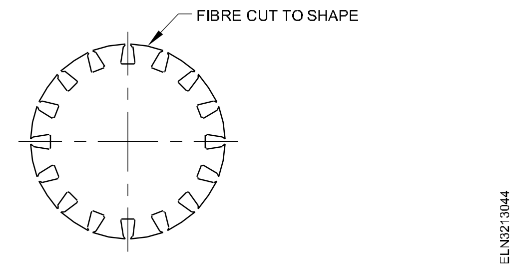
They have no opening on the periphery to receive the conductors. Therefore, conductors are pushed through the slots. The reluctance is lower than in the above two types, and so the efficiency is high.

Insulation scheme for armature

For armature winding, the following insulation schemes are required.

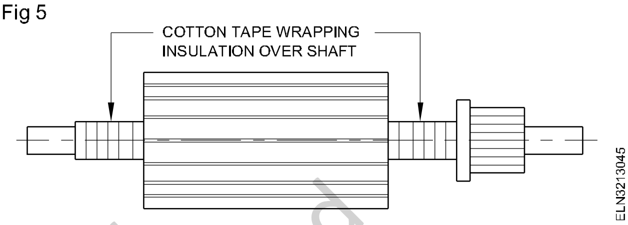
Armature core insulation : Both the sides of the armature core ends have to be insulated with fibre or insulation paper cut in the shape of the stampings. (Fig 4)

Fig 4



Shaft insulation: The exposed portion of the shaft on either side of the armature shall be insulated. Cotton or fibre glass tapes are wound on the area of the shaft where the overhangs of the winding are exposed. The number of layers of tapping depends upon the overhang projection. (Fig 5)

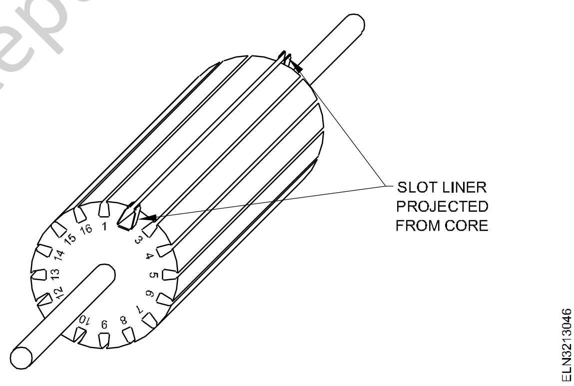
Fig 5



Slot insulation

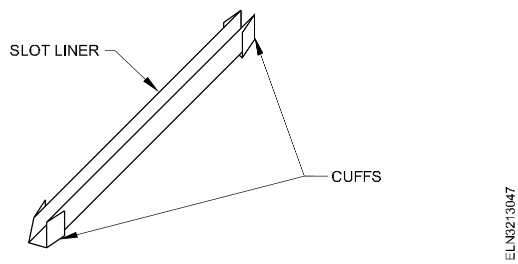
Slot liner : The slot liner is an insulation sheet cut to the inner dimensions of the slots and projected on either side of the slots. (Fig 6)

Fig 6



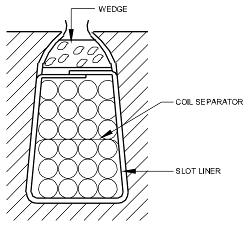
Cuffing : In some applications, the edges of the slot liner are folded on either end to prevent them from sliding in the slots. (Fig 7)

Fig 7



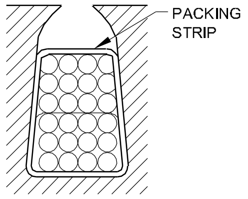
Coil separator : When multi-layer windings are used to insulate the winding layers from each other, coil separators are used. They should be extended on either side of the slot. (Fig 8)

Fig 8



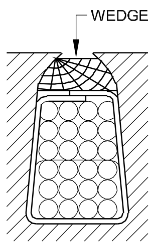
Packing strip : The thick insulation paper used in between the slot liner and wedge is called a packing strip. This should extend beyond each end of the armature core. (Fig 9)

Fig 9



Wedge : A solid insulation piece like bamboo or fibre used to prevent the conductors from coming out of slots is called a wedge. This should be tightly held in the slots. (Fig 10)

Fig 10

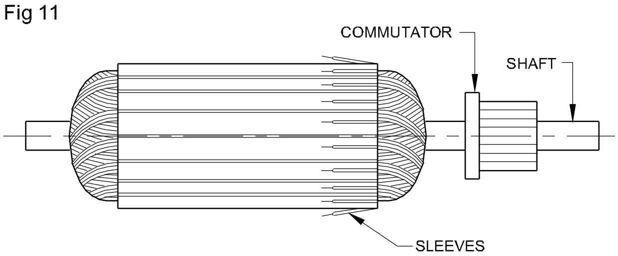


Coil insulation : In some applications, the slot portions of the coil sides are taped with cotton or fibre glass tapes. This is known as coil insulation.

Overhang insulation : The overhang portion of the winding, insulated with flexible insulation sheets like fibre glass cloth, to prevent the conductors of different groups contacting each other is known as overhang insulation.

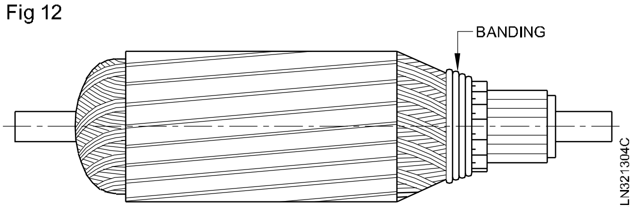
Lead insulation : Lead insulation is one where the end leads of armature conductors are insulated with sleeves, like empire or fibre glass, before soldering with the commutator segments. (Fig 11)

Fig 11



Banding insulation : In the case of small armatures, overhangs of armature are tied with hemp/terylene threads. In large DC armatures overhang is insulated with insulating sheets and tied with steel wires (banding). (Fig 12)

Fig 12

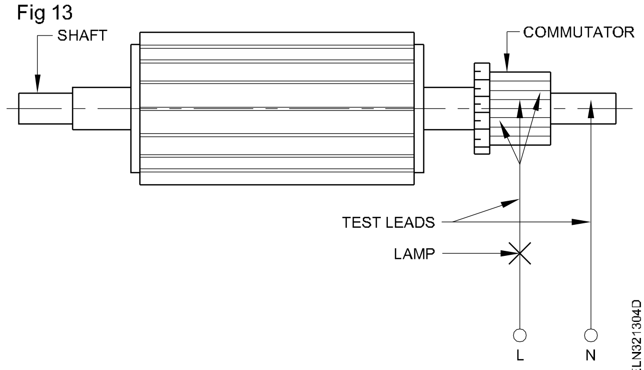


Varnishing : Baking varnish is used for impregnation of armature windings. This process is known as varnishing.

Testing of the commutator before winding : Before attempting to wind the armature, the usual procedure is to test the commutator. This is done to facilitate repairs in case the commutator is defective. The commutator is tested for grounded bars and shorted bars. If the commutator is extensively damaged and the segments have come out, the commutator has to be replaced with a new one.

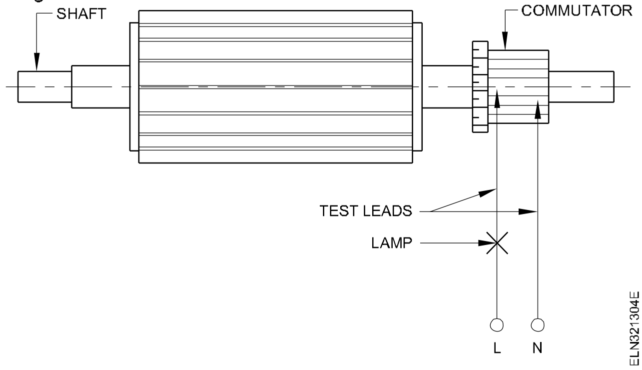
Test for grounded commutator : A commutator is grounded when one or more bars contact the iron core of the commutator or shaft. This can be tested by a test lamp as shown in Fig 13. Touch one lead of the test lamp permanently to the shaft of the armature. Touch the other lead of the test lamp on the commutator bar. If the commutator is not grounded the lamp should not glow; there should be no sparking or arcing between the bar and the ground. Place the test lead on the next commutator bar and test in the same manner. Similarly test all the bars individually. If the lamp lights when a bar is touched that bar is grounded.

Fig 13



Test for shorted commutator : The test which is illustrated in Fig 14 is made to reveal defects in the mica between the bars. Place one test lead on a commutator bar and the other test lead on an adjacent bar. No light should be visible in the test lamp. If a light is observed, a short exists between the bars contacted by the test leads. Move each lead over one bar at a time and test as before. Continue in this manner until all the bars have been tested.

Fig 14



Rewinding of mixer/liquidizer

Objectives: At the end of this lesson you shall be able to
- **explain the type of winding used in mixer/liquidizer**
- **explain the connections of coils, with and without loops**
- **explain the data to be collected for rewinding an armature**
- **explain the term 'lead swing'**
- **explain the method of winding the armature**
- **explain the method of balancing the armature.**

Almost all the domestic mixers/liquidizers use universal motors for their high speed and high torque requirements. Though the basic design remains the same, there will be variation in capacity, number of slots, segments, size of winding wire, brush grade and time rating etc.

When rewinding the mixer/liquidizer, great care needs to be exercised in taking data so as to strictly follow the pattern of winding as in the original. Even a slight change in the diameter of the winding wire or change of number of turns will result in bad performance of the rewound mixer. In general, care should be taken while selecting the winding wire, insulation paper, solder and the soldering iron. As the armature winding requires high skill, most of the beginners may not be successful in their first attempt. As it has high potential for self-employment with good financial gains, go ahead with a number of attempts till you reach perfection. But at each time of failure of winding, investigate the fault and do not repeat that mistake.

Before collecting the necessary data for rewinding it is essential that the trainee is familiar with the type of windings used in mixer/liquidizers and the variations thereof. Types of armature winding is discussed in the earlier portion of this information sheet. Normally simplex lap winding with loops is used in mixers/liquidizers. Winding may further be progressive or retrogressive as shown in Figs 1 (a) and (b).

Lap winding with loops : A lap winding with two coils per each slot which is commonly found in mixers/ liquidizers is shown in Fig 2. A 12 slot armature in this case has 24 coils and 24 segments. There must be twice as many commutator segments as slots. As shown in Fig 2 one loop is made short and the next one long, so that the leads may be soldered to the segments in proper sequence.

Fig 1

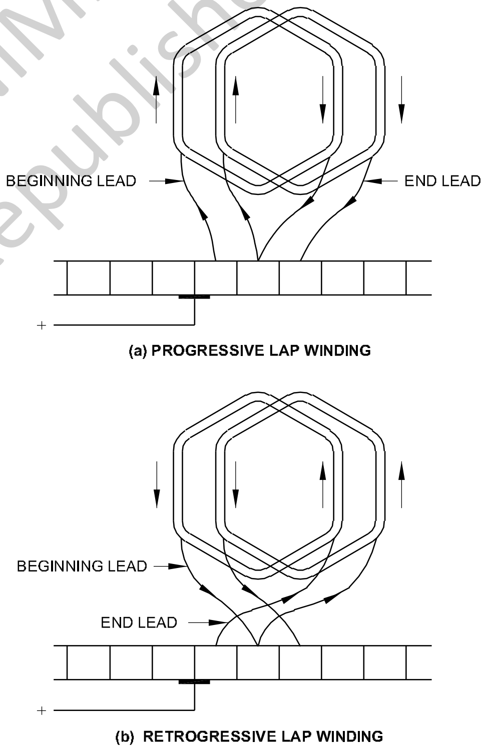
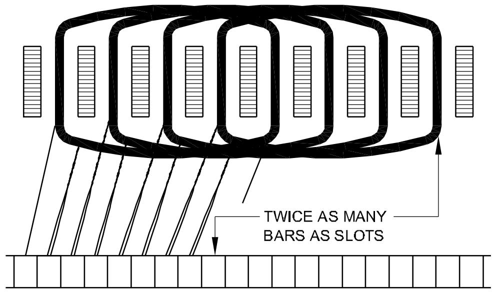


Fig 2



Lap winding may also have three coils for each slot. Then it is necessary to have three times as many commutator segments as slots.

Lap winding without loops : In lap winding each coil can be wound independently and the two ends of the coil brought out. Then the end leads may be connected to the segments in proper sequence.

Collection of data for rewinding a mixer : When rewinding the armature and field of a universal motor, sufficient information must be gathered on the process of stripping to enable the trainee to rewind it exactly as it was wound originally. Initially we should take the name-plate details and a sample is given in Table 1.

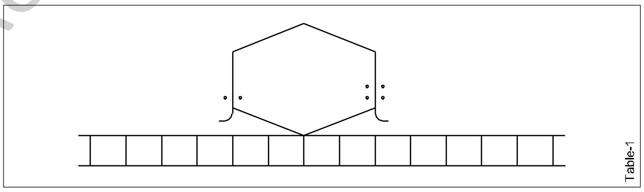
After taking the name plate details, dismantle the mixer and strip the winding carefully. During this process collect the information as detailed in the data sheet shown in Table 2.

Table 1

Name-plate details

Make	:____________	Type	:____________	Code No	:____________
KW	:____________	Volts	:____________	Amps	:____________
No. of poles	:____________	Hertz	:____________	r.p.m	:____________
Frame	:____________	Model	:____________		

Table 2

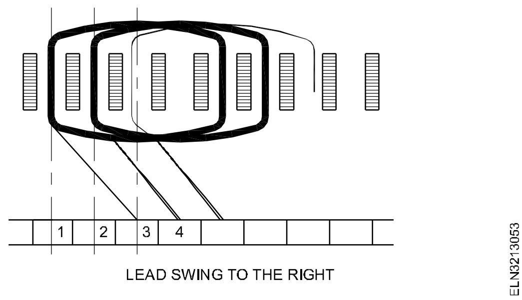
	Size of wire	Turns	Insulation	Connection
STATOR				
	Size of wire	No.of turns	Coil pitch	Coils/Slots
ROTOR				
	No.of slots	Bars	Draw the end connection and show the lead swing.	
Details of lead swing Centre of slots to	Centre of bars Centre of mica			
Lap	Commutator pitch	Wave		

Lead swing : As the machines are desinged to have a particular position of the brushes in the periphery of the commutator, the coil end connections to the commutator segments are fixed at certain positions which should not be changed while rewinding to have trouble free operation. The positioning of the coil leads to the particular segment is called lead swing.

One of the most important operations in the winding of an armature is placing the coil leads in the proper commutator bars. Leads may be placed in the bars in any one of three different positions, depending on the original location. If a slot in the armature is viewed from the commutator end, the leads to the commutator may swing to the right of the slot as shown in Fig 3 or to the left, as shown in Fig 4 or they may be aligned with it as shown in Fig 5. The following method is used in determining the position of the leads in the commutator.

Stretch a piece of cord or string through the centre of a slot. Note whether it is aligned with a commutator bar or with the mica between bars. If the data calls for a lead swing of three bars to the right, place the lead of the first coil three bars to the right, counting the bar that lines up with the slot as No.1. All the other leads follow in succession, as shown in the figure 3. If the centre of the slot is in line with the mica, consider the bar to the right of the mica as bar No.1.

Fig 3



Method of winding single or double coil per slot

Armature with one coil per slot : The procedure for winding and connecting an armature having one coil per slot is as follows:

Fig 4

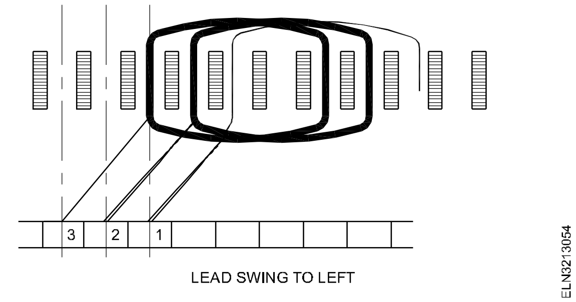
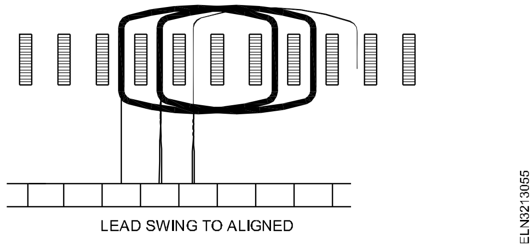
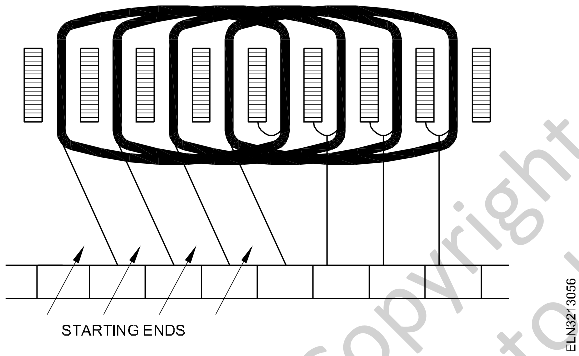


Fig 5



Start in any slot and wind one complete coil in the slots of proper pitch. Place the beginning of coil 1 into the proper commutator according to the lead swing bar and leave the end lead free for connections after the armature is wound as shown in Fig 6.

Fig 6



Wind the entire armature in this manner, leaving all the end leads disconnected. After all the coils are wound, start connecting all the top or end lead to the commutator bar adjacent to the bottom lead of the same coil to produce a simplex lap winding like that given in the Fig 7.

Armature with two coils per slot : Simplex lap-wound armatures having two coils per slot are more common than those having one coil per slot. The procedure for winding this type of armature is as follows:

Start winding with two wires and place the beginning leads in the commutator bars according to the data taken. Cut the wires when the proper number of turns have been wound into the slots and leave the end leads free. Start the next coil, one slot to the left of the first coil as viewed from the commutator end. (When the coils proceed to the left, the winding is called left- handed and to the right, right-handed.) Follow this procedure until all coils have been wound. (Fig 8). Then place the top or end, leads in the commutator bars in the proper succession. This is shown in Fig 9.

Fig 7

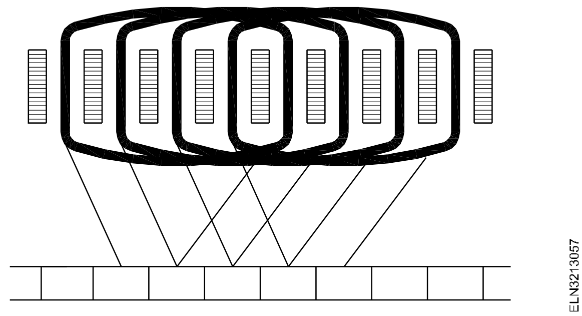


Fig 8

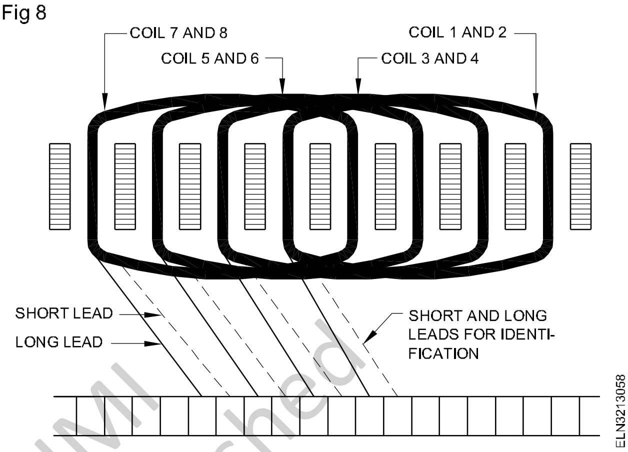
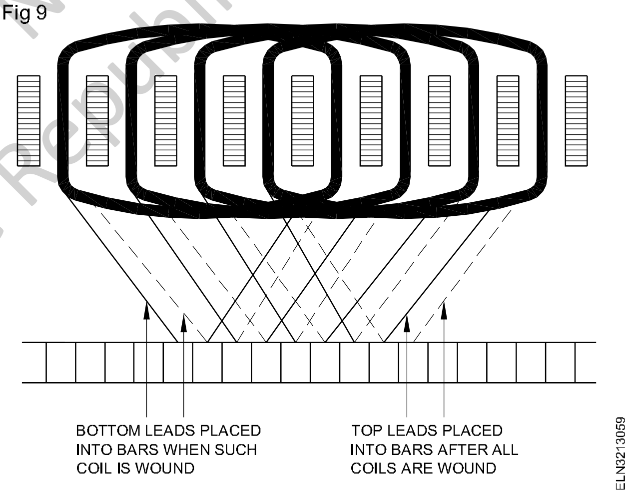


Fig 9



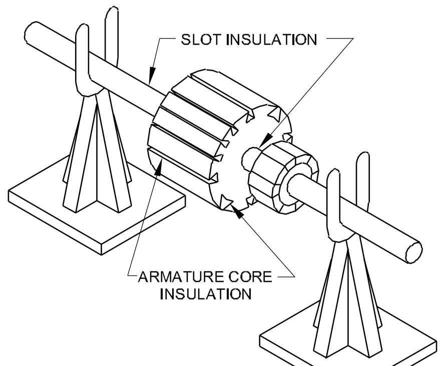
Sleeving of different colours is used for identification of the leads. One colour is used for the beginning and end of the first coil and another colour for the second coil in the same slot, the third coil uses the same colour as the first and so on. It will be necessary to test the first top lead and the colours to identify all the others. Using short and long leads for the two coils in the same slot is another method of identifying the leads so that they can be connected properly.

Method of rewinding and balancing the armature

Objectives: At the end of this lesson you shall be able to
- **explain the method of rewinding a DC armature**
- **explain the methods of soldering/brazing/hot stacking of the winding ends to the commutator raisers**
- **explain the necessity of banding and the method of banding**
- **state the necessity of balancing and the method of balancing the armature.**

Method of winding the armature : To start the armature winding, the armature is mounted on the winding stand as in Fig 1; then the shaft, armature core and slots are insulated as per the insulation scheme taken from the data.

Fig 1



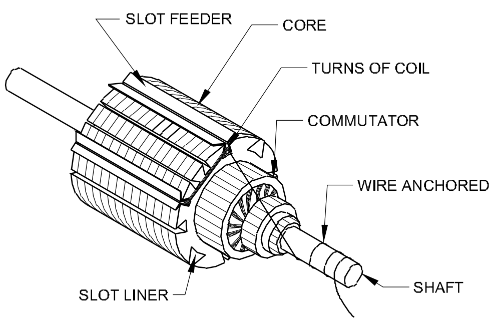
Winding methods : There are two methods of winding the armature.

Hand winding

Formed coil winding

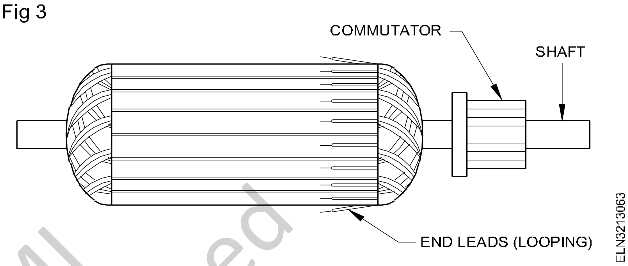
Hand winding : For hand winding, four numbers of slot feeders are placed in the two designated slots at a distance from the coil pitch. The required number of turns are wound into the slots, say slots Nos.1 and 4 as in Fig 2. Enough tension is applied on the wire to make a tight winding without breaking the wire. A loop is made at the end of the first coil and the beginning of the second coil. The second coil is started in the designated slot and the coil is wound with the same number of turns as in coil 1. The span of coil 2, has to be equal to that of coil 1.

Fig 2



When the second coil is finished, a loop is made again and then the third coil is started. In this manner the winding is continued, until all the coils have been wound. The end lead of the last coil is connected to the beginning lead of the first coil. After the entire armature is wound, there will be two coil sides in each slot, in double layer winding. It has to be ensured that all the coils have the same pitch and turns. The loops made at the end of the coils will look as shown in Fig 3, and have to be connected to the commutator raisers. The procedure of making loops while winding, explained here, is for simplex lap winding. This method is usually adopted for small armatures. For wave winding and multiplex windings, connection for raisers shall be taken from the coil ends according to the winding pattern.

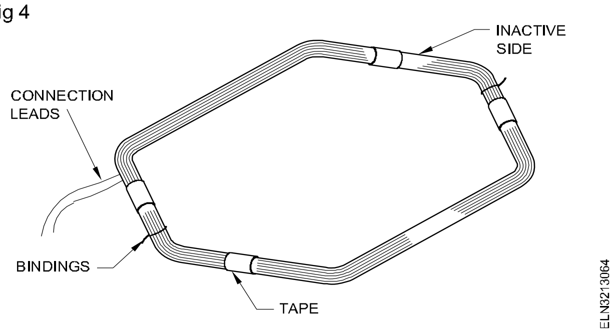
Fig 3



Formed coil winding : For this method, wooden formers are made to the dimensions of the armature coils, similar to those of the field coils as explained in Exercise 1. The total number of coils required for the armature are wound and kept ready.

The inactive side of the coils is bound with tape and tied with cotton strings as shown in Fig 4.

Fig 4



The active side of the coil is spread as in Fig 5 and the coil sides are inserted in the respective armature slots, conductor by conductor as shown in Fig 6. Similarly all the coils of the armature are placed in the respective slots and the coil ends are looped and soldered to the respective commutator segments.

Fig 5

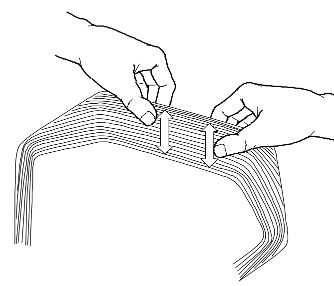
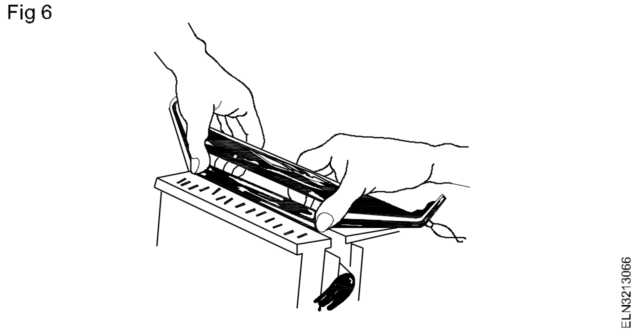


Fig 6

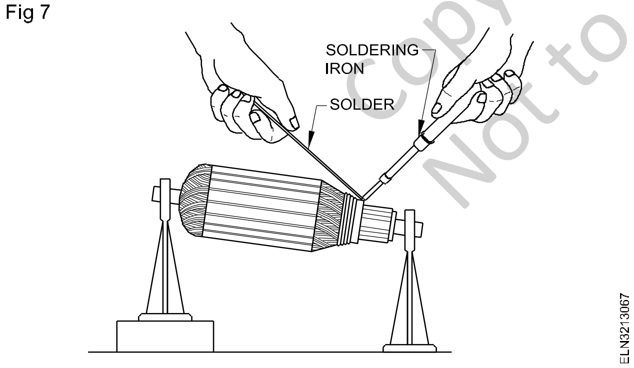


Connection of winding ends with the commutator segments : After winding the armature, the end leads of the armature conductors are placed in the slits of the commutator raisers. (Raiser slits should be properly cleaned and well prepared to receive the conductors.) For secure and good electrical contact, these conductors are well cleaned to remove insulation and dirt. Then the conductor ends are placed in the respective raiser slits and soldered/brazed or hot-stacked.

Soldering : For soldering, electric irons are generally used on small armatures and gas irons on the larger ones. The size of the iron used depends on the size of the commutator. Leads are soldered to the commutator by means of soldering iron or torch.

The procedure of soldering is as follows. First the soldering flux is applied over the wires to be soldered and also the identified commutator raiser. The wires are then placed in the respective raisers. Then the tip of the soldering iron is kept on the commutator raiser as shown in Fig 7 for some time until the heat from the iron is transferred to the area of the commutator raiser. This heat transfer could be identified by the bubbling of the flux.

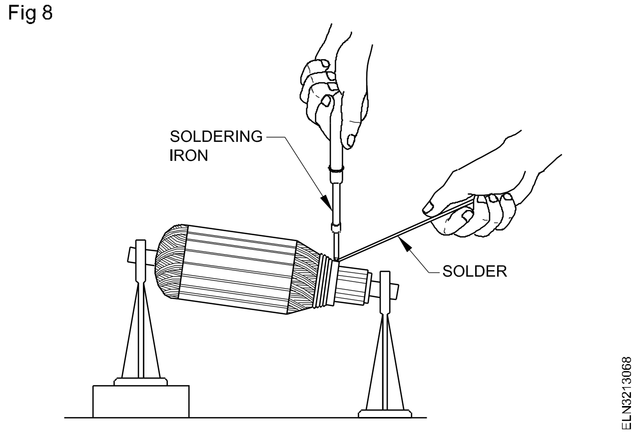
Fig 7



When the commutator raiser is sufficiently hot, the solder is placed on the commutator raiser, and the iron is kept over it and the solder melted. The solder is allowed to flow entirely around the leads. To prevent the solder from flowing down the back of the commutator and thereby causing short circuits, raise one end of the armature. To prevent the solder from flowing from one bar to another, the iron is held as shown in Fig 8. Excess flux is wiped out after the soldering is completed.

Brazing : In the case of large armature windings, the armature winding lead ends are brazed with the respective commutator raiser slits by means of a gas torch. Close inspection and care should be exercised in the control of the flame.

Fig 8



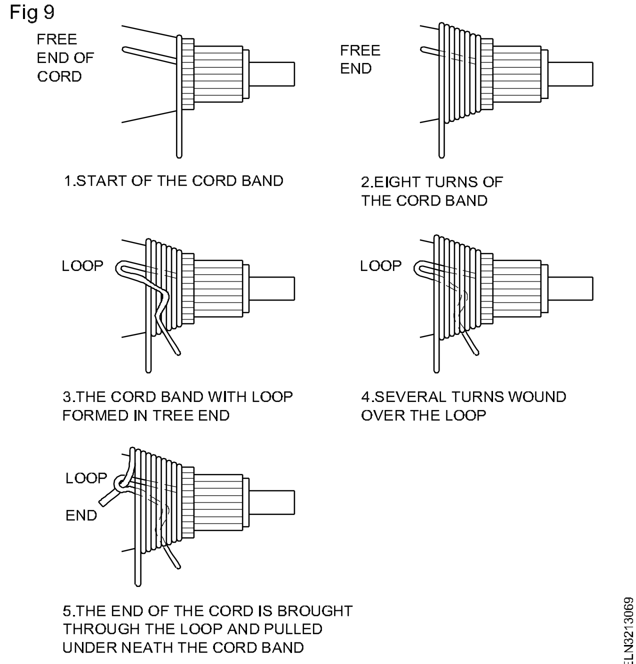
Hot stacking : In the case of small DC armatures, the armature conductors are kept in the commutator raiser slits and spot-welded. This is called hot stacking. A specially designed hot-stacking machine is available for this purpose.

Banding the armature : A temporary banding is sometimes applied on the armature before the permanent banding is done, to keep the coils in position and to facilitate shaping of the overhang.

Permanent bands are used on armatures to hold the armature end leads in position. A cord band is used on small armatures to prevent the leads from flying out of the slots, while the armature is rotating. Large armatures have steel bands for the same purpose. For large armatures having open-type slots, steel or tape bands are used to prevent the coil from flying out of the slots.

Cord bands : The procedure for making a cord band on an armature is shown in Fig 9, and the following directions should be observed.

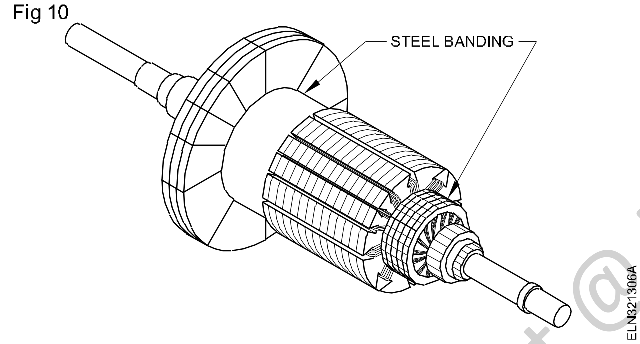
Fig 9



Use a proper size of banding cord - heavy for larger armatures, light for smaller armatures. Start at the end nearest the commutator and wind several turns in layers, allowing about 150mm long cord at the beginning to be free. Bend the cord in the form of a loop as shown in Fig 9. After winding several turns over the loop, insert the last end of the cord band through the loop, and then pull the free end of the loop. This will pull the end under the core band and secure it there. Then the pulled end of the cord can be cut off. Use enough pressure in winding so that the band will be tight.

Steel bands : Steel bands are placed on the front and back ends of the coils. These bands are put on the armature in a different manner than in the cord bands. The procedure is illustrated in Fig 10, and is as follows. Place the armature in a lathe and place mica or paper insulation in the band slot around the entire armature to insulate the band from the coil sides. Hold the insulation in place by tying a turn of cord around it.

Fig 10



Place small strips of tin or copper under the cord, equidistant around the armature, in order to secure the band after it is wound. Use the same gauge steel band wire as is found in the original band.

Steel bands must be put on the armature with much more pressure than is needed for cord bands. It is, therefore, necessary to utilize a device called a wire clamp to provide the required pressure. This device consists of two pieces of fibre fastened together by means of two screws and two wing nuts. The steel band wire is fed through this clamp to the armature. The clamp has to be secured to a bench so that it can be held stationary while slowly turning the armature while banding. Take care not to put too much pressure on the wire; otherwise it will break. After the band is placed on the coil, copper or tin strips are turned over and the entire band is soldered. One by one each band is completed in this manner.

Testing the new winding : After the rewinding and connections are completed, it is important that both the winding and the connections are tested for shorts, grounds, open circuits and correctness of connections. This must be done before varnishing the winding so that any defect that is found may be corrected more readily.

Baking and varnishing : After the armature has been wound, soldered, banded and tested, the next operation is varnishing. This process makes it moisture-proof and also prevents vibration of the coils of wire in the slots. Vibration has a tendency to impair the insulation on the wires and cause shorts. Moisture will also cause the insulation on the wires to deteriorate. Before varnishing the armature, it must be preheated to drive out the moisture on it.

Armatures may be varnished by either baking varnish or air-drying varnish. Air-drying varnish is applied to the armature when baking is undesirable or inconvenient. Baking varnish is more effective because the moisture can be eliminated fully only by baking.

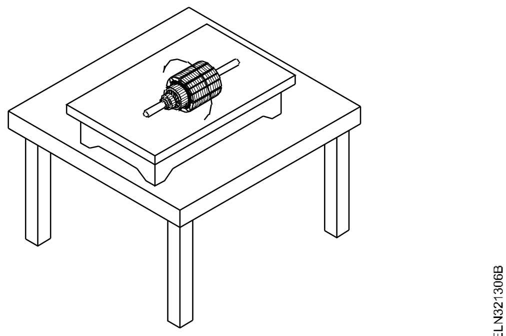
Importance of balancing the armature : The armature used in mixers/liquidizers runs at 3000 to 6000 r.p.m. depending on the load. As such these armatures should have equal weight in all directions. The causes of unbalance in weight are given below :

- Unequal turns in coils.
- Unequal core assembly.
- Unequal weight of wedges.
- Unequal slot liner insulations.

In case of unbalance, the centrifugal force which is produced due to high speed of the armature may shake loose its core and commutator in a very short space of time. In extreme cases the armature will damage the bearings and fly out. In mild cases of unbalance, there will be vibration and noise while the motor is running. Most of the manufacturers use a dynamic balancing machine to balance the armature. To balance higher weight of one side, the opposite side is plugged with lead weights. In certain cases the heavier side is balanced by drilling suitable sized holes in the periphery of the armature to reduce the weight.

Static balancing - method 1 : In small sized winding shops, the rewound armature is rolled on the surface of a horizontally positioned surface plate as shown in Fig 11. For every rolling, if the armature stops at different positions of its periphery, then it is regarded as balanced. On the other hand for each rolling the armature stops at the same position of the periphery then the armature is regarded as unbalanced. Where the armature stops at the same place and the portion of the armature touches the surface plate is regarded to have higher weight than the opposite portion.

Fig 11



In such cases, the wedges in the lighter portion have to be removed and replaced with heavier wedges made of brass or lead. However, this rolling test should be carried out a number of times till the electrician is completely satisfied that the armature is perfectly balanced.

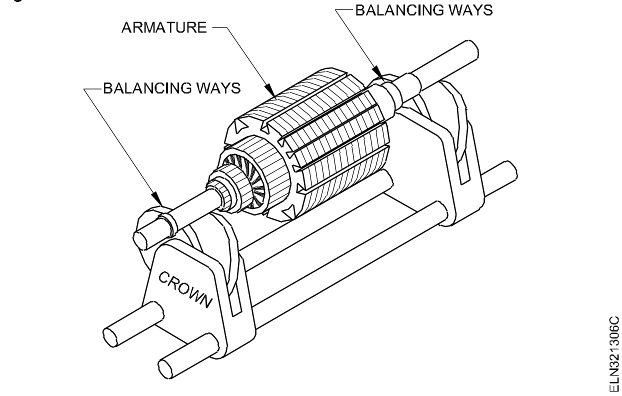
To avoid such unbalanced condition, the armature winder should see to it the causes of unbalancing are removed at the time of winding itself.

Static balancing - method 2: A balancer, similar to the balancing grinding wheel in machine shops, may be used. These balancers are built in various sizes. The method of balancing an armature using this type is as follows.

Place the armature on the balancing ways, (Fig 12) and roll the armature gently. When the armature comes to a stop, the heavier portion of the armature will be at the bottom. Mark this point (portion) with a chalk piece. With such successive rolling, if the armature stops at different positions, the armature is balanced, and if it stops in a particular position, it is necessary to counterbalance it with weights diagonally opposite to the heavy portion.

This is accomplished by placing a lead or a small metal piece on the banding of the armature. In small armatures, this weight may be placed in the place of the wedge, under the banding. Experience will determine the amount of metal necessary to balance the armature. This method of balancing is called 'static balancing'.

Fig 12



Dynamic balancing : Dynamic balancing machines are available to balance the armature or rotating the parts of electrical machines. The armatures are fixed on those machines and rotated at the rated speed. A pointer or an indicator shows the position on the armature and the weight to be added. The balancing machines available are either with the mechanical balancing or with the stroboscopic balancing.

Testing of armature winding

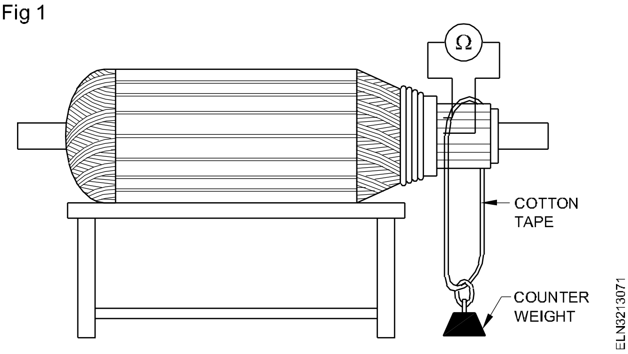
Objectives: At the end of this lesson you shall be able to
- **describe the methods of testing armature, such as the**
  - **winding resistance test**
  - **insulation resistance test**
  - **growler test**
  - **voltage drop test.**

Testing the winding : After an armature is wound and the leads are connected to the commutator, a test should be conducted. From this test, defects may be revealed, which might have occurred during winding. The common defects in armature windings are grounding, shorts in the coils, open in the coil and reversal in the coil connection. These defects can be located by different test procedures.

Armature winding resistance test : Resistance of the armature coil is measured by using a low range ohmmeter and preferably with the Kelvin bridge. Resistance between consecutive segments in the case of simplex lap winding (for wave and multiplex windings at a distance of commutator pitch Y_c) is measured. Fig 1 shows a simple arrangement to measure the resistance between the successive commutator segments.

As shown in Fig 1, a cotton tape with a counterweight is passed around the commutator to hold the connecting leads to the segments. Measurement of resistance is done in all the coils by changing the position of the connecting leads to successive commutator segments. The resistance measured should be the same in all coils. Lower resistance shows short in turns, while a higher resistance shows higher numbers of turns or open in the coil.

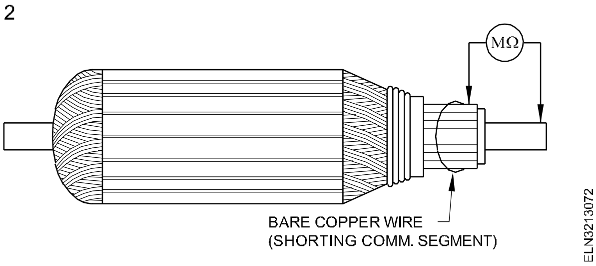
Fig 1



Insulation resistance test : With a bare copper wire short all the commutator segments. (Fig 2) Test the insulation resistance between the body and the commutator segments by a 500V Megger, for armatures rated up to 250 volts. The IR so measured shall be greater than 1 megohm. If the value is less than 1 megohm, moisture in the winding or a weak insulation is to be suspected.

This test is sometimes conducted by a series test lamp and is called the 'ground test'. It will only indicate if any coil is grounded, and not the insulation resistance.

Fig 2

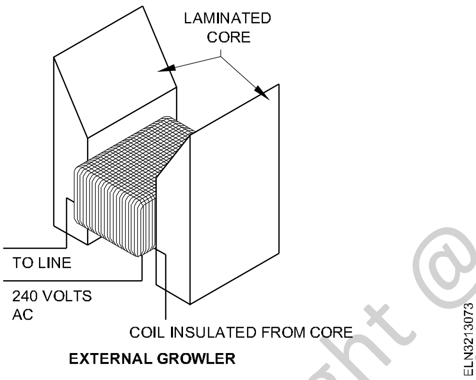


Growler test : A simple and most common method to test armature winding for short and open coils is by a growler.

Growler : There are two types of growlers - 1) internal and 2) external growlers. An external growler is used for testing small armatures and an internal growler for large DC armatures and AC motor stator windings.

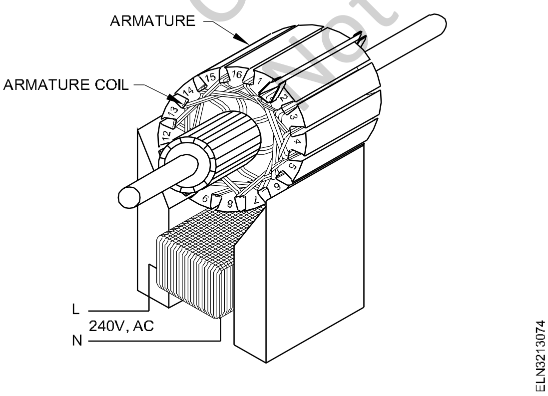
External growler : An external growler, shown in Fig 3, is an electromagnetic device that is used to detect and locate grounded, shorted and open coils in an armature.

Fig 3



This growler consists of a coil wound around an iron core and is connected to a 240 volt AC line. The core is generally H shaped and cut out on top so that the armature will fit on it, as shown in Fig 4.

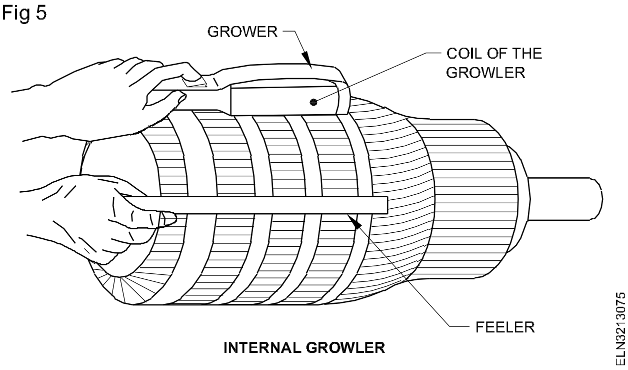
Fig 4



When an alternating current is applied to the growler coil, the voltage will be induced in the armature coils by transformer action.

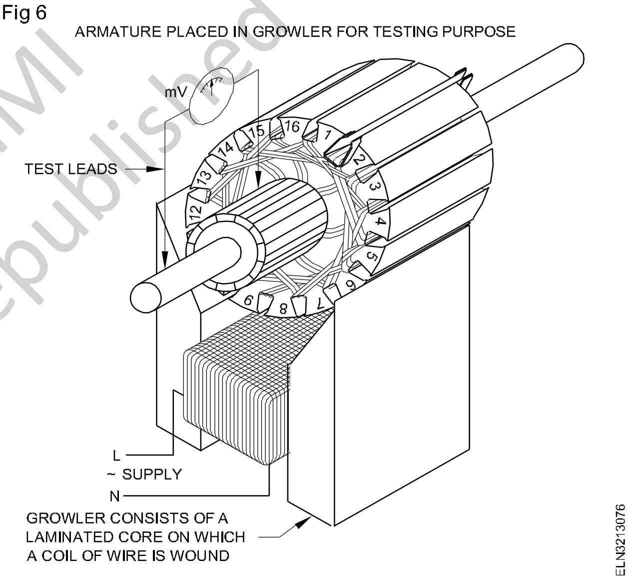
Internal growler : An internal growler, such as the one used for stators, may be used for armatures as well. These are made with or without built-in feelers. The growler with a built-in feeler has a flexible blade attached to the growler so that a hacksaw blade or similar instrument is not necessary. This type is especially desirable in smaller stators that have no room for a separate feeler. Fig 5 shows an internal growler with a separate feeler, used for large armatures.

Fig 5



Growler test for grounded coil : The armature to be tested is placed on the growler and then the growler is switched 'ON'. Place one lead of an AC milli-voltmeter on the top commutator bar and the other meter lead on the shaft, as shown in Fig 6.

Fig 6

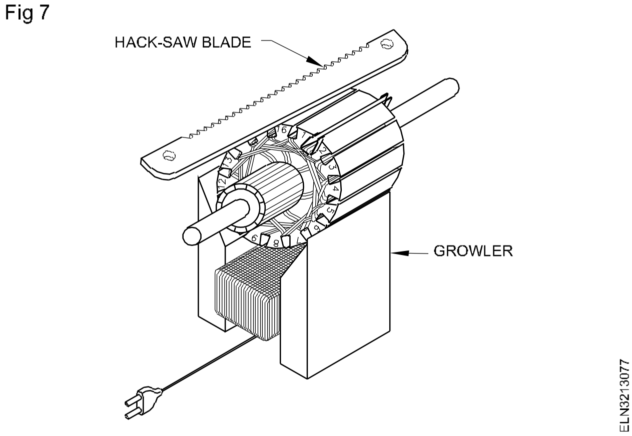


If a reading is noticed on the meter, turn the armature so that the next commutator bar is in the same position as the earlier one, and test as before. Continue in this manner until all the bars are tested. Where the meter gives no deflection, it is an indication that the grounded coil is connected to this particular bar.

Growler test for shorted coil : The procedure to test for short circuits in an armature is as follows.

The armature to be tested is placed on the growler and then the growler is switched on. A thin piece of metal, such as a hacksaw blade, is held over the top slot of the armature as shown in Fig 7. In case of short in the winding, the blade will vibrate rapidly and create a growling noise. If the blade remains stationary, it is an indication that no short exists in the coil under test. After several top slots have been given the hacksaw blade test, turn the armature so that the next few slots are on top. Test as before and continue this procedure for the entire armature.

Fig 7

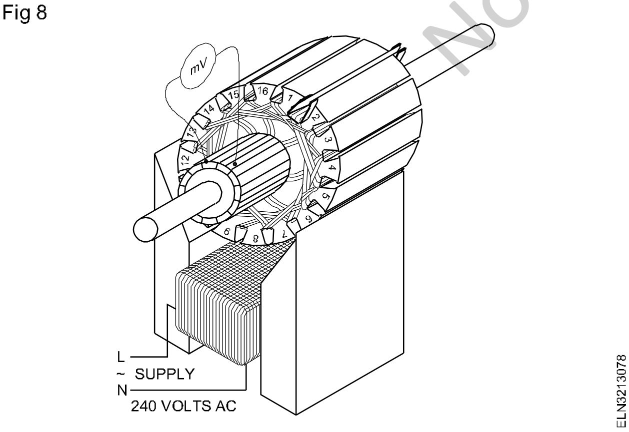


An armature having cross connections or equalizers cannot be given the hacksaw blade test. This type of armature will cause the blade to vibrate at every slot, which would seem to indicate that possibly every coil is shorted.

Test for open coil : Growlers are also provided with meters (milli-volt or ammeter) on the panel with variable resistance. In this case an open in the armature coil can be found out as follows.

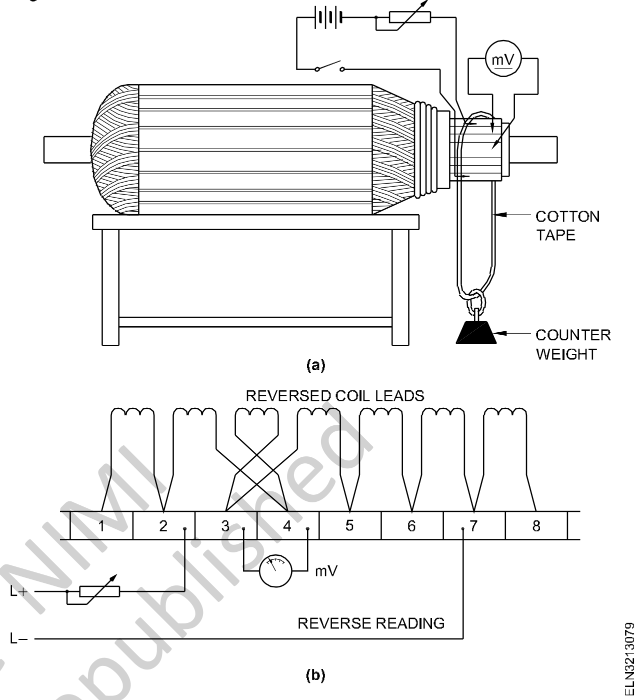
Growler test for an open coil : To locate an open coil with a growler, set up the armature on the growler in the usual manner. Test the top two adjacent bars with an AC milli-voltmeter as shown in Fig 8. Rotate the armature and continue testing the adjacent bars. When the milli-voltmeter bridges the two bars connected to the open coil, the meter pointer will not deflect. All the other bars will give a deflection. This test for an open coil can be made without the meter by shorting the two top bars with a piece of wire. Absence of a spark indicates that the coil is open. The open may be either at the commutator bar or in the coil itself. The procedure may be used to determine the location of the leads of a shorted coil. However, the hacksaw blade test is the most satisfactory method of determining a shorted coil.

Fig 8



Drop test : The most accurate method of testing the armature for correct resistance, number of turns, short and open and reversed coil connection is by the drop test. Connect a low voltage DC supply across the commutator segments at a distance of pole pitch. Insert a variable resistance in series with the circuit. Switch 'ON' the DC supply and connect a milli-voltmeter to the adjacent segments as in Fig 9a and b.

Fig 9



Adjust the readings to a specified value, by using a variable rheostat. Record the milli-voltmeter readings on the consequent commutator segments by rotating the armature in one direction. The position of the segments and the connection should be the same as in the first set up. The result could be concluded as enumerated below.

- If all the readings are the same, the winding is correct.
- If the milli-voltmeter reads zero or low voltage, the coil connected to the segment is short.
- If the milli-voltmeter reads high voltage, the coil connected to the segment is open.
- If the milli-voltmeter deflects in the reverse direction as shown in Fig 9b, the coil connected with the segment is reversed.

Generally armatures are tested as a routine for insulation resistance and for shorted coils. Only when a fault in the armature winding is suspected, a drop test is conducted.

Principle of induction motor

Objectives: At the end of this lesson you shall be able to
- **state the principle of a 3-phase induction motor**
- **explain briefly the method of producing a rotating magnetic field.**

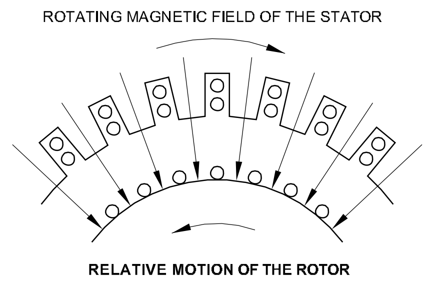
The three-phase induction motor is used more extensively than any other form of electrical motor, due to its simple construction, trouble-free operation, lower cost and a fairly good torque speed characteristic.

Principle of 3-phase induction motor: It works on the same principle as a DC motor, that is, the current-carrying conductors kept in a magnetic field will tend to create a force. However, the induction motor differs from the DC motor in fact that the rotor of the induction motor is not electrically connected to the stator, but induces a voltage/ current in the rotor by the transformer action, as the stator magnetic field sweeps across the rotor. The induction motor derives its name from the fact that the current in the rotor is not drawn directly from the supply, but is induced by the relative motion of the rotor conductors and the magnetic field produced by the stator currents.

The stator of the 3-phase induction motor is similar to that of a 3-phase alternator, of revolving field type. The three-phase winding in the stator produces a rotating magnetic field in the stator core as it will be explained later. The rotor of the induction motor may have either shorted rotor conductors in the form of a squirrel cage or in the form of a 3-phase winding to facilitate the circulation of current through a closed circuit.

Let us assume that the stator field of the induction motor is rotating in a clockwise direction as shown in Fig 1. This makes for the relative motion of the rotor in an anticlockwise direction as shown in Fig 1. Applying Fleming's right hand rule, the direction of emf induced in the rotor will be towards the observer as shown in Fig 2. As the rotor conductors have a closed electric path, due to their shorting, a current will flow through them as in a short-circuited secondary of a transformer.

Fig 1



The magnetic field produced by the rotor currents will be in a counter-clockwise direction as shown in Fig 2 according to Maxwell's Corkscrew rule. The interaction between the stator magnetic field and the rotor magnetic field results in a force to move the rotor in the same direction as that of the rotating magnetic field of the stator, as shown in Fig 3. As such the rotor follows the stator field in the same direction by rotating at a speed lesser than the synchronous speed of the stator rotating magneticfield.

Fig 2

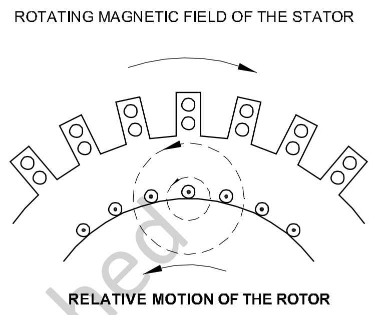
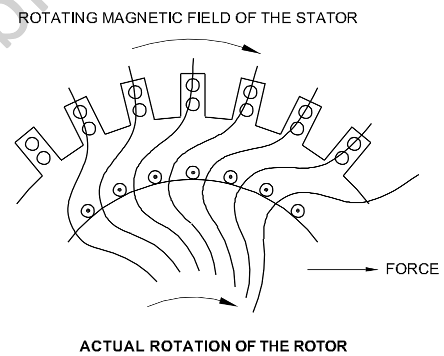


Fig 3



At higher speeds of the rotor nearing to synchronous speeds, the relative speed between the rotor and the rotating magnetic field of the stator reduces and results in a smaller induced emf in the rotor. Theoretically, if we assume that the rotor attains a speed equal to the synchronous speed of the rotating magnetic field of the stator, there will be no relative motion between the stator field and the rotor, and thereby no induced emf or current will be there in the rotor. Consequently there will not be any torque in the rotor. Hence the rotor of the induction motor cannot run at a synchronous speed at all. As the motor is loaded, the rotor speed has to fall to cope up with the mechanical force; thereby the relative speed increases, and the induced emf and current increase in the rotor resulting in an increased torque.

To reverse the direction of rotation of a rotor: The direction of rotation of the stator magnetic field depends upon the phase sequence of the supply. To reverse the direction of rotation of the stator as well as the rotor, the phase sequence of the supply is to be changed by changing any two leads connected to the stator.

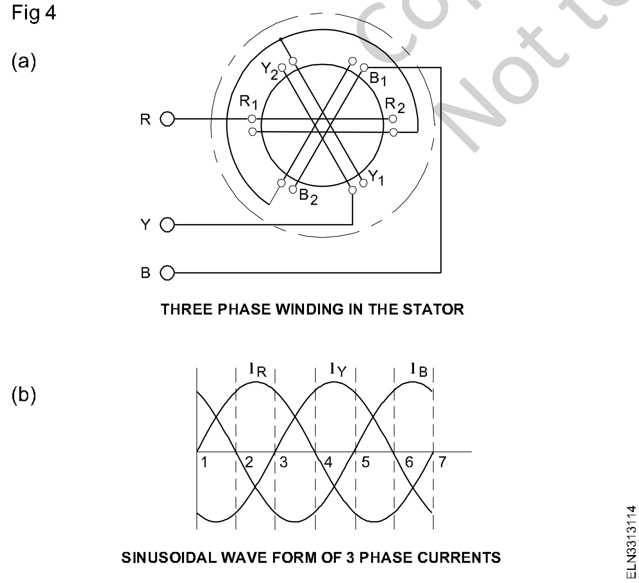
Rotating magnetic field from a three-phase stator: The operation of the induction motor is dependent on the presence of a rotating magnetic field in the stator. The stator of the induction motor contains three-phase windings placed at 120 electrical degrees apart from each other. These windings are placed on the stator core to form non-salient stator field poles. When the stator is energized from a three-phase voltage supply, in each phase winding will set up a pulsating field. However, by virtue of the spacing between the windings, and the phase difference, the magnetic fields combine to produce a field rotating at a constant speed around the inside surface of the stator core. This resultant movement of the flux is called the **`rotating magnetic field'**, and its speed is called the **`synchronous speed'**.

The manner, in which the rotating field is set up, may be described by considering the direction of the phase currents at successive instants during a cycle. Fig 4a shows a simplified star-connected, three-phase stator winding. The winding shown is for a two-pole induction motor. Fig 4b shows the phase currents for the three-phase windings. The phase currents will be 120 electrical degrees apart as shown in Fig 4b. The resultant magnetic field produced by the combined effect of the three currents is shown at increments of 60° for one cycle of the current.

At position (1) in Fig 4b, the phase current I_R is zero, and hence coil R will be producing zero flux. However, the phase current I_B is positive and I_y is negative.

Considering the instantaneous current directions of these three phase windings, as shown in Fig 4b at position 1, we can indicate the current direction in Fig 5(1).

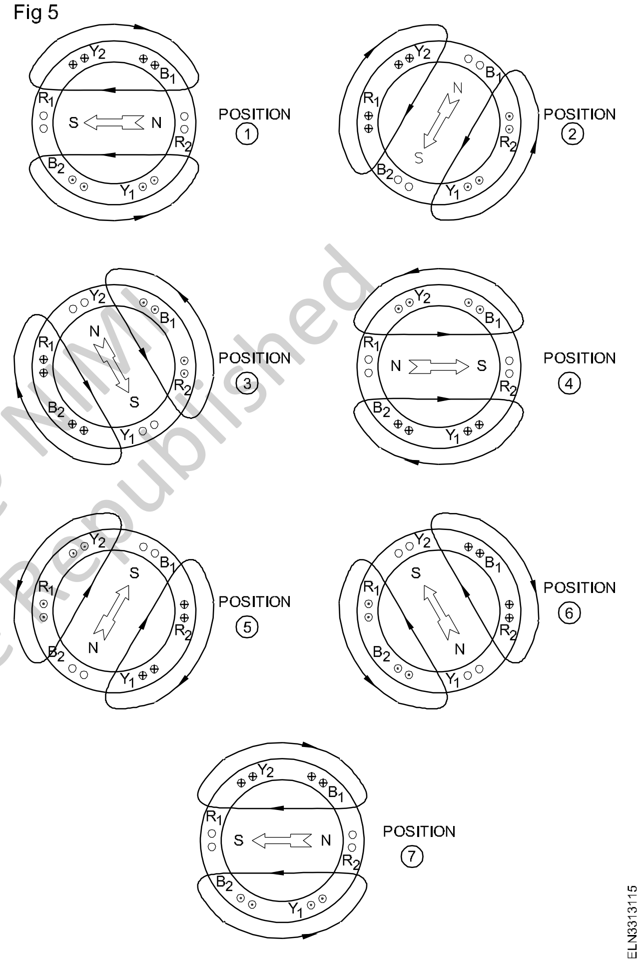
Fig 4



For convenience the +ve current is shown as +ve sign, and the -ve current is shown as dot (•) sign. Accordingly Y_2 and B_1 are shown as positive and Y_1 and B_2 are shown as negative. Using Maxwell's corkscrew rule, the resulting flux by these currents will produce a flux as shown in Fig 5(1). The arrow shows the direction of the magnetic field and the magnetic poles in the stator core.

At position 2, as shown by Fig 5(2), 60 electrical degrees later, the phase current I_B is zero, the current I_R is positive and the current I_Y is negative. In Fig (2) the current is now observed to be flowing into the conductors at the coil ends R_1 and Y_2, and out of the conductors at coil R_2 and Y_1. Therefore, as shown in Fig 5(2), the resultant magnetic poles are now at a new position in the stator core. In fact the poles in position 2 have also rotated 60° from position (1).

Fig 5



Using the same reasoning as above for the current wave positions 3, 4, 5, 6 and 7, it will be seen that for each successive increment of 60 electrical degrees, the resultant stator field will rotate a further 60° as shown in Fig 5. Note that from the resultant flux from position (1) to position (7), it is obvious that for each cycle of applied voltage the field of the two-pole stator will also rotate one revolution around its core.

From what is stated above it will be clear that the rotating magnetic field could be produced by a set of 3-phase stationary windings, placed at 120° electrical degrees apart, and supplied with a 3-phase voltage.

The speed at which the field rotates is called synchronous speed, and, it depends upon the frequency of supply and the number of poles for which the stator is wound.

Hence

N_s = Synchronous speed in r.p.m.

$$= \frac{120F}{P} \text{ rpm}$$

where `P' is the number of poles in the stator, and `F' is the frequency of the supply.

Construction of a 3-phase squirrel cage induction motor - relation between slip, speed, rotor frequency, copper loss and torque

Objectives: At the end of this lesson you shall be able to
- **describe the construction of a 3-phase, squirrel cage induction motor**
- **describe the construction of double squirrel cage motor and its advantage**
- **explain slip, speed, rotor frequency, rotor copper loss, torque and their relationship.**

Three-phase induction motors are classified according to their rotor construction. Accordingly, we have two major types.

– Squirrel cage induction motors

– Slip ring induction motors.

Squirrel cage motors have a rotor with short-circuited bars whereas slip ring motors have wound rotors having three windings, either connected in star or delta. The terminals of the rotor windings of the slip ring motors are brought out through slip-rings which are in contact with stationary brushes.

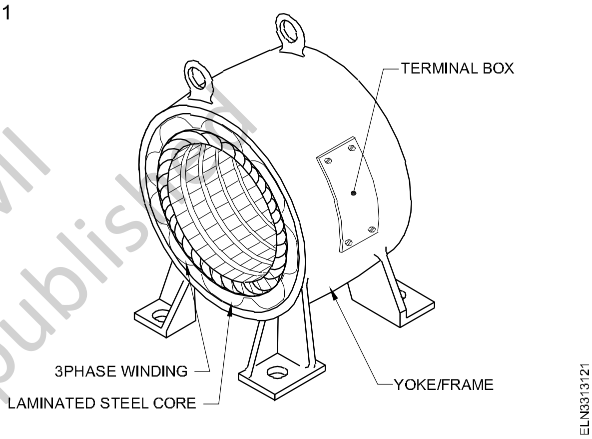
Development of these two types of induction motors is due to the fact that the torque of the induction motor depends upon the rotor resistance. Higher rotor resistance offers higher starting torque but the running torque will be low with increased losses and poor efficiency. For certain applications of loads where high starting torque and sufficient running torque are the only requirements, the rotor resistance should be high at the time of starting, and low while the motor is running. If the motor circuit is left with high resistance, the rotor copper loss will be more, resulting in low speed and poor efficiency. Hence it is advisable to have low resistance in the rotor while in operation.

Both these requirements are possible in slip-ring motors by adding external resistance at the start and cutting it off while the motor runs. As this is not possible in squirrel cage motors, the above requirements are met by developing a rotor called double squirrel cage rotor where there will be two sets of short circuited bars in the rotor.

Stator of an induction motor: There is no difference between squirrel cage and slip-ring motor stators.

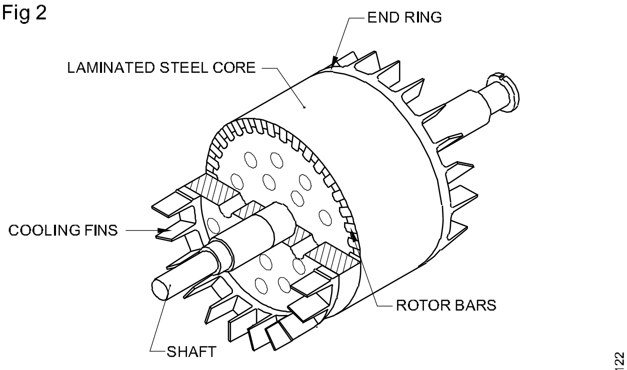
The induction motor stator resembles the stator of a revolving field, three-phase alternator. The stator or the stationary part consists of three-phase winding held in place in the slots of a laminated steel core which is enclosed and supported by a cast iron or a steel frame as shown in Fig 1. The phase windings are placed 120 electrical degrees apart, and may be connected in either star or delta externally, for which six leads are brought out to a terminal box mounted on the frame of the motor. When the stator is energised from a three-phase voltage it will produce a rotating magnetic field in the stator core.

Fig 1



Rotor of a squirrel cage induction motor: The rotor of the squirrel cage induction motor shown in Fig 2 contains no windings. Instead it is a cylindrical core constructed of steel laminations with conductor bars mounted parallel to the shaft and embedded near the surface of the rotor core. These conductor bars are short circuited by an end-ring at either end of the rotor core. On large machines, these conductor bars and the end-rings are made up of copper with the bars brazed or welded to the end rings as shown in Fig 3. On small machines the conductor bars and end-rings are sometimes made of aluminium with the bars and rings cast in as part of the rotor core.

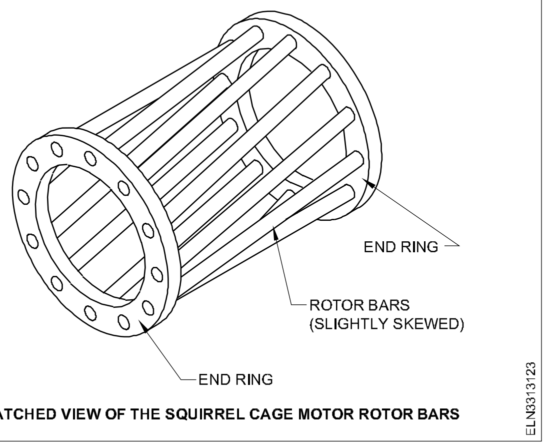
Fig 2



CAGE-TYPE ROTOR IN PART SECTION SHOWING CAST ALUMINIUM BARS AND END RINGS

The rotor or rotating part is not connected electrically to the power supply but has voltage induced in it by transformer action from the stator. For this reason, the stator is sometimes called the primary, and the rotor is referred to as the secondary of the motor. Since the motor operates on the principle of induction; and as the construction of the rotor, with the bars and end-rings resembles a squirrel cage, the name squirrel cage induction motor is used. (Fig 3)

Fig 3



DETATCHED VIEW OF THE SQUIRREL CAGE MOTOR ROTOR BARS

The rotor bars are not insulated from the rotor core because they are made of metals having less resistance than the core. The induced current will flow mainly in them. Also, the bars are usually not quite parallel to the rotor shaft but are mounted in a slightly skewed position. This feature tends to produce a more uniform rotor field and torque; also it helps to reduce some of the internal magnetic noise when the motor is running.

End shields: The function of the two end shields which are to support the rotor shaft. They are fitted with bearings and attached to the stator frame with the help of studs or bolts.

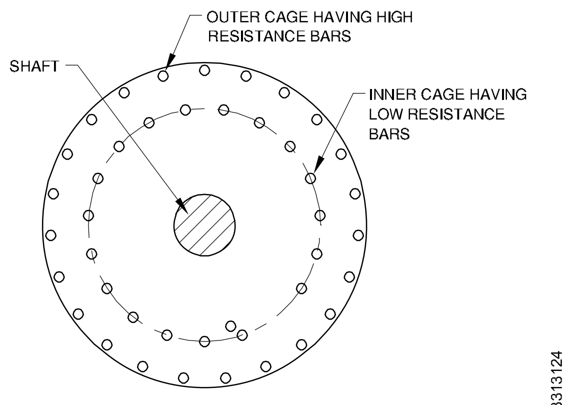
Double squirrel cage induction motor

Rotor construction and its working: This consists of two sets of conductor bars called outer and inner cages as shown in Fig 4. The outer cage consists of bars of high resistance metals like brass, and is short-circuited by the end-rings. The inner cage consists of low resistance metal bars like copper, and is short-circuited by the end-rings. The outer cage has high resistance and low reactance, whereas the inner cage has low resistance but being situated deep in the rotor core, has a large ratio of reactance to resistance.

At the time of starting, the rotor frequency is the same as the stator frequency. Hence the inner cage which has higher inductive reactance offers more resistance to the current flow. As such very little current flows through the inner cage at the time of starting.

The major part of the rotor current at the time of starting could flow through the outer ring which has high resistance. This high resistance enables to produce a high starting torque.

Fig 4

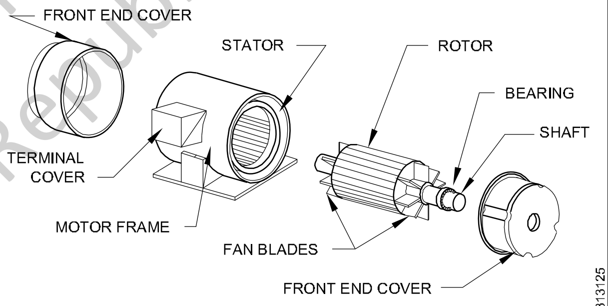


ROTOR OF THE DOUBLE SQUIRREL CAGE MOTOR

As the speed increases, the rotor frequency is reduced. At low frequency, the total resistance offered for the current flow in the inner cage reduces due to reduction of reactance ($X_L = 2\pi f_r L$), and the major part of the rotor current will be in the inner cage rather than in the highly resistant outer cage.

As such, the low resistance of the inner cage becomes responsible for producing a torque just sufficient to maintain the speed. Fig 5 shows the exploded view of 3 phase squirrel cage induction motor

Fig 5



PARTS OF 3 PHASE SQUIRREL CAGE INDUCTION MOTOR

Slip and rotor speed: We have already found that the rotor of an induction motor must rotate in the same direction as the rotating magnetic field, but it cannot rotate at the same speed as that of the magnetic field. Only when the rotor runs at a lesser speed than the stator magnetic field, the rotor conductors could cut the stator magnetic field for an emf to be induced. The rotor current could then flow and the rotor magnetic field will set up to produce a torque.

The speed at which the rotor rotates is called the rotor speed or speed of the motor. The difference between the synchronous speed and the actual rotor speed is called the `slip speed'. Slip speed is the number of revolutions per minute by which the rotor continues to fall behind the revolving magnetic field.

When the slip speed is expressed as a fraction of the synchronous speed, it is called a fractional slip.

Therefore, fractional slip S

$$= \frac{N_s - N_r}{N_s}$$

Then percentage slip (% slip)

$$= \frac{N_s - N_r}{N_s} \times 100$$

where N_s = synchronous speed of the stator magnetic field

N_r = Actual rotating speed of the rotor in r.p.m.

Most squirrel cage induction motors will have a percentage slip of 2 to 5 percent of the rated load.

Example

Calculate the percentage slip of an induction motor having 6 poles fed with 50 cycles supply rotating with an actual speed of 960 r.p.m.

Given:

Poles = 6

N_r = Rotor speed = 960 r.p.m.

F = frequency of supply = 50 Hz

N_s = Synchronous speed

$$= 120 \frac{f}{P}$$

$$= \frac{120 \times 50}{6} = 1000 \text{r.p.m.}$$

$$\% \text{ slip} = \frac{N_s - N_r}{N_s} \times 100$$

$$= \frac{1000 - 960}{1000} \times 100 = 4\%$$

Generated voltage in the rotor and its frequency: As the rotor cuts the stator flux, it induces voltage in rotor conductors and it is called the rotor voltage. The frequency of this rotor voltage is equal to the product of the slip and stator (supply) frequency (f_s).

Frequency of the rotor voltage

f_r = Fractional slip x stator frequency

$$= \frac{N_s - N_r}{N_s} \times f \text{ (or)}$$

From the above, we find that, at the time of starting, the rotor is at rest, and the slip will be equal to one and the rotor frequency will be the same as the stator frequency. When the motor is running at high speed, the slip will be low and the frequency of the rotor will also be low.

Example 1

A 3-phase induction motor is wound for 4 poles, and is supplied from a 50 Hz supply. Calculate a) the synchronous speed, b) the speed of the rotor when the slip is 4 percent, and c) the rotor frequency.

a Synchronous speed $= N_s = \frac{120f}{P}$

$$= \frac{120 \times 50}{4} = 1500 \text{ r.p.m.}$$

b Actual speed of the rotor = N_r

$$\text{Percentage slip} = \frac{N_s - N_r}{N_s} \times 100$$

$$N_s - N_r = \frac{N_s \times \text{Percentage slip}}{100}$$

$$N_r = N_s - \frac{N_s \times \%\text{slip}}{100}$$

$$= 1500 - \frac{1500 \times 4}{100}$$

= 1440 r.p.m.

c Rotor frequency f_r = Slip x Stator frequency

$$= \frac{N_s - N_r}{N_s} \times f$$

$$= \frac{1500 - 1440 \times 50}{1500}$$

$$= \frac{60 \times 50}{1500} = 2 \text{ Hz.}$$

Example 2

A 12-pole, 3-phase alternator driven at a speed of 500 r.p.m. supplies power to a 8-pole, 3-phase induction motor. If the slip of the motor at full load is 3%, calculate the full load speed of the motor.

Let N_r = actual speed of motor

Supply frequency = frequency of alternator

$$= \frac{12 \times 500}{120} = 50 \text{ Hz.}$$

Synchronous speed N_s of the induction motor

$$= \frac{120 \times 50}{8} = 750 \text{r.p.m.}$$

$$\% \text{ slip } S = \frac{N_s - N_r}{N_s} \times 100 = 3$$

$$= \frac{750 - N_r}{750} \times 100 = 3$$

$$750 - N_r = \frac{3 \times 750}{100} = 22.5$$

N_r = 727.5 r.p.m.

Example 3

A 400V, 3-phase, eight-pole 50 Hz squirrel cage motor has a rated full load speed of 720 r.p.m. Determine

a the synchronous speed

b the rotor slip at rated load

b the percentage slip at rated load

d the percentage slip at the instant of start up

e the rotor frequency at the rated load

f the rotor frequency at the instant of start up.

Solution

a Synchronous speed $N_s = \frac{120 \times f}{p}$

$$= \frac{120 \times 50}{8} = 750 \text{r.p.m.}$$

b Slip at rated load = 750 - 720 = 30 r.p.m.

c Percent slip at rated load= $\frac{30 \times 100}{750} = 4\%$

d At the instant of start up the rotor speed is zero, and hence the percentage slip will be 100 percent.

e Rotor frequency at rated load f_r

$$= \frac{(f \times \text{percentage slip})}{100}$$

$$= \frac{50 \times 4}{100} = 2 \text{ Hz.}$$

f At the instant of starting the slip is 100 percent. Therefore, at this instant the rotor frequency will be equal to the stator frequency f_r (at starting) = f = 50 Hz.

Rotor copper loss: Rotor copper loss is the loss of power taking place in the rotor due to its resistance and the rotor current. Though the resistance of the rotor for a squirrel cage motor remains constant, the current in the rotor depends upon the slip, transformation ratio between the stator and rotor voltages and the inductive reactance of the rotor circuit.

Let T = torque developed by the motor

P_R = power developed in the rotor

P_m = power converted in the rotor as mechanical power

n_S = the synchronous speed in r.p.m.

n_r = the rotor speed in r.p.m.

Then $P_R = 2\pi n_s T$ watts

$P_m = 2\pi n_r T$ watts.

The difference between P_R - P_m is the rotor copper loss.

$P_R - P_m$ = Rotor copper loss

Rotor copper loss $= 2\pi T(n_s - n_r)$

$$\frac{\text{Rotor copper loss}}{2\pi T} = (n_s - n_r)$$

$$\frac{\text{Rotor copper loss}}{2\pi n_s T} = \frac{(n_s - n_r)}{n_s}$$

= Fractional slip

Rotor copper loss = Fractional slip x Input power to the rotor

$= S \times 2\pi n_s T$.

Torque : The torque production in an induction motor is more or less the same as in the DC motor. In the DC motor the torque is proportional to the product of the flux per pole and the armature current. Similarly in the induction motor the torque is proportional to the flux per stator pole, the rotor current and also the rotor power factor.

Thus we have,

Torque is proportionally = Stator flux x rotor current x rotor power factor.

Let E_1 be the applied voltage

Ø be the stator flux which is proportional to E_1

S be the fractional slip

R_2 be the rotor resistance

X_2 be the rotor inductive reactance at standstill

SX_2 be the rotor inductive reactance at fractional slip S

K be the transformation ratio between stator and rotor voltages

E_2 be the rotor induced emf and equal to SKE_1

I_2 be the rotor current,

Cosθ be the rotor power factor.

Z_2 be the rotor impendence.

We can conclude mathematically the following final results.

$$T \ \alpha \ Ø \, I_2 \cos\theta$$

This can be deduced in to a formula

$$T \propto \frac{SKE_1^2 R_2}{R_2^2 + S^2 X_2^2}$$

$$T \propto \frac{\text{Rotor copper loss}}{\text{Fractional slip}}$$

$$\text{Starting torque} \propto \frac{R_2}{R_2^2 + X_2^2} \quad \text{as fractional slip S = 1}$$

$$\text{Maximum torque} \propto \frac{1}{X_2}$$

where X_2 in inductive reactance of the rotor at standstill and is constant.

Motor torque calculation: Since the stator flux and induced rotor current for an induction motor are not easily measured, the torque equation $T = K \varnothing_s I_R \cos\theta_R$ is not the most practical equation to be used for determining a motor torque. Instead the Prony Brake torque equation described earlier may be used, provided the motor's output power and Rev/min are known.

$$\text{Output power in watts} = \frac{2\pi \text{ x torque x Rev/min}}{60}$$

$$\text{Torque (newton metres)} = \frac{(60 \text{ x output watts})}{(2\pi \text{ x Rev/min})}$$

$$= \frac{(9.55 \text{ x output watts})}{(\text{Rev/min})}$$

A motor's power may also be stated in British horsepower (hp). In this case the output power in watts will be equal to the output horsepower multiplied by 746 (1 hp = 746w).

In case the motor power is given in metric horsepower, the output power in watts will be equal to the metric horsepower, multiplied by 735.6 (1 metric horsepower = 735.6 watts).

Example

Determine the torque in Newton metres produced by a 5 hp squirrel cage motors rotating at 1440 r.p.m.

Assuming it is metric horsepower, output power in watts

= hp x 735.5

= 5 x 735.5 = 3677.5 Watts.

$$\text{Torque (Newton metres)} = \frac{(60 \text{ x } 3677.5)}{(2 \text{ x } 3.14 \text{ x } 1440)}$$

= 24.4 Newton metres.

Classification of squirrel cage motors

Objectives: At the end of this lesson you shall be able to

- **state the squirrel cage bar arrangement for different classes of induction motors say class A, B, C, D, E & F**
- **compare the starting torque, starting current and slip for different types of squirrel-cage motors.**

The three-phase squirrel cage motors have been standardised according to their electric characteristics into six types designated as design A, B, C, D, E and F. Standard squirrel cage induction motors which were of shallow, slot types are designated as class A. For this reason class A motors are used as a reference and are referred to as 'normal starting-torque', normal starting current, normal slip motors.

Classes of squirrel-cage motors

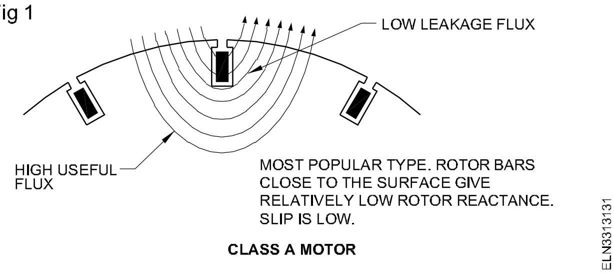
(According to starting characteristics)

Class	Starting torque	Starting	Current Slip
A	Normal	Normal	Normal
B	Normal	Low	Normal
C	High	Low	Normal
D	High	Low	High
E	Low	Normal	Low
F	Low	Low	Normal

Out of these six, four specific designs A through D are common squirrel cage motors. These four classes, however, cover nearly all practical applications of induction machines.

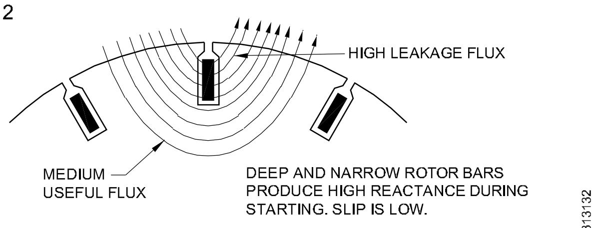
Class A motors: These motors are characterised by having a low rotor-circuit resistance and reactance. Its locked rotor current with full voltage is generally more than 6 times the full load current. Because of their low resistance, starting currents are very high. They operate at very small slips (s < 0.01) under full load. Machines in this class are suitable only in situations where very small starting torques are required. The rotor bar construction of such motor is shown in Fig 1.

Fig 1



Class B motors: These are general purpose motors of normal starting torque and starting current. The speed regulation at full load is low (usually under 5%) and the starting torque is in the order of 15% of the rated speed being lower for the lower speed and larger motors. It should be realised that although the starting current is low, it generally is 600% of full load value (Fig 2).

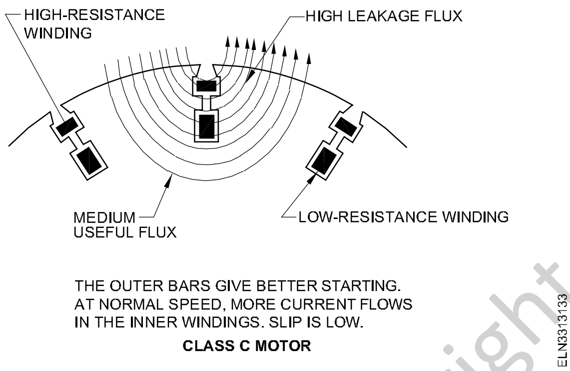
Fig 2



CLASS B MOTOR

Class C motors: Compared to class B motors, class C motors have higher starting torque, normal starting current and run at slips of less than 0.05 at full load. The starting torque is about 200% of the rated speed and the motors are generally designed to start at full-load. Typical application of this class motor is driving conveyors, reciprocating pumps, and compressors (Fig 3).

Fig 3



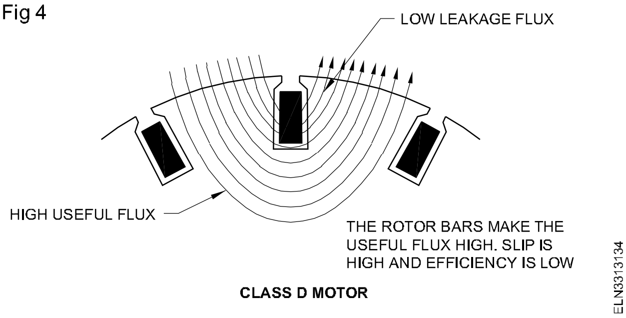
CLASS C MOTOR

Class D motors: These are high slip motors with high starting torque and relatively low starting current. As a result of the high full load slip, their efficiency is generally lower than that of the other motor classes. The peak of the torque speed curve, resulting in a starting torque of about 300%, is identical to the starting torque. (Fig 4)

Class E motor: The Fig 5 shows the class 'E' motor having Low starting torque and low current slip

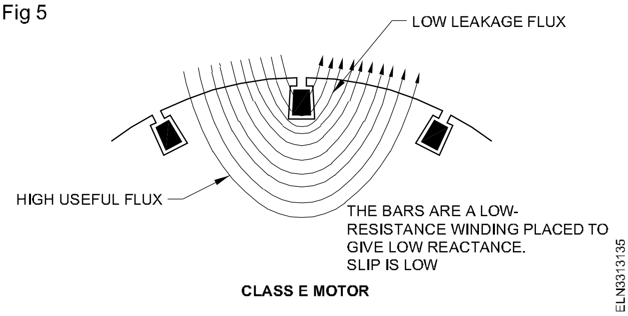
Class F motor: The Fig 6 shows the class 'F' motor having low starting torque and normal current slip

Fig 4



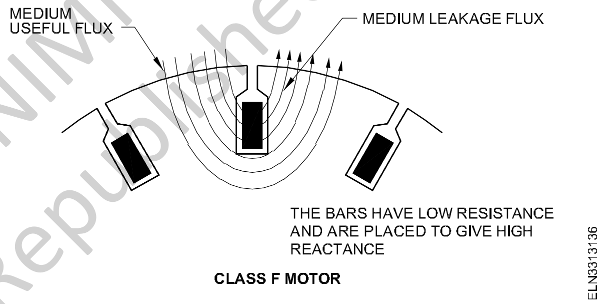
CLASS D MOTOR

Fig 5



CLASS E MOTOR

Fig 6



CLASS F MOTOR

Now when the motor is stationary, the frequency of the rotor current is the same as the supply frequency. But when the rotor starts revolving, then the frequency depends upon the relative speed or on slip speed. Let at any slip speed, the frequency of the rotor current be f', then

$$N_s - N = \frac{120f'}{p}$$

also, $N_s = \dfrac{120f}{p}$

Dividing one by the other, we get

$$\frac{f'}{f} = \frac{N_s - N}{N_s} = s \quad f' = sf$$

Insulation test on 3 phase induction motors

Objectives: At the end of this lesson you shall be able to

- **state the necessity for and the method of testing continuity and insulation resistance in a 3-phase induction motor**
- **state the necessity of continuity test before insulation test**
- **state the N.E. code and B.I.S. recommendations pertaining to insulation tests and earthing of a 3-phase induction motor.**

It is often said that electricity is a good servant but a bad master. This is because electricity is so useful but can cause accidents, and even death if one is careless. A large number of accidents, which occur in electrical motors, is due to leakage of current from the conducting part of the motor to the non-conducting part. The main reason is the weak insulation caused by the damaged insulation materials of the motor.

Insulation materials used on winding wires or in between winding wires and the slots of the laminated core, or the insulated sleeves of lead cables may get damaged due to the following reasons.

- Moisture content in the atmosphere (*Ex.* Electrical motors in harbours)
- Chemicals and their fumes in the surroundings (Ex. Electrical machines in chemical plants)
- High temperature of the surrounding (Ex. Electrical machines in steel rolling mill)
- High temperature emanating from the machine itself while working. (Ex. Electrical machines at hill tops where the cooling ability of the thin air is poor.)
- Dust, dirt, oil particles deposited on the windings and cables. (Ex. Electrical machines in cement plants, oil mills, chemical plants etc.)
- Aging of the machine.

When the insulation deteriorates, the insulation resistance value is reduced, and the current may leak to the frame of the electrical machine. If the machine is not properly earthed, the leakage currents may develop a dangerous potential on the frame. If somebody comes in contact with the frame, he may get even fatal shocks. These leakage currents also produce erroneous readings in the measuring equipment, and also affect the working of the other electrical equipments. As such the National Electrical Code has stipulated certain minimum standards for the insulation resistance value.

Method of testing insulation resistance of the electrical motor and the recommended value of the resistance as per National Electrical Code: Before putting into operation, the electrical motor must be tested for its insulation resistance. This is to make sure that there is no leakage between the current carrying parts of the motor and the non-current carrying metal parts of the motor. As insulation resistance may fail during the course of operation due to the reasons mentioned above, it is most necessary to check the insulation resistance at intervals, say once in a month, for any motor which is in operation, as a preventive maintenance check. These values of insulation resistance must be recorded in the maintenance card and whenever the value goes below the accepted value, the motor winding has to be dried and varnished to improve the conditions.

Condition and acceptable test results: According to NE code, the insulation resistance of each phase winding against the frame and between the windings shall be measured. A megohm-meter of 500V or 1000V rating shall be used. Star points should be disconnected while testing.

To avoid accidents due to weak insulations, first the insulation resistance value between any conducting part of the machine and the frame of the machine should be tested, and the measured value should not be lesser than one megohm as a thumb rule, or more precisely should not be less than a value based on the voltage and rated power of the motor as given in the National Electrical Code.

$$\text{Insulation resistance } R_i = \frac{20 \times E}{1000 + 2P}$$

where

R_1 is the insulation resistance in megohms at 25°C

E_n related phase-to-phase voltage and

P rated power in KW.

If the resistance is measured at a temperature different from 25°C, the value shall be corrected to 25°C.

General instruction for the measurement of insulation resistance: Insulation resistance of an electric motor may be in the range of 10 to 100 megohms but as it varies greatly in accordance with the temperature and humidity of the electric motor, it would be difficult to give a definite value. When the temperature of such a motor is raised, the insulation resistance will initially drop considerably, even below the acceptable minimum. If any suspicion exists on this score, the motor winding shall be dried out. The equation given above is used to calculate the insulation resistance as a standard value. However it should not be less than 1 megohm as an acceptable value.

Secondly, in the case of accidental leakage of currents from any current carrying part to non-current carrying metal part, there should be a ground system which should provide a minimum impedence path for the faulty (leakage) current to flow. Thereby protective devices like fuses or circuit-breakers or earth leakage circuit-breakers or earth fault relays would function and disconnect the supply to the defective motor circuit.

However, this will not be possible unless and until the ground (earth) system has minimum impedance. This could be achieved by the following means.

– Using low resistance earth continuity conductors between the frame of the motor and the earth electrode.

– Providing rust-proof metal parts like bolts, nuts and lugs for connecting the earth continuity conductor (ECC) with the frame as well as the main electrodes. (Galvanised nuts and bolts are to be used.)

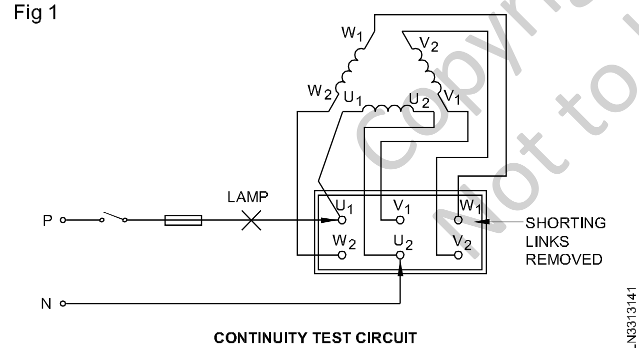
– Keeping the earth electrode resistance value as low as possible such that in case of leakage, any one unit of the protective system will operate to isolate the motor from the supply.

Necessity of continuity test before insulation test: While testing the insulation resistance between the winding and the frame, it is the usual practice to connect one prod of the Megger to the frame and the other prod to any one of the terminals of the winding. Likewise, when testing insulation resistance between windings, it is the usual practice to connect the two prods of the Megger to any two ends of a different winding. In all the cases it is assumed that the windings are in sound condition and the two ends of the same winding will be having continuity. However, it is possible the winding may have a break, and part of the winding may have a higher insulation resistance and the other part might have been grounded. Hence, to increase the reliability of the insulation resistance test, it is recommended that continuity test may be conducted in the motor before the insulation test, to be sure, that the winding is sound and the insulation resistance includes the entire winding.

Continuity test: The continuity of the winding is checked by using a test lamp in the following method as shown in Fig 1. First the links between the terminals should be removed.

The test lamp is connected in series with a fuse and a switch to the phase wire and the other end is connected to one of the terminals (say U_1 in Fig 1). The neutral of the supply wire is touched to the other terminals one by one. The terminal in which the lamp lights is the other end of the winding connected to the phase wire (say U_2 in Fig 1). The pairs are to be found in a similar manner. Lighting of the lamp between two terminals shows continuity of the winding. Lighting of the lamp between more than two terminals shows short between the windings.

Fig 1

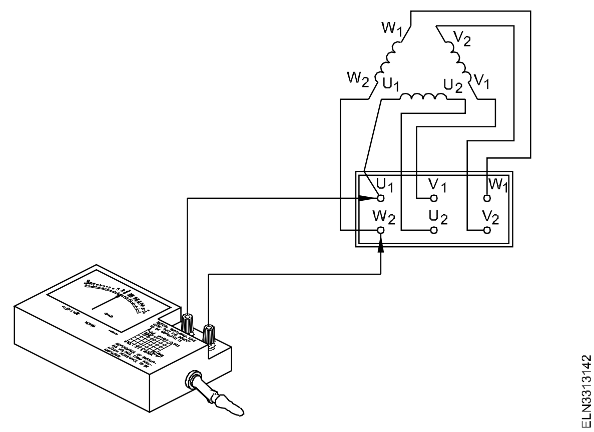


CONTINUITY TEST CIRCUIT

Limitations of lamp continuity test: However, this test only shows the continuity but will not indicate any short between the turns of the same winding. A better test would be to use an ohmmeter having an accurate low resistance range to measure the resistance of the individual windings. In a 3-phase induction motor, the resistance of the three windings should be the same, or more or less equal. If the reading is less in one winding, it shows that the winding is shorted.

Insulation test between windings: As shown in Fig 2, one of the Megger terminals is connected to one terminal of any one winding (say U_1 in Fig 2) and the other terminal of the Megger is connected to one terminal of the other windings (say W_2 in Fig 2).

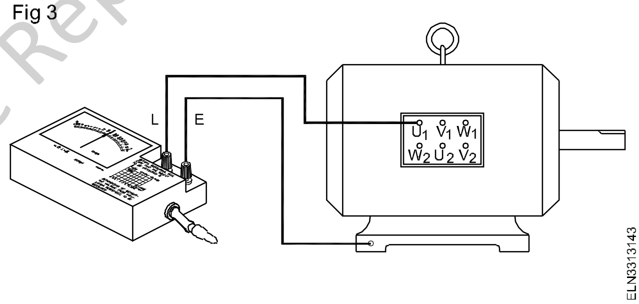
Fig 2



When the Megger handle is rotated at its rated speed, the reading should be more than one megohm. A lower reading than one megohm shows weak insulation between the windings, and needs to be improved. Likewise the insulation resistance between the other windings is tested.

Insulation resistance between windings and frame: As shown in Fig 3, one terminal of the Megger is connected to one of the phase windings, and the other terminal of the Megger is connected to the earthing terminal of the frame. When the Megger handle is rotated at the rated speed, the reading obtained should be more than one megohm. A lower reading than one megohm indicates poor insulation between the winding and the frame and needs to be improved by drying and varnishing the windings.

Fig 3



Likewise the other windings are tested.

Necessity of frame earthing: The frame of the electrical equipment/machine needs to be earthed because :

- the earthing system provides safety for persons and apparatus against earth faults.
- the object of an earthing frame is to provide as nearly as possible a surface under and around the motor which shall be of uniform potential, and as near zero or absolute earth potential, as possible.

According to I.E.rules, for reasons of safety, the frame of the motor has to be connected by two distinct earth connections to two earth electrodes with the help of properly sized earth continuity conductors. Further the earth system resistance (earth electrode 5 ohms and earth continuity conductor one ohm, if not specified) should be sufficiently low such that the protective devices in the motor circuit will operate and isolate the circuit in case of earth faults.

Starter for 3-phase induction motor - power control circuits - D.O.L starter

Objectives: At the end of this lesson you shall be able to
- **state the necessity of starters for a 3-phase induction motor and name the types of starters**
- **explain the basic contactor circuit with a single push-button station for start and stop**
- **state the function of the overload relay, different types of overload relays**
- **state the function of a no-volt coil, its rated voltage, position of operation, its common troubles, their causes and remedies.**

Necessity of starter: A squirrel cage induction motor just before starting is similar to a polyphase transformer with a short-circuited secondary. If normal voltage is applied to the stationary motor, then, as in the case of a transformer, a very large initial current, to the tune of 5 to 6 times the normal current, will be drawn by the motor from the mains. This initial excessive current is objectionable, because it will produce large line voltage drop, which in turn will affect the operation of other electrical equipment and lights connected to the same line.

The initial rush of current is controlled by applying a reduced voltage to the stator winding during the starting period, and then the full normal voltage is applied when the motor has run up to speed. For small capacity motors, say up to 3 Hp, full normal voltage can be applied at the start. However, to start and stop the motor, and to protect the motor from overload currents and low voltages, a starter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to the motor at the time of starting.

Types of starters: Following are the different types of starters used for starting squirrel cage induction motors.

- Direct on-line starter
- Star-delta starter
- Step-down transformer starter
- Auto-transformer starter

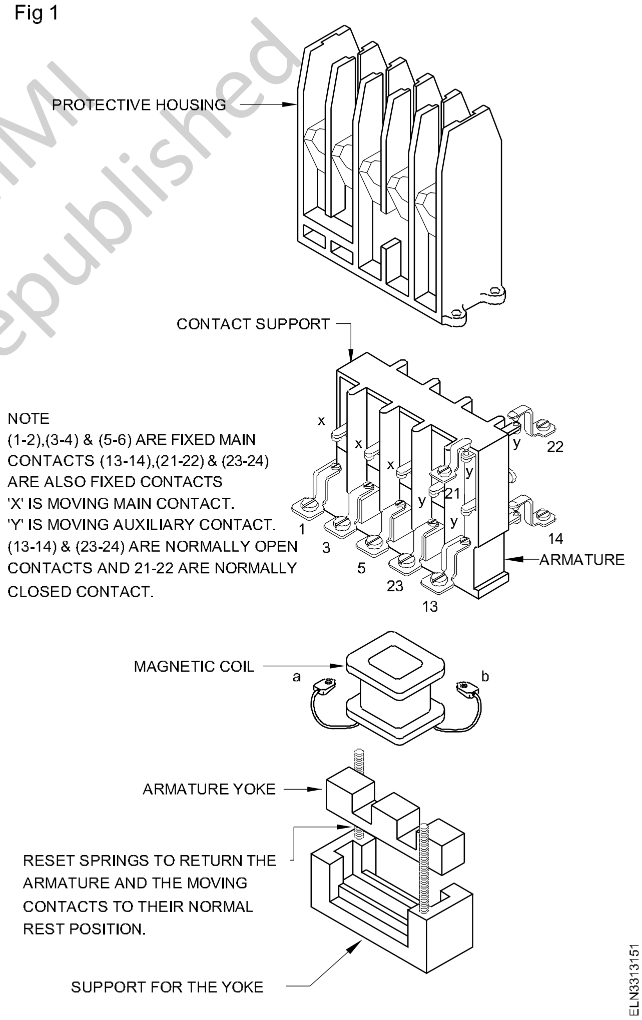
In the above starters, except for the direct on-line starter, reduced voltage is applied to the stator winding of the squirrel cage induction motor at the time of starting, and regular voltage is applied once the motor picks up the speed.

Selection of starter: Many factors must be considered when selecting starting equipment. These factors include starting current, the full load current, voltage rating of motor, voltage (line) drop, cycle of operation, type of load, motor protection and safety of the operator.

Contactors: The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 60 cycles per hour or more. It may be operated by hand (mechanical), electromagnetic, pneumatic or electro-pneumatic relays.

The contactors shown in Fig 1 consist of main contacts, auxiliary contacts and no-volt coil. As per Fig 1, there are three sets of normally open, main contacts between terminals 1 and 2, 3 and 4, 5 and 6, two sets of normally open auxiliary contacts between terminals 23 and 24, 13 and 14, and one set of normally closed auxiliary contact between terminals 21 and 22. Auxiliary contacts carry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an integrated part, but will have to be used as separate accessories along with the contactor to form the starter function.

Fig 1

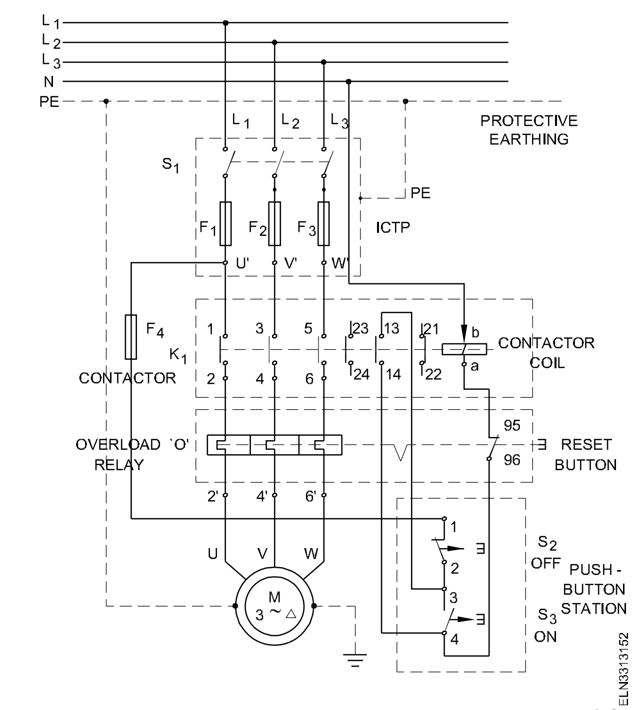


The main parts of a magnetic contactor are shown in Fig 1, and Fig 2 shows the schematic diagram of the contactor when used along with fused switches (ICTP), push-button stations and OL relay for connecting a squirrel cage motor for starting directly from the main supply. In the same way the direct on-line starter consists of a contactor, OL relay and push-button station in an enclosure.

Functional description

Power circuit: As shown in Fig 2, when the main ICTP switch is closed and the contactor K_1 is operated, all the three windings U V & W of the motor are connected to the supply terminals R Y B via the ICTP switch, contactor and OL relay.

Fig 2

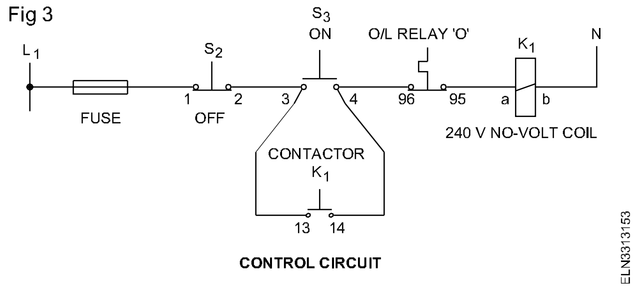


The overload current relay (bimetallic relay) protects the motor from overload (`motor protection'), while the fuses F1/F2/F3 protect the motor circuit in the event of phase-to-phase or phase-to-frame short circuits.

Control circuits

Push-button actuation from one operating location: As shown in the complete circuit Fig 2, and the control circuit Fig 3, when the `ON' push-button S_3 is pressed, the control circuit closes, the contactor coil is energised and the contactor K_1 closes. An auxiliary, a normally open contact 13,14 is also actuated together with the main contacts of K_1. If this normally open contact is connected in parallel with S_3, it is called a self-holding auxiliary contact.

Fig 3



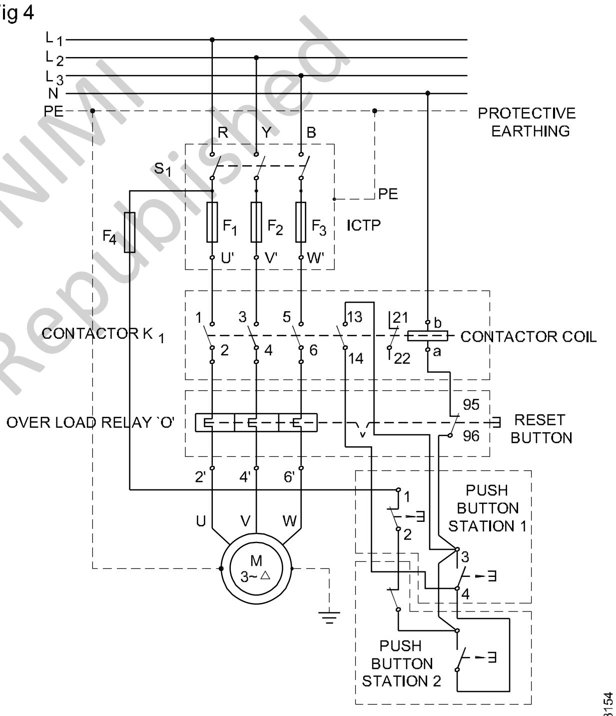
After S_3 is released, the current flows via this self-holding contact 13,14, and the contactor remains closed. In order to open the contactor, S_2 must be actuated. If S_3 and S_2 are actuated simultaneously, the contactor is unaffected.

In the event of overloads in the power circuit, the normally closed contact 95 and 96 of overload relay `O' opens, and switches off the control circuit. Thereby $K_1$ switches `OFF' the motor circuit. (Fig 3)

Once the contact between 95 and 96, is opened due to the activation of the overload relay `O', the contacts stay open and the motor cannot be started again by pushing the `ON' button S_3. It has to be reset to normally closed position by pushing the reset button. In certain starters, the reset could be done by pushing the `OFF' button which is in line with the overload relay `O'.

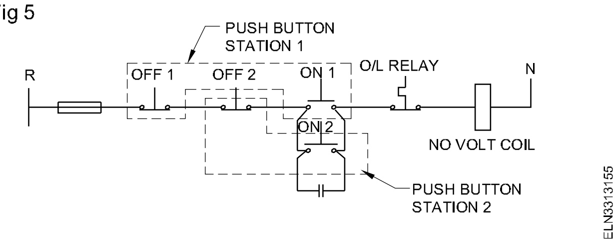
Push-button actuation from two operating locations: If it is desired to switch a contactor off and on from either of the two locations, the corresponding OFF push-buttons should be connected in series, and the ON push-buttons in parallel, as shown in the complete diagram Fig 4 and the control diagram Fig 5.

Fig 4



COMPLETE CIRCUIT DIAGRAM OF THE CONTACTOR AND THE 3 PHASE SQUIRREL CAGE INDUCTION MOTOR

Fig 5



If either of the two ON push-buttons is actuated, K_1 is energised and holds itself closed with the help of normally-open contact 13 & 14 which is closed by contactor K_1. If either of the two OFF push -buttons is actuated, the contactor opens.

Purpose of overload relays: The overload relays protect the motor against repeated, excessive momentary surges or normal overloads existing for long periods, or high currents caused in two phases by the single-phasing effect. These relays have characteristics which help the relay to open the contactor in 10 seconds if the motor current is 500 percent of the full load current, or in 4 minutes if the current is 150 percent of the full load current.

Types of overload relay

There are two types of overload relays. They are :

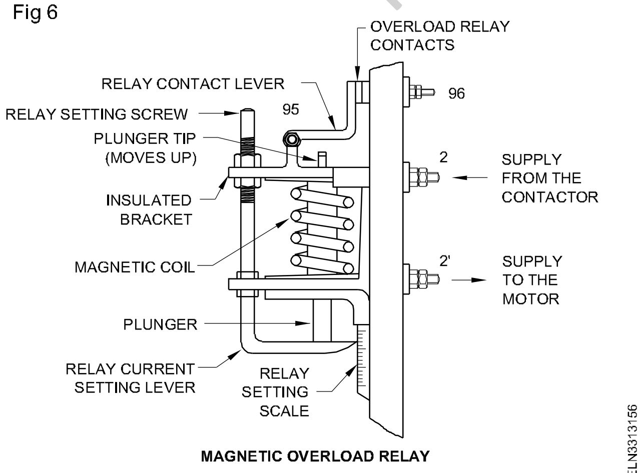
- magnetic overload relay
- thermal (bimetallic) overload relay.

Normally there are 3 coils in a magnetic relay and 3 sets of heater coils in a bimetallic relay so that two coils will operate in case of single phasing which help in avoiding the burning out of the motor.

Magnetic overload relay: The magnetic overload relay coil is connected in series with the motor circuits as shown in Fig 2. The coil of the magnetic relay must be wound with a wire, large enough in size to pass the motor current. As these overload relays operate by current intensity and not by heat, they are faster than bimetal relays.

As shown in Fig 6, the magnetic coil carries the motor current through terminals 2 and 2' which is in series with the power circuit. The relay contacts, 95 and 96, are in series with the control circuit. When a current more than a certain stipulated value, as set by the relay set scale, passes through the power circuit, the magnetic flux produced by the coil will lift the plunger in an upward direction. This upward movement makes the plunger tip to push the relay contact lever, and the contact between terminals 95 and 96 opens. This breaks the no volt coil circuit and the contactor opens the power circuit to the motor. The relay contacts between terminals 95 and 96 stay open till the rest-button (not shown in the figure) is pressed.

Fig 6



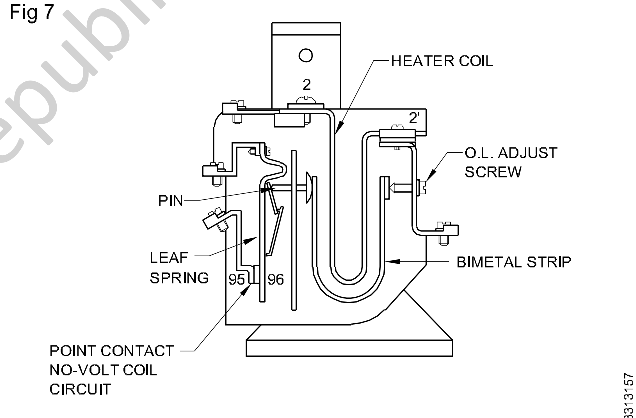
MAGNETIC OVERLOAD RELAY

Bimetallic overload relays: Most bimetallic relays can be adjusted to trip within a range of 85 to 115 per cent of the nominal trip rating of the heater unit. This feature is useful when the recommended heater size may result in unnecessary tripping, while the next larger size will not give adequate protection. Ambient temperatures affect thermally-operated overload relays.

The tripping of the control circuit in the bimetallic relay results from the difference of expansion of two dissimilar metals fused together. Movement occurs if one of the metal expands more than the other when subjected to heat. A U-shaped bimetallic strip is used in the relay as shown in Fig 7. The U-shaped strip and a heater element inserted in the centre of the U compartments for avoiding possible uneven heating due to variations in the mounting location of the heater element.

As shown in Fig 7, under normal conditions, the bimetallic strip pushes the pin against the leaf-spring tension, and the point contacts 95 and 96 are in a closed position, and hence the no-volt coil circuit is completed while the motor is running. When a higher current passes through the heater coil connected to terminals 2 and 2', the heat generated in the coil heats up the bimetal strip which bends inward. Hence the pin retracts in the right hand direction and the leaf-spring opens the contact between 95 and 96 to open the contactor. The relay cannot be reset immediately as the heat in the bimetallic strips require some time for cooling.

Fig 7



BIMETALLIC OVERLOAD RELAY

Relay setting: The overload relay unit is the protection centre of the motor starter. Relays come in a number of ranges. Selection of a relay for a starter depends upon the motor type, rating and duty.

For all direct on-line starters, relays should be set to the actual load current of the motor. This value should be equal to or lower than the full load current indicated on the name-plate of the motor. Described here is a simple procedure for setting the relay to the actual load current.

Set the relay to about 80% of the full load current. If it trips, increase the setting to 85% or more till the relay holds. The relay should never be set at more than the actual current drawn by the motor. (The actual current drawn by a motor will be less than the full load current in most cases, as motors may not be loaded to capacity.)

Tripping of starters: A starter may trip due to the following reasons.

- Low voltage or failure of power supply
- Persistent overload on the motor

In the first instance, the tripping occurs through the coil which opens the contacts when the voltage falls below a certain level. The starter can be restarted as soon as the supply is back to normal.

The relay trips the starter when there is an overload. It can be restarted only after the relay is reset and the load becomes normal.

No-volt coil: A no-volt coil consists of generally more number of turns of thin gauge of wire.

Coil voltages: Selection of coils depends on the actual supply voltage available. A wide variety of coil voltages like 24V, 40V, 110V, 220 V (or) 230/250 V, 380V (or) 400/ 440V AC or DC are available as standard for contactors and starters.

Troubleshooting in contactor: Table 1 gives the common symptoms their causes and remedies.

Table 1

Symptoms	Causes	Remedies
Motor does not start when the 'start' button is pressed. However on pressing the armature of the contactor manually, motor starts and runs.	Open in no-volt coil circuit.	Check the main voltage for lower than acceptable value. Rectify the main voltage. Check the control circuit wiring for loose connection. Check the resistance of the no-volt coil winding. If found incorrect replace the coil.
Motor starts when `ON' button is pressed. It however stops immediately when `ON' button is released.	Auxiliary contact in parallel with the start-button is not closing.	Check the parallel connection from `ON' button terminals to the auxiliary contact of the contactor. Rectify the defect. Check the auxiliary contact points of the contactor for erosion and pittings. Replace, if found defective.
Motor does start when the start-button is pressed. However, a humming or chattering noise comes from the starter.	Movable armature and fixed limb of electromagnet are not stably attracted.	Dust or dirt or grit between the mating surfaces of the electromagnetic core. Clean them. Low voltage supply. Find the cause and rectify the defect. Break in the shading ring in the case of AC magnet.
Failure of contactor due to too much heating of the `No' volt coil.	Higher incoming supply rating. No-volt coil rating is not high.	Higher supply voltage than normal. Reduce the incoming voltage. Voltage rating of the no-volt coil is less. Replace with standard rating, according to the main supply.
Motor does not restart immediately after tripping of OL relay even though OL relay was reset.	It takes a little time for the thermal bimetal to cool and reset.	Wait for 2 to 4 minutes before re-starting.
Coil does not get energised even though supply voltage is found across the no-volt coil terminals.	Open-circuited NVC. NVC burnt out.	Check the nylon strip on relay. Check the nylon button below the start button Replace, if necessary.
Relay coil has been changed. However motor does not start when the start-button is pressed.	Control circuit of relay open.	Check the control circuit for open. Clean the control station contacts. Overload relay not reset.

Symptoms	Causes	Remedies
Humming or chattering noise.	Low voltage. Magnetic face between yoke and armature is not clean. Shading ring on iron core missing.	Feed the rated voltage. Clean the surfaces of yoke and armature. Provide shading ring in the iron core

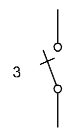
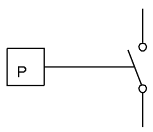
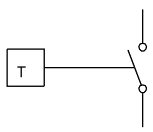
B.I.S. symbols pertaining to contactor and machines

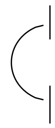
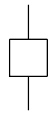
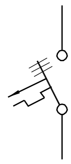
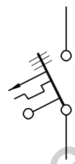
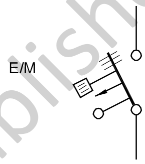
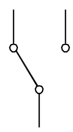
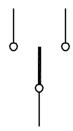
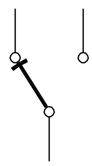
Objective: At the end of this lesson you shall be able to

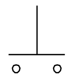
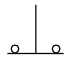
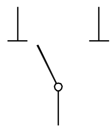
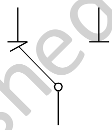
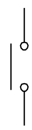
- **identify B.I.S. symbols pertaining to rotating machines and transformers (BIS 2032 Part IV), contactors, switch, gear and mechanical controls (BIS 2032 Part VII, 2032 Part XXV and XXVII).**

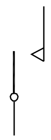
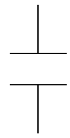
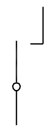
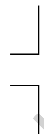
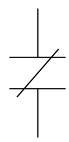
The table given below contains most of the important symbols used by an electrician. However, you are advised to refer to the quoted B.I.S. standards for further additional information.

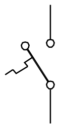
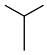
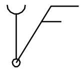
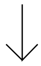
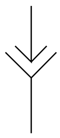
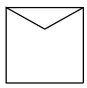
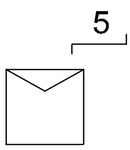
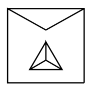
Table

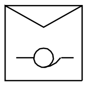
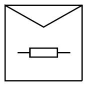
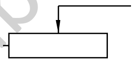
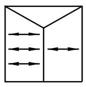
S.No.	BIS Code No.	Description	Symbol	Remarks
	BIS 2032 (Part XXV)-1980			
	9	**Switch gear, accessories**		
1	9.1	Switch, general symbol		
2	9.1.1	Alternate symbol for switch.		
3	9.2	Three-pole switch, single line representation.		
4	9.2.1	Alternate symbol for three-pole switch, single line representation.		
5	9.3	Pressure switch		
6	9.4	Thermostat		
7	9.5	Circuit-breaker		

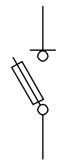
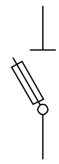
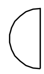
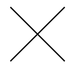
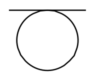
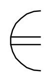
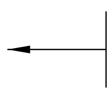
S.No.	BIS Code No.	Description	Symbol	Remarks
8	9.5.1	Alternate symbol of circuit-breaker. **Note : The rectangle of symbol 9.5 should contain some indication that a circuit-breaker is connected.**		
9	9.5.2	Alternate symbol for circuit breaker.		
10	9.5.3	Circuit-breaker with short circuit under voltage and thermal overload releases.		
11	9.5.4	Hand-operated circuit-breaker with short circuit, thermal overload protection and no-volt tripping.		
12	9.5.5	Motor - solenoid operated air circuit-breaker with short circuit and no-volt tripping (triple pole).		
13	9.6	Change over contact, break before make. NOTE : The fixed contacts may be placed at any angle except at 60°. In order to facilitate the work of the draughtsman, the contacts may be arranged differently.		
14	9.7	Two-way contact with neutral position		
15	9.8	Make-before-break contact.		
16	9.9	Contactor, normally open.		
17	9.9.1	Contactor, normally closed.		

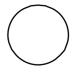
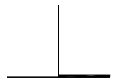
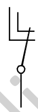
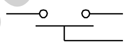
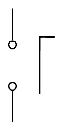
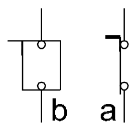
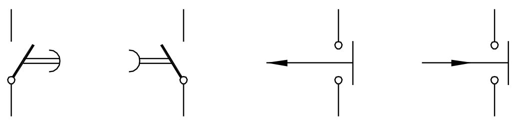
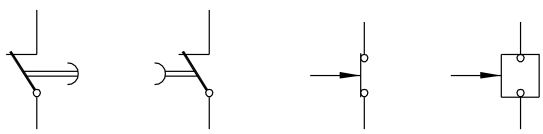
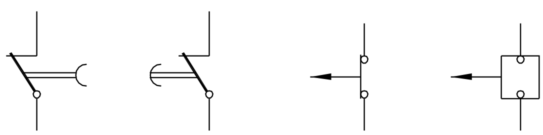
S.No.	BIS Code No.	Description	Symbol	Remarks
18	9.10	Push-button with normally open contact.		
19	9.10.1	Push-button with normally closed contact.		
20	9.11	Isolator.		
21	9.12	Two-way isolator with interruption of circuit.		
22	9.13	Two-way isolator without interruption of circuit.		
23	9.14	Make contact, general symbol.		
24	9.14.1	Alternate symbol for make contact, general symbol.		
25	9.14.2	Alternate symbol for make-contact.		
26	9.14.3	Alternate symbol for make-contact.		
27	9.14.4	Alternate symbol for make-contact.		
28	9.14.5	Alternate symbol for make-contact.		

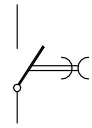
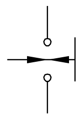
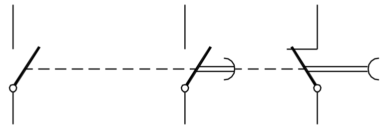
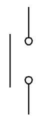
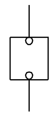
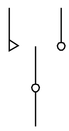
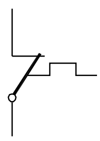
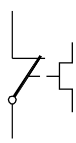
S.No.	BIS Code No.	Description	Symbol	Remarks
29	9.14.6	Alternate symbol for make-contact.		
30	9.14.7	Alternate symbol for make-contact.		
31	9.14.8	Alternate symbol for make-contact.		
32	9.14.9	Alternate symbol for make-contact.		
33	9.15	Break-contact, general symbol.		
34	9.15.1	Alternate symbol for break-contact.		
35	9.15.2	Alternate symbol for break-contact.		
36	9.15.3	Alternate symbol for break-contact.		
37	9.15.4	Alternate symbol for break-contact.		
38	9.15.5	Alternate symbol for break-contact.		

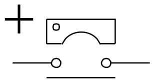
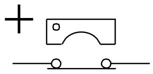
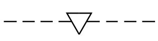
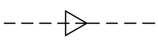
S.No.	BIS Code No.	Description	Symbol	Remarks
39	9.16	Thermal overload contact.		
40	9.17	Socket (female).		
41	9.17.1	Alternate symbol for socket (female).		
42	9.17.2	Socket with switch.		
43	9.18	Plug (male).		
44	9.18.1	Alternate symbol for plug (male).		
45	9.19	Plug and socket (male and female).		
46	9.19.1	Alternate symbol for plug and socket (male and female).		
47	9.20	Starter, general symbol.		
48	9.21	Starter by steps (Example: 5 steps).		
49	9.22	Star-delta starter.		

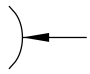
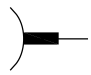
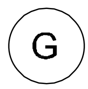
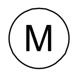
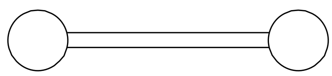
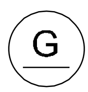
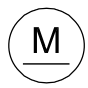
S.No.	BIS Code No.	Description	Symbol	Remarks
50	9.23	Auto-transformer starter.		
51	9.24	Pole-changing starter (Example, 8/4 poles).		
52	9.25	Rheostatic starter.		
53	9.26	Direct on-line starter.		
54	9.27	Sliding contact, general symbol.		
55	9.27.1	Resistor with moving contact, general symbol.		
56	9.28	Combined control panel for two motors (multiple speed and reversible).		
57	9.29	Fuse.		
58	9.29.1	Alternate symbol for fuse.		
59	9.29.2	Alternate symbol for fuse where supply side is indicated by a thick line.		
60	9.29.3	Alternate symbol for fuse where supply side is indicated by a thick line.		

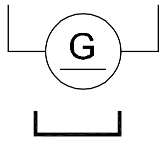
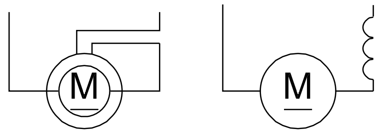
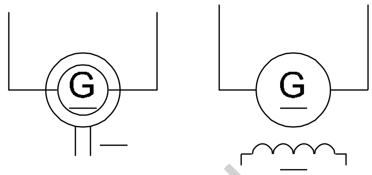
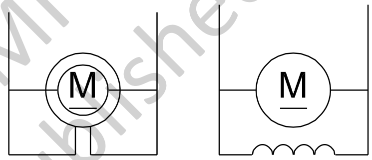
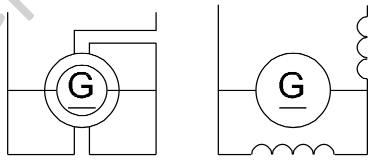
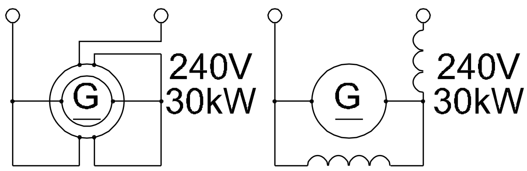
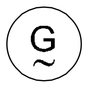
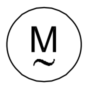
S.No.	BIS Code No.	Description	Symbol	Remarks
61	9.30	Isolating fuse-switch, switching on load.		
62	9.31	Isolating fuse-switch.		
	BIS 2032 Part(XXV11) 1932	**Contactors**		
	3.2	**Qualifying symbols**		
63	3.2.1	Contactor function.		
64	3.2.2	Circuit-breaker function.		
65	3.2.3	Disconnector (isolator) function.		
66	3.2.4	Switch-disconnector (isolator switch) function.		
67	3.2.5	Automatic release function.		
68	3.2.6	Delayed action. Convention - delayed action in direction of movement from the arc towards its centre. **Note: This symbol must be linked by a double line to the symbol of the device, the action of which is delayed.**	 	
69	3.2.6.1	Delayed action convention - delayed action in the direction of movement of the arrow mark.		

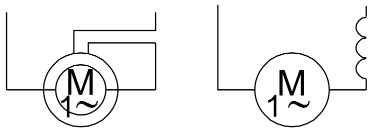
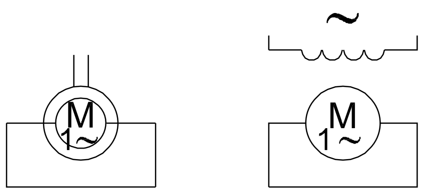
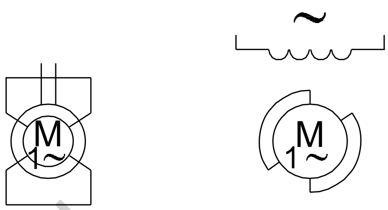
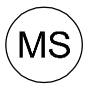
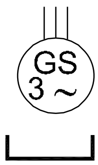
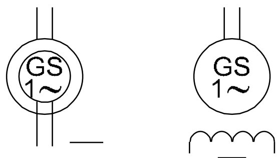
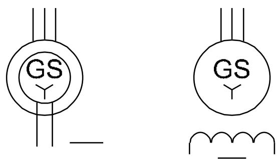
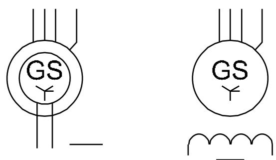
S.No.	BIS Code No.	Description	Symbol	Remarks
70	3.2.7	Non-spring return (stay put) function. NOTE : The symbols shown above may be used to indicate spring-return and stay-put contacts. When this convention is invoked, its use should be appropriately referenced. These symbols should not be used together with the qualifying symbols Nos. 3.1 to 3.4.		
71	3.2.8	Hand reset.		
72	3.3.7	Contact with two makes.		
73	3.3.8	Contact with two breaks.		
74	3.3.9	Three-point contact.		
75	3.3.10	Make contact-hand reset.		IR
76	3.3.11	Break contact-hand reset.		IR
77	3.3.19	Make-contact delayed when operating.		
78	3.3.20	Break-contact delayed when operating.		
79	3.3.21	Break-contact delayed when releasing.		

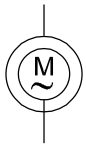
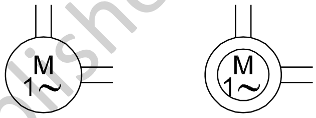
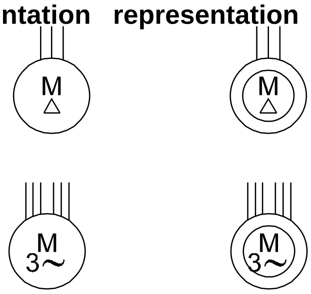
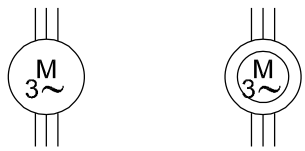
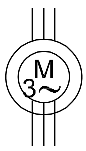
S.No.	BIS Code No.	Description	Symbol	Remarks
80	3.3.22	Make-contact delayed when operating and releasing.		
81	3.3.23	Contact assembly with one make-contact not delayed. One make contact delayed when operating and one break-contact delayed when releasing.		
82	3.3.24	Make-contact with spring return.		
83	3.3.25	Make-contact without spring return (stay-put)		 SR
84	3.3.26	Break-contact with spring return.		 SR
85	3.3.27	Two-way contact with centre off position with spring. Return from the left-hand position but not from the right hand one (stay-put).		
86	3.3.28	Temperature-sensitive make-contact. **Note: May be replaced by the value of the operating temperature conditions.**		
87	3.3.29	Temperature sensitive break-contact. NOTE : may be replaced by the value of the operating temperature conditons.		
88	3.3.30	Self-operating thermal-break contact. NOTE : It is important to distinguish between a contact as shown and a contact of a thermal relay, which in detached representation is shown in the example below.		
		Example: Break contact of a thermal relay.		

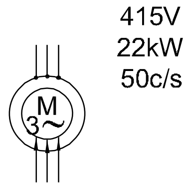
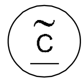
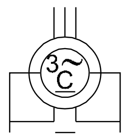
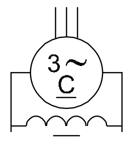
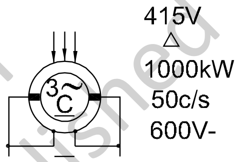
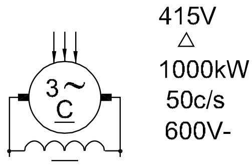
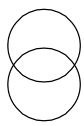
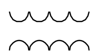
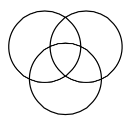
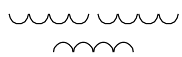
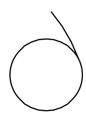
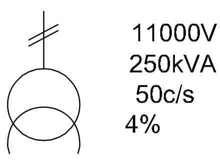
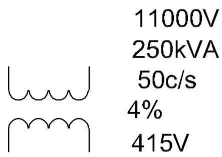
S.No.	BIS Code No.	Description	Symbol	Remarks
89	3.3.32	Blow-out magnetic make-contact.		
90	3.3.33	Blow-out magnetic break-contact.		
	BIS:2032 (PART VII) 1974	**Mechanical controls**		
91	8.4	**Mechanical interlock**		
92	8.5	Reset a Automatic reset b Non-automatic reset **Note : These symbols should be used only if it is essential to indicate the type of reset.**	 	
	BIS:2032 (Part IV) 1964	**Classification** In this standard, more than one symbol have been used to designate the same type of rotating machine or transformer depending on the type and class of drawing involved. For the same type of rotating machines, in simplified as well as in the complete, multi-line symbols have been specified. In the case of transformers, symbols for single line and multi-line representation have been given separately. Wherever single line representation is required for rotating machines, reference may be made to IS:2032(Part II)-1962. Elements of symbols		
93	3.14	Winding Note: The number of half circles is not fixed, but if desired a distinction might be made for the different windings of a machine as specified in 3.2,3.3 and 3.4.		
94	3.24	Commutating or compensating winding.		
95	3.34	Series winding.		

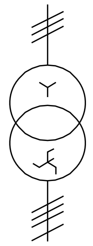
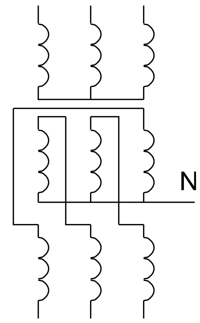
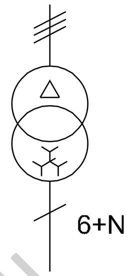
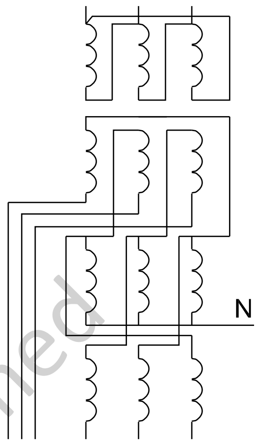
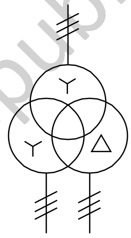
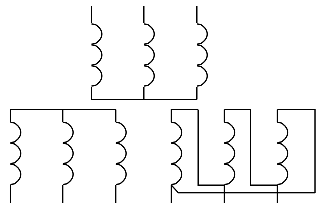
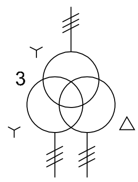
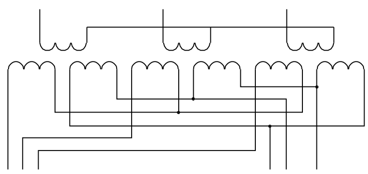
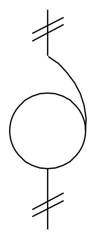
S.No.	BIS Code No.	Description	Symbol	Remarks
96	3.44	Shunt winding or separate winding.		
97	3.54	Brush or slip-ring.		
98	3.64	Brush on commutator.		
99	3.74	**Supplementary indications, numerical data.** **Supplementary indications (method of connecting windings, letter M, G or C and numerical data) are shown only on one symbol for each class of machine, as an example.**		
	4	**Rotating machines**		
	4.1	**General symbols**		
100	4.1.14	Generator		
101	4.1.2	Motor		
102	4.1.3	Machine capable of use as generator or motor.		
103	4.1.4	Mechanically coupled machines. **Note: Other special types of coupling, that is, monobloc construction, shall be suitably indicated wherever necessary.**		
	4.2	**Direct current machine**		
104	4.2.1	Direct current generator, general symbol.		
105	4.2.2	Direct current motor, general symbol.		

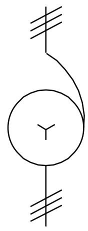
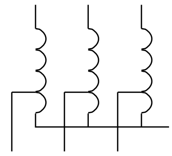
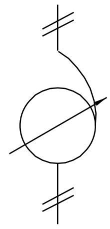
S.No.	BIS Code No.	Description	Symbol	Remarks
106	4.2.3	DC 2-wire permanent magnet generator(G) or motor (M).		
			Simplified multiline representation **Complete multiline representation**	
107	4.2.4	DC 2-wire series generator (G) or motor (M).		
108	4.2.5	DC 2-wire generator (G) or motor (M) separately excited.		
109	4.2.6	DC 2-wire shunt generator (G) or motor (M).		
110	4.2.7	DC 2-wire generator (G) or motor (M), compound-excited, short shunt.		
111	4.2.8	Symbol showing terminals, brushes and numerical data. *Example* : DC 2-wire generator compound excited short shunt, 240 V, 30 KW.		
	4.3	**Alternating current machines**		
112	4.3.1	AC generator, general symbol.		
113	4.3.2	AC motor, general symbol.		
	4.4	**Alternating current Commutator machines.**	**Simplified multiline representation** **Complete multiline representation**	

S.No.	BIS Code No.	Description	Symbol	Remarks
114	4.4.1	AC series motor, single phase.		
115	4.4.2	Repulsion motor, single phase.		
116	4.4.3	AC series motor, single phase, Deri type.		
	4.5	**Synchronous machines**		
117	4.5.1	Synchronous generator, general symbol.		
118	4.5.2	Synchronous motor - general symbol.		
119	4.5.3	Permanent magnet synchronous generator (GS) or synchronous motor (MS), three-phase.		
			Simplified multiline representation **Complete multiline representation**	
120	4.5.4	Synchronous generator (GS) or synchronous motor (MS) single-phase.		
121	4.5.5	Synchronous generator (GS) or synchronous motor (MS) three-phase, star-connected, neutral not brought out.		
122	4.5.6	Synchronous generator (GS) or synchronous motor (MS) three-phase star-connected with neutral brought out.		

S.No.	BIS Code No.	Description	Symbol	Remarks
	4.6	**Induction Machines**		
		Note : In symbols 4.6.1 to 4.6.9 groups of conductors may be placed in another manner than generally shown below. For example, symbol 4.6.6.		
123	4.6.1	Induction motor, with short-circuited rotor, general symbol.		
124	4.6.2	Induction motor, with wound rotor, general symbol.		
125	4.6.3	Induction motor, single phase, squirrel-cage.		
126	4.6.4	Induction motor, single phase, squirrel cage, leads of split-phase brought out.		
			Simplified multiline representation **Complete multiline representation**	
127	4.6.5	Induction motor, three-phase, squirrel-cage.		
128	4.6.6	Induction motor, three-phase, squirrel cage, both leads of each phase brought out.		
129	4.6.7	Induction motor, three-phase, with wound rotor.		
130	4.6.8	Induction motor, three-phase, star-connected, with automatic starter in the rotor.		

S.No.	BIS Code No.	Description	Symbol	Remarks
131	4.6.9	Symbol showing terminals, brushes and numerical data. *Example* : Induction motor, three-phase, with wound rotor 415V, 22 kW, 50 c/s.		
	4.7	**Synchronous converters.**		
132	4.7.1	Synchronous converter, general symbol.		
133	4.7.2	Three-phase synchronous converter, shunt excited. 72	 	
134	4.7.3	Symbol showing terminals, brushes and numerical data. *Example* : Three-phase synchronous converter, shunt excited 600 V, 1000 kW, 50 c/s.	 	
	5	**Transformers**		
	5.1	**General symbols**		
135	5.1.1	Transformer with two separate windings.	 **Simplified multiline representation**  **Complete multiline representation**	
136	5.1.2	Transformer with three separate windings.	 	
137	5.1.3	Auto-transformers	 	
	5.2	**Transformers with two or three Windings.**		
138	5.2.1	Single-phase transformer with two separate windings.	 	

S.No.	BIS Code No.	Description	Symbol	Remarks
139	5.2.4	Three-phase transformer with two separate windings. Connection: star zig-zag.		
140	5.2.5	Three-phase transformer with two separate windings. Connection: delta 6-phase fork.		
141	5.2.6	Three-phase transformer with three separate windings. Connection: star, star-delta.	 **Simplified multiline representation**	 **Complete multiline representation**
142	5.2.7	Three-phase bank of single-phase transformers with three separate windings. Connection : star, star-delta.		
	5.3	**Auto-transformers**		
143	5.3.1	Auto-transformer, single-phase.		

S.No.	BIS Code No.	Description	Symbol	Remarks
144	5.3.2	Auto-transformer, three-phase. Connection:star.		
145	5.3.3	Single-phase auto-transformer with continuous voltage regulation.		

D.O.L. starter

Objectives: At the end of this lesson you shall be able to
- **state the specification of a D.O.L. starter, explain its construction, operation and application**
- **explain the necessity of a back-up fuse and its rating according to the motor rating.**

A D.O.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated in an enclosure.

Construction and operation: A push-button type, direct on-line starter, which is in common use, is shown in Fig 1. It is a simple starter which is inexpensive and easy to install and maintain.

There is no difference between the complete contactor circuit explained in Exercise 3.1.04 and the D.O.L.starter, except that the D.O.L. starter is enclosed in a metal or PVC case, and in most cases, the no-volt coil is rated for 415V and is to be connected across two phases as shown in Fig 1. Further the overload relay can be situated between ICTP switch and contactor,or between the contactor and motor as shown in Fig 1, depending upon the starter design. Trainees are advised to write the working of the D.O.L. starter on their own

Specification of D.O.L. starters: While giving specification, the following data are to be given.

D.O.L. STARTER

Phases - single or three.

Voltage 240 or 415V.

Current rating 10, 16, 32, 40, 63, 125 or 300 amps.

No-volt coil voltage rating AC or DC 12, 24, 36, 48, 110, 230/250, 360, 380 or 400/440 volts.

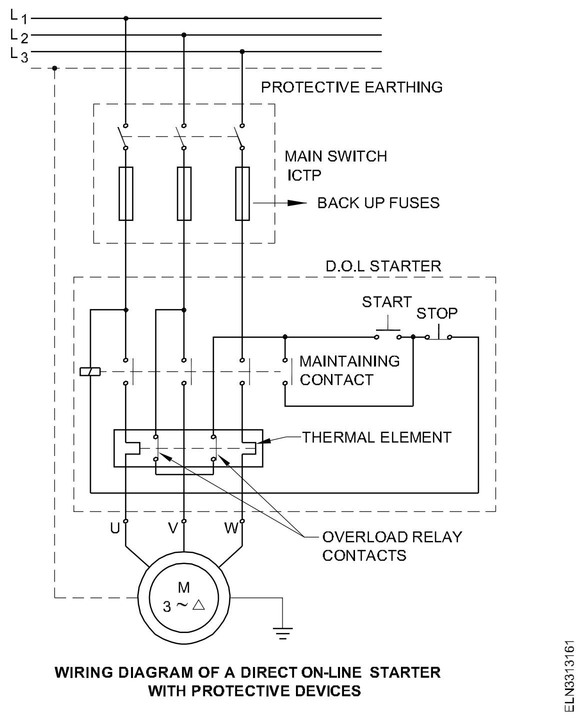
Number of main contacts 2, 3 or 4 which are normally open.

Number of auxiliary contacts 2 or 3. 1 NC + 1 NO or 2 NC + 1 NO respectively.

Push-button - one `ON' and one `OFF' buttons.

Overload from setting – amp-to-amp. Enclosure - metal sheet or PVC.

Fig 1



WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES

Applications: In an induction motor with a D.O.L. starter, the starting current will be about 6 to 7 times the full load current. As such, D.O.L. starters are recommended to be used only up to 3 HP squirrel cage induction motors, and up to 1.5 kW double cage rotor motors.

Necessity of back-up fuses: Motor starters must never be used without back-up fuses. The sensitive thermal relay mechanism is designed and calibrated to provide effective protection against overloads only. When sudden short circuits take place in a motor circuit, the overload relays, due to their inherent operating mechanism, take a longer time to operate and open the circuit. Such delays will be sufficient to damage the starter motor and connected circuits due to heavy in-rush of short circuit currents. This could be avoided by using quick-action, high-rupturing capacity fuses which, when used in the motor circuit, operate at a faster rate and open the circuit. Hence H.R.C. diazed (DZ) type fuses are recommended for protecting the installation as well as the thermal overload relay of the motor starter against short circuits. In case of short circuits, the back-up fuses melt and open the circuit quickly. A reference table indicating fuse ratings for different motor ratings is given.

It is recommended that the use of semi-enclosed, rewirable, tinned copper fuses may be avoided as for as possible.

The given full load currents apply in the case of single phase, capacitor-start type motors, and in the case of 3-phase, squirrel cage type induction motors at full load having average power factor and efficiency. The motors should have speeds not less than 750 r.p.m.

Fuses upto and including 63 A are DZ type fuses. Fuses from 100 A and above are IS type fuses (type HM).

Table of relay ranges and back-up fuses for motor protection

Sl. No.	Motor ratings 240V 1-phase			Motor ratings 415V 3-phase			Relay range A	Nominal back-up fuse recommended
	hp	kW	Full load current	hp	kW	Full load current	a	c
1				0.05	0.04	0.175	0.15 - 0.5	1A
2	0.05	0.04		0.1	0.075	0.28	0.25 - 0.4	2A
3				0.25	0.19	0.70	0.6 - 1.0	6A
4	0.125	0.11		0.50	0.37	1.2	1.0 - 1.6	6A
5	0.5	0.18	2.0	1.0	0.75	1.8	1.5 - 2.5	6A
6	0.5	0.4	3.6	1.5	1.1	2.6	2.5 - 4.0	10A
7				2.0	1.5	3.5	2.5 - 4.0	15A
8	0.75	0.55		2.5	1.8	4.8	4.0 - 6.5	15A
9				3.0	2.2	5.0	4.0 - 6.5	15A
10	1.0	0.75	7.5	5.0	3.7	7.5	6.0 - 10	20A
11	2.0	1.5	9.5	7.5	5.5	11.0	9.0 - 14.0	25A
12	3.0	2.25	14	10.0	7.5	14	10.0 - 16.0	35A

Numerical problems in ac 3-phase induction motors

Objective: At the end of this lesson you shall be able to
- **solve the numerical problems in 3 phase induction motor.**

On very many occasions, an electrician may be asked to wire up a workshop well before the proposed machine is installed, having been provided with information only regarding the voltage rating and horsepower of the electrical motor.

While planning the wiring, the cable sizes need to be selected, based upon the full load current of the motor which could be calculated when sufficient data is available. The examples given below illustrate the method of determining the full-load current when other data are provided or vice versa.

To illustrate:

The output of the motor is given in metric horsepower.

Output of the motor = Metric HP x 735.6 watts.

Input of the motor = $\sqrt{3}\, E_L\, I_L\, \text{Cos}\,\theta$ watts

where E_L is the line voltage

I_L is the line current

Cos θ is the power factor

Also input = output + losses

= output + copper loss + iron loss + mechanical losses like windage, friction etc.

Efficiency of the motor = $\frac{\text{Output}}{\text{Input}} \times 100$

$= \frac{\text{Metric horsepower} \times 735.5}{\sqrt{3} E_L I_L \cos\theta}$

Example 1

A 3-phase, 6000 volts, star-connected induction motor develops 200 HP (Metric). Calculate the full load current per phase if the efficiency of the motor is 85% and the power factor is 0.8.

Input $= \frac{\text{Output} \times 100}{\text{Efficiency}}$

$= \sqrt{3} E_L I_L \cos\theta$

Line current $I_L = \frac{\text{Output} \times 100}{\text{Efficiency} \times E_L \cos\theta \times \sqrt{3}}$

$= \frac{200 \times 735.5}{0.85 \times \sqrt{3} \times 6000 \times 0.8}$

= 20.81A

In star, as the line current is equal to the phase current, we have the phase current at full load - 20.9 amps.

Example 2

A 3-phase, induction motor takes a current of 100 amps from 400V 50 HZ supply. Determine the power factor if the output of the motor is 70 HP (metric) and the efficiency is 90%.

Input $= \frac{\text{Output}}{\text{Efficiency}}$

$\sqrt{3} E_L I_L \cos\theta = \frac{70 \times 735.5}{\frac{90}{100}}$

$\cos\theta = \frac{70 \times 735.5 \times 100}{90 \times \sqrt{3} \times 400 \times 100}$

Power factor = 0.82.

Example 3

A 3-phase, 400V, 50 HZ, delta-connected induction motor draws a line current of 150 amps with a P.F. of 0.85 and is delivering an output of 100 (Metric) HP. Calculate the efficiency.

% of efficiency $= \frac{\text{Output} \times 100}{\text{Input}}$

$= \frac{100 \times 735.5 \times 100}{\sqrt{3} \times 400 \times 150 \times 0.85}$

= 83.3 %

Example 4

A 3-phase, 400 V, induction motor takes a line current of 30 amperes with a power factor of 0.9. The efficiency of the motor is 80%. Calculate the output in metric horsepower.

Output in watts = Input x Efficiency

$= \frac{\sqrt{3} \times 400 \times 30 \times 0.9 \times 80}{100}$

Output in metric HP $= \frac{\text{Output in watts}}{735.5}$

$= \frac{\sqrt{3} \times 400 \times 30 \times 0.9 \times 80}{100 \times 735.5}$

= 20.3 HP.

Jogging (inching) control circuits for motors

Objectives: At the end of this lesson you shall be able to

- **define the process of jogging/inching control**
- **state the purpose of jogging/inching control**
- **describe the operation of a jogging control using a selector switch**
- **describe the operation of a jogging control using a push-button station**
- **describe the operation of a jogging control using a control relay.**

Jogging (inching): In some industrial applications, the rotating part of a machine may have to be moved in small increments. This could be done by a control system called jogging (inching). Jogging is defined as the repeated closure of the circuit to start a motor from rest, producing small movements in the driven machine. By pressing the jog push-button the magnetic starter is energised and the motor runs; when the jog push-button is released, the motor stops.

When a jogging circuit is used, the motor can be energised only as long as the jog-button is depressed. This means the operator has instantaneous control of the motor drive.

Purpose of jogging/inching controls: Normally jogging (inching) controls are incorporated in the following machines for operational convenience shown against each.

- Lathe machine controls - for checking the trueness of the job and setting the tool initially.
- Milling machine controls - for checking the concentric running of the cutter at initial setting and also to set the graduated collar for depth of feed of the cutter.
- Grinding machine controls - for checking proper mounting of the wheel.
- Paper cutting machine - for adjusting the cut.

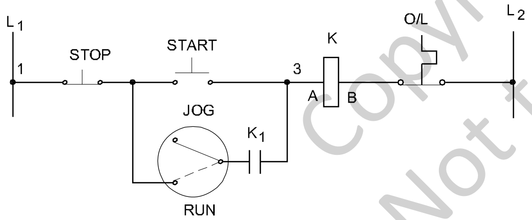
Apart from the above, the inch control is the prime control in cranes, hoists and conveyor belt mechanism so that incremental movements either vertically or horizontally could be achieved in the driven machinery.

Jogging may be accomplished by the following methods.

- Selector switch
- Push-button
- Push-button with a jog relay

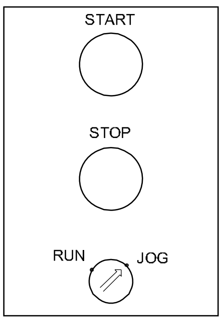
Jogging control using a selector switch: By using a selector switch, the existing start button can be used as a jogging push-button in addition to its function as a starting push-button. The holding contacts of the contactor which are in parallel to the start-button are disconnected and the selector switch is placed in the jog position as shown by the circuit in Fig 1 and the panel layout in Fig 2.

Fig 1



CONTROL CIRCUITS WITH JOG-RUN SELECTOR SWITCH.

Fig 2



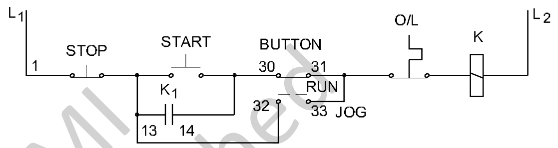
A PANEL OF A STATION IN WHICH THE START BUTTON CAN BE USED FOR INCHING OR JOGGING.

ELN3313172

The motor can be started or stopped by jogging/inching the start button. The motor will operate as long as the start-button is held pressed.

Jogging control using a push-button: Fig 3 shows the control circuit of a D.O.L. starter connected to a start-jog-stop push-button station. When the `ON' push-button is pressed, coil K is energised as the no-volt coil circuit is complete through the normally closed `jog' button contacts 30 & 31, thereby closing the main contactor, and the motor runs. The self-holding auxiliary contact K_1 between terminals 13 and 14 gets closed, and keeps the no-volt coil circuit in function though the `ON' button is released. As soon as the jog push-button is pushed, as the circuit of the no-volt coil opens initially, the contactor is de-energised and the motor stops if it is running. Then the jog-button closes the bottom contacts 32 & 33, thereby the no-volt coil circuit closes and the motor runs as long as the jog-button is held pressed. By pushing and releasing the jog-button repeatedly, the motor starts and stops causing the driven machinery to `inch' forward to the desired position. On the other hand, pressing the start-button will make the motor to run normally.

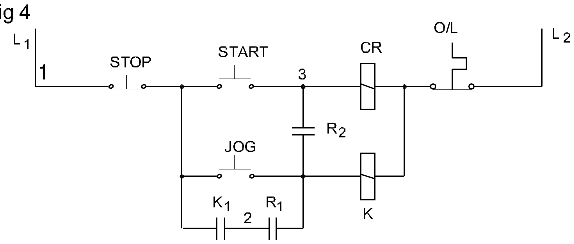
Fig 3



CONTROL CIRCUIT WITH JOG PUSH-BUTTON

Jogging control using a relay: Fig 4 shows the control circuit of a D.O.L. starter connected to a control relay with the other usual components. When the start button is pressed, the control relay coil CR is energised and closes the contacts R_1 and R_2, thereby momentarily completing the no-volt coil `K' circuit through relay contact R_2. This in turn closes the self-holding auxiliary contact K_1 of the no-volt coil relay K, and the motor runs continuously even though the pressure on the start-button is released.

Fig 4



LINE DIAGRAMS USING CONTROL RELAYS IN TYPICAL INSTALLATIONS

When the motor is not running, if the jog-button is pressed the no-volt coil, K circuit, is completed, and the motor runs only as long as the jog-button is held pressed as the holding circuit through R_1 is not completed for the starter coil as the control relay CR is not energised.

For a 3-phase, D.O.L. starter having the jog control through relay, four normally open contacts (3 for main and 1 for auxiliary) are required and the control relay should have two normally open contacts as shown in Fig 4.

Rotary type switches

Objectives: At the end of this lesson you shall be able to

- **explain the type of rotary switches - specifications like voltage rating, current rating, poles, function, position, type of mounting, type of handle, number of operations per hour and special requirement,**
- **explain the schematic diagram of rotary switches along with connection diagram of motors for ON/OFF three-pole switch, forward, stop and reverse three-pole switch, star-delta switch and pole changing switch.**

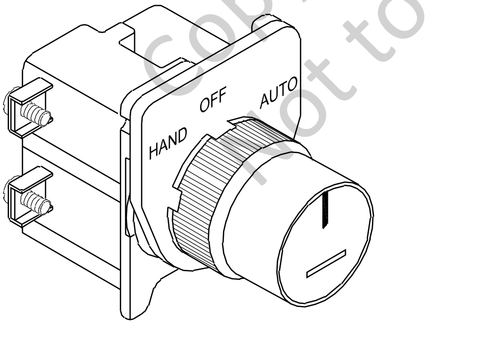
Rotary switches are most commonly used in lathes, milling and drilling machines due to their exact visual position and easiness in operation. These switches are operated by levers or knobs which in turn operate cams inside the switch to contact various terminals in sequence by the internal contact blocks. These cams and blocks are made of hard P.V.C. and are designed to withstand many operations. It is possible to get many circuit combinations by combining various cams and contact blocks. As the contact blocks, terminals and cams are spring-loaded, these switches should not be opened by inexperienced persons for repairs.

These rotary switches are classified according to

- poles
- function
- position
- mounting type
- handle design, and
- frequency of operations.

Poles: According to the number of independent connecting terminals and operation, they are called 2-pole (single phase, refer to Fig 1) or 3-pole (3-phase, refer to Fig 2) switches.

Fig 1

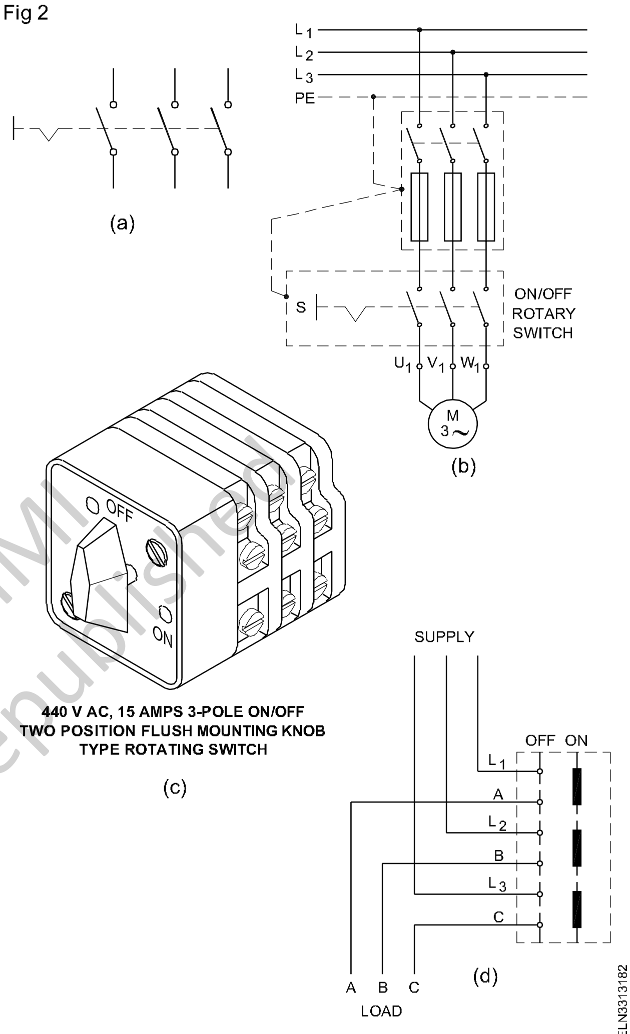


250 V AC 15 AMPS 2-POLE THREE POSITION FLUSH MOUNTING COIN-SLOT OPERATOR

Function: Rotary switches can do a number of functions depending upon the cam and contact block combinations. Accordingly they can be

- ON/OFF switches (Fig 2)
- manual forward/reversing switches (Fig 3)
- manual star-delta switches (Fig 4)
- pole changing switches for speed control. (Fig 5)

Fig 2



440 V AC, 15 AMPS 3-POLE ON/OFF TWO POSITION FLUSH MOUNTING KNOB TYPE ROTATING SWITCH

In addition to the above voltmeter/ammeter selector switches, 4-position, air-conditioner switches are also available.

Position: Selector switches of rotary type are available in two (Fig 2), three (Figs 1, 3 and 4) and four positions. They provide maintained or spring-return (momentary) control operation. Two-position and three-position switches can be either maintained or spring-returned whereas four-position switches are maintained in all four positions.

Mounting type: According to requirement, we may select any one of the following types for mounting.

- Surface mounting type
- Flush mounting type (Fig 1)
- Box mounting type (Fig 4)

Fig 3

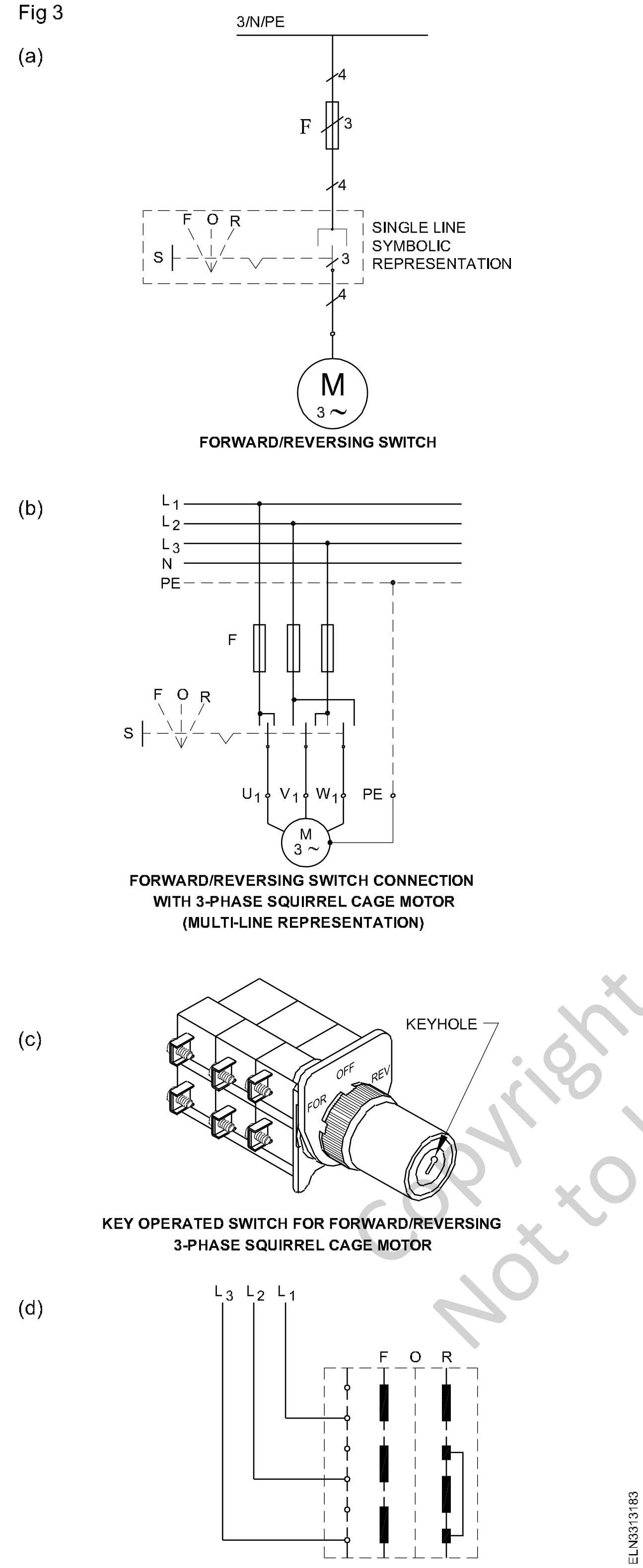
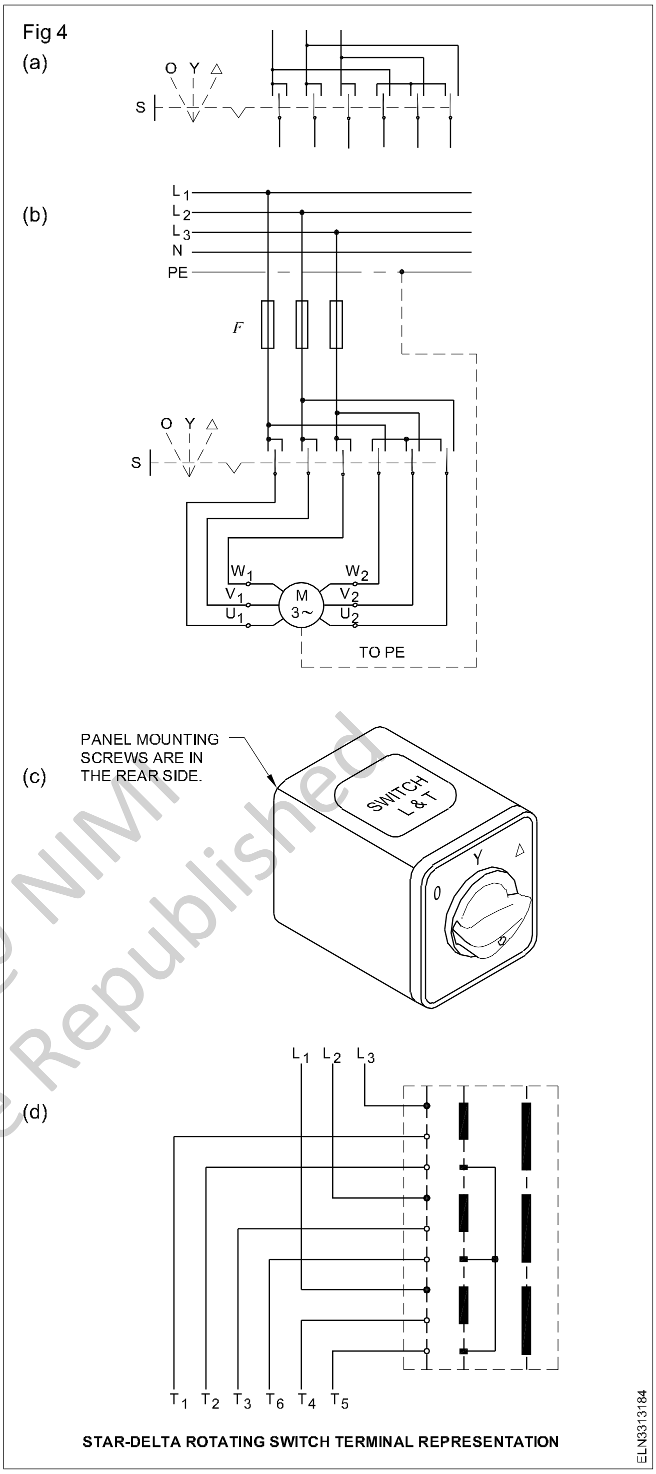


Fig 4



Handle design: According to the nature of operation it could be done by

- a knob (Fig 2c)
- a lever (Fig 5d)
- a coin slot (Fig 1)
- key operation. (Fig 3c)

Frequency of operation: The number of operations of these switches per hour is specified in B.I.S. 10118 (Part II) 1982. The details given below are taken from the B.I.S. as per the reference cited.

Sl. No.	Description	Operations per hour
1	On-off and system selector switch	Up to 150 times
2	Pole-changing switch	Up to 150 times
3	Manual star-delta switch	Up to 30 times
4	Speed control switch	Up to 150 times

Specification: Specification of rotary switches should contain the following information, for procurement in the market.

- Working voltage and kind of operation - AC or DC
- Load current
- Poles
- Function
- Position of operation
- Type of mounting
- Desired handle type
- Frequency of operation
- Accepted maximum dimensions
- Type of casing

Schematic diagram of rotary switches

ON/OFF switch: These switches are used for a 3-phase squirrel cage motor for direct starting, which is symbolically represented in Fig 2a. The complete connection diagram shown in Fig 2b and Fig 2c shows the normal appearance of such a switch, with a knob type handle, having a box mounting type body.

Fig 2d shows the manufacturer's catalogue representation of an ON/OFF switch.

Manual forward/reversing switch: These switches are used for forward and reverse running operation of the squirrel cage induction motors. A symbolic representation is shown in Fig 3a. The complete diagram is shown in Fig 3b and Fig 3c shows the normal appearance of such a switch with a key operated type switch, having box-type enclosure mounting.

Fig 3d shows the manufacturer's catalogue representation of a forward|reversing rotary switch.

Manual star-delta starter switch: These switches are used for starting a 3-phase squirrel cage induction motor in star position and to run it in delta position.

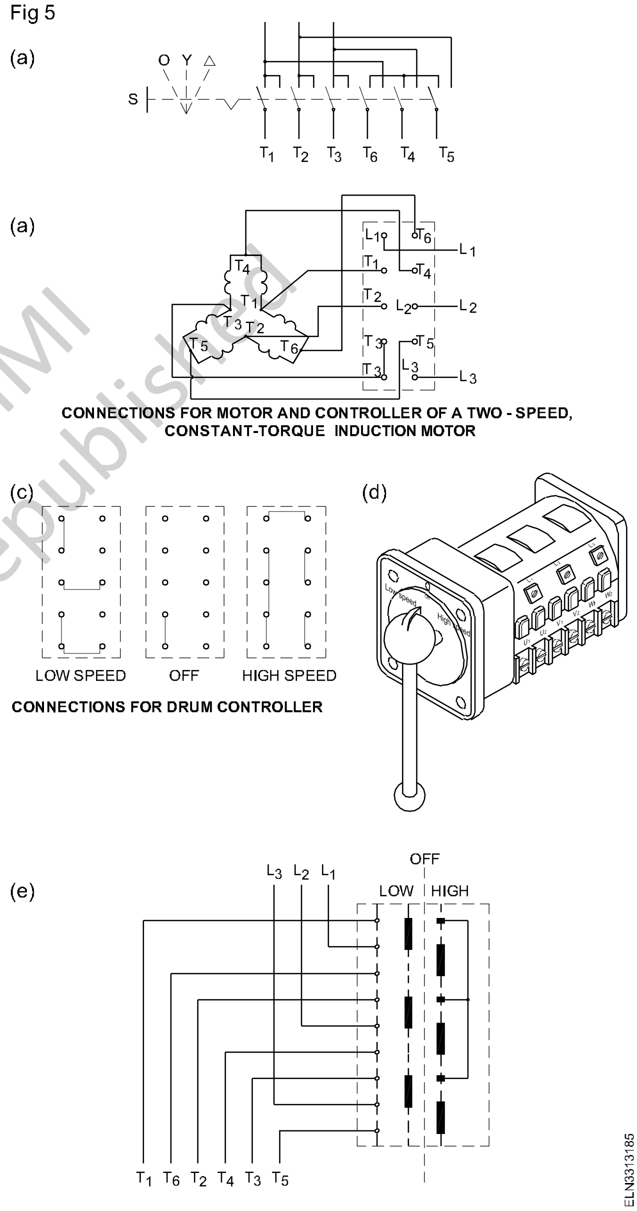
Fig 4a shows the symbolic representation of the star-delta manual switch, the complete diagram of connection to the 3-phase induction motor is shown in Fig 4b, and Fig 4c shows the normal appearance of such a starter switch with knob operation having a box-type body. Fig 4d shows the manufacturer's catalogue representation of a manual star-delta rotary switch.

Pole-changing rotary switch: This is used for changing the speed of a three-phase squirrel cage induction motor from one speed to another with the help of either two separate windings or by six windings arranged for series delta (low speed) or parallel star (high speed) connection. (Fig 5)

Fig 5a shows the symbolic representation of the pole-changing rotary switch, Figs 5b and 5c show the complete connection diagram of the pole-changing switch with motor connection, and Fig 5d shows the normal appearance of such a switch with lever operation.

Fig 5e shows the manufacturer's catalogue representation of the pole-changing rotary switch shown in Figs 5a, b and c.

Fig 5



Manual star-delta starter

Objectives: At the end of this lesson you shall be able to
- **state the necessity of a star-delta starter for a 3-phase squirrel cage induction motor**
- **explain the construction, connection and working of a star-delta switch and starter**
- **specify the back-up rating of the fuse in the motor circuit.**

Necessity of star-delta starter for 3-phase squirrel cage motor: If a 3-phase squirrel cage motor is started directly, it takes about 5-6 times the full load current for a few seconds, and then the current reduces to normal value once the speed accelerates to its rated value. As the motor is of rugged construction and the starting current remains for a few seconds, the squirrel cage induction motor will not get damaged by this high starting current.

However with large capacity motors, the starting current will cause too much voltage fluctuations in the power lines and disturb the other loads. On the other hand, if all the squirrel cage motors connected to the power lines are started at the same time, they may momentarily overload the power lines, transformers and even the alternators.

Because of these reasons, the applied voltage to the squirrel cage motor needs to be reduced during the starting periods, and regular supply could be given when the motor picks up its speed.

Following are the methods of reducing the applied voltage to the squirrel cage motor at the start.

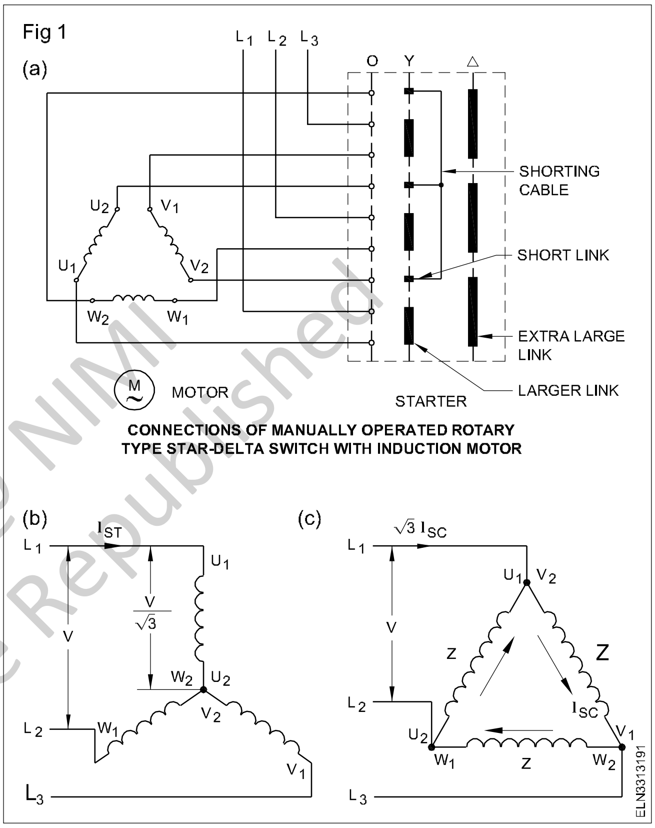
- Star-delta switch or starter
- Auto-transformer starter
- Step-down transformer starter

Star-delta starter: A star-delta switch is a simple arrangement of a cam switch which does not have any additional protective devices like overload or under-voltage relay except fuse protection through circuit fuses, whereas the star-delta starter may have overload relay and under voltage protection in addition to fuse protection. In a star-delta switch/starter, at the time of starting, the squirrel cage motor is connected in star so that the phase voltage is reduced to $1/\sqrt{3}$ times the line voltage, and then when the motor picks up its speed, the windings are connected in delta so that the phase voltage is the same as the line voltage. To connect a star-delta switch/starter to a 3-phase squirrel cage motor, all the six terminals of the three-phase winding must be available.

As shown in Fig 1a, the star-delta switch connection enables the 3 windings of the squirrel cage motor to be connected in star, and then in delta. In star position, the line supply L_1, L_2 and L_3 are connected to the beginning of windings U_1, W_1 and V_1 respectively by the larger links, whereas the short links, which connect V_2 U_2 and W_2, are shorted by the shorting cable to form the star point. This connection is shown as a schematic diagram. (Fig 1b)

When the switch handle is changed over to delta position, the line supply L_1, L_2 and L_3 are connected to terminals U_1 V_2, W_1 U_2 and V_1 W_2 respectively by the extra large links to form a delta connection. (Fig 1c)

Manual star-delta starter: Fig 2a shows the conventional manual star-delta starter. As the insulated handle is spring-loaded, it will come back to OFF position from any position unless and until the no-volt (hold-on) coil is energised. When the hold-on coil circuit is closed through the supply taken from U_2 and W_2, the coil is energised and it holds the plunger, and thereby the handle is held in delta position against the spring tension by the lever plate mechanism. When the hold-on coil is de-energised the plunger falls and operates the lever plate mechanism so as to make the handle to be thrown to the off position due to spring tension. The handle also has a mechanism (not shown in Fig) which makes it impossible for the operator to put the handle in delta position in the first moment. It is only when the handle is brought to star position first, and then when the motor picks up speed, the handle is pushed to delta position.

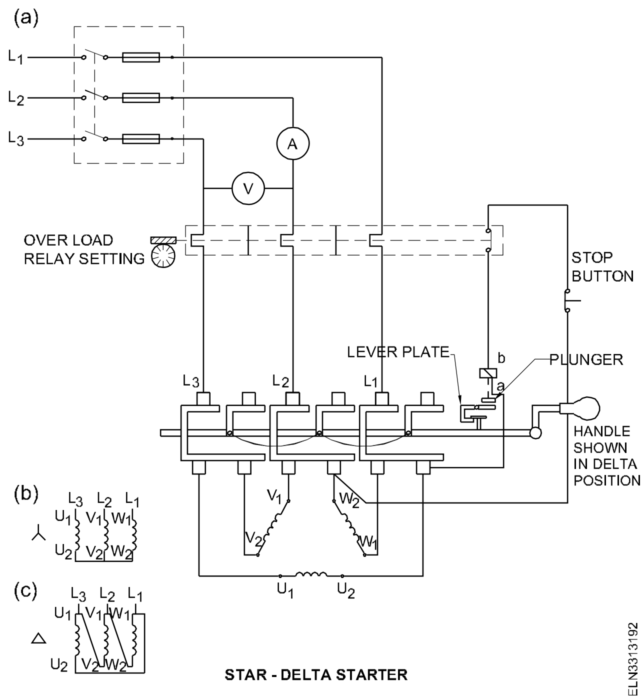


The handle has a set of baffles insulated from each other and also from the handle. When the handle is thrown to star position, the baffles connect the supply lines L_1, L_2 and L_3 to beginning of the 3-phase winding W_1, V_1 and U1 respectively. At the same time the small baffles connect V_2, W_2 and U_2 through the shorting cable to form the star point. (Fig 2b)

When the handle is thrown to delta position, the larger end of the baffles connect the main supply line L_1, L_2 and L_3 to the winding terminals W_1U_2, V_1W_2 and U_1V_2 respectively to form the delta connection. (Fig 2c)

The overload relay current setting could be adjusted by the worm gear mechanism of the insulated rod. When the load current exceeds a stipulated value, the heat developed in the relay heater element pushes the rod to open the hold-on coil circuit, and thereby the coil is de-energised, and the handle returns to the off position due to the spring tension.

Fig 2



The motor also could be stopped by operating the stop button which in turn de-energises the hold-on coil.

Back-up fuse protection: Fuse protection is necessary in the star-delta started motor circuit against short circuits. In general, as a thumb rule for 415V, 3-phase squirrel cage motors, the full load current can be taken as 1.5 times the H.P. rating. For example, a 10 HP 3-phase 415V motor will have approximately 15 amps as its full load current.

To avoid frequent blowing of the fuse and at the same time for proper protection, the fuse wire rating should be 1.5 times the full load current rating of the motor. Hence for 10 HP, 15 amps motor, the fuse rating will be 23 amps, or say 25 amps.

Comparison of impact of star and delta connections on starting current and torque of the induction motor: When the three-phase windings of the squirrel cage motor are connected in star by the starter, the phase voltage across each winding is reduced by a factor of $1/\sqrt{3}$ of the applied line voltage (58%), and hence the starting current reduces to 1/3 of that current which would have been drawn if the motor were directly started in delta. This reduction in starting current also reduces the starting torque to 1/3 of the starting torque which would have been produced in the motor, if it were started directly in delta.

The above statement could be explained through the following example.

Example

Three similar coils of a 3-phase winding of a squirrel cage induction motor, each having a resistance of 20 ohms and inductive reactance of 15 ohms, are connected in (a) star (b) delta through a star-delta starter to a 3-phase 400V 50 Hz supply mains.

Calculate the line current and total power absorbed in each case. Compare the torque developed in each case.

Solution

Impedence per phase

$$Z_{ph} = \sqrt{R^2 + X^2}$$

$$= \sqrt{20^2 + 15^2} = 25\Omega$$

Star connection

$$E_{Ph} = \frac{E_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231 \text{ volts}$$

$$I_{Ph} = \frac{E_{ph}}{Z_{ph}} = \frac{231}{25} = 9.24\text{amps}$$

$I_L = I_{sh} = 9.24$amps.

Power absorbed = $\sqrt{3}\, E_L I_L \cos\theta$

$= \sqrt{3}$ x 400 x 9.24 x 1

Assuming PF = 1, we have = 6401 watts.

Delta connection

$E_{ph} = E_L = 400V$

$$I_{Ph} = \frac{E_{ph}}{Z_{ph}} = \frac{400}{25} = 16A$$

$I_L = \sqrt{3}\, I_{ph} = 1.732 \times 16 = 27.7$ A

Power absorbed = $\sqrt{3}\, E_L I_L \cos\theta$

(assume PF = 1)

$= \sqrt{3}$ x 400 x 27.7 x 1

= 19190 W. (19.19W)

The torque developed is proportional to the square of the voltage across the winding.

In the case of star, the voltage across the winding E_{ph}

$$E_{ph} = \frac{E_L}{\sqrt{3}}$$

$$= \frac{E^2_L}{\sqrt{3}} K \text{ in star}$$

In the case of delta, the voltage across the E_{ph} winding

$E_{ph} = E_L$.

Hence torque

$(E_L)^2 K = E^2_L K.$

By comparison the torque developed in star connection at the time of starting is 1/3 of the torque developed in a delta connection (running).

As the torque is 3 times less in starting due to the star connection, whenever a motor has to be started with heavy loads, the star-delta starter is not used. Instead an auto-transformer or step-down transformer starter could be used as the voltage tapping can be changed to more than 58% of the line voltage to suit the torque requirement.

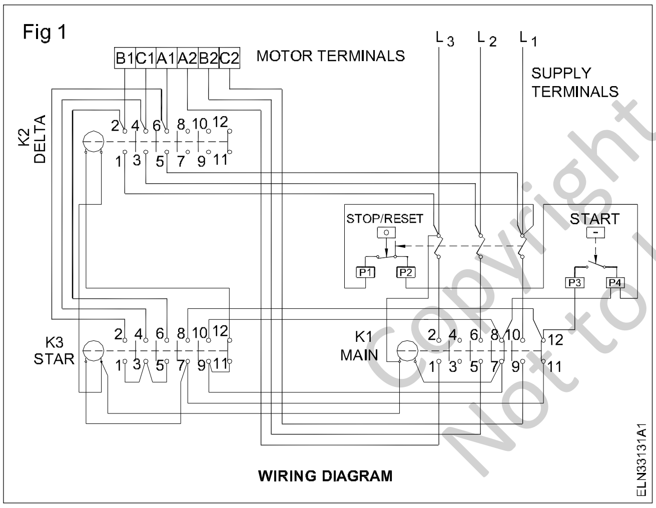
Semi-automatic star-delta starter

Objectives: At the end of this lesson you shall be able to
- **explain the wiring diagram of semi-automatic star-delta starter**
- **describe the operation of semi-automatic star-delta starter.**

The standard squirrel cage induction motors with both ends of each of the three windings brought out (six terminals) are known as star-delta motors. If the starter used has the required number of properly wired contactors, the motor can be started in star and run in delta.

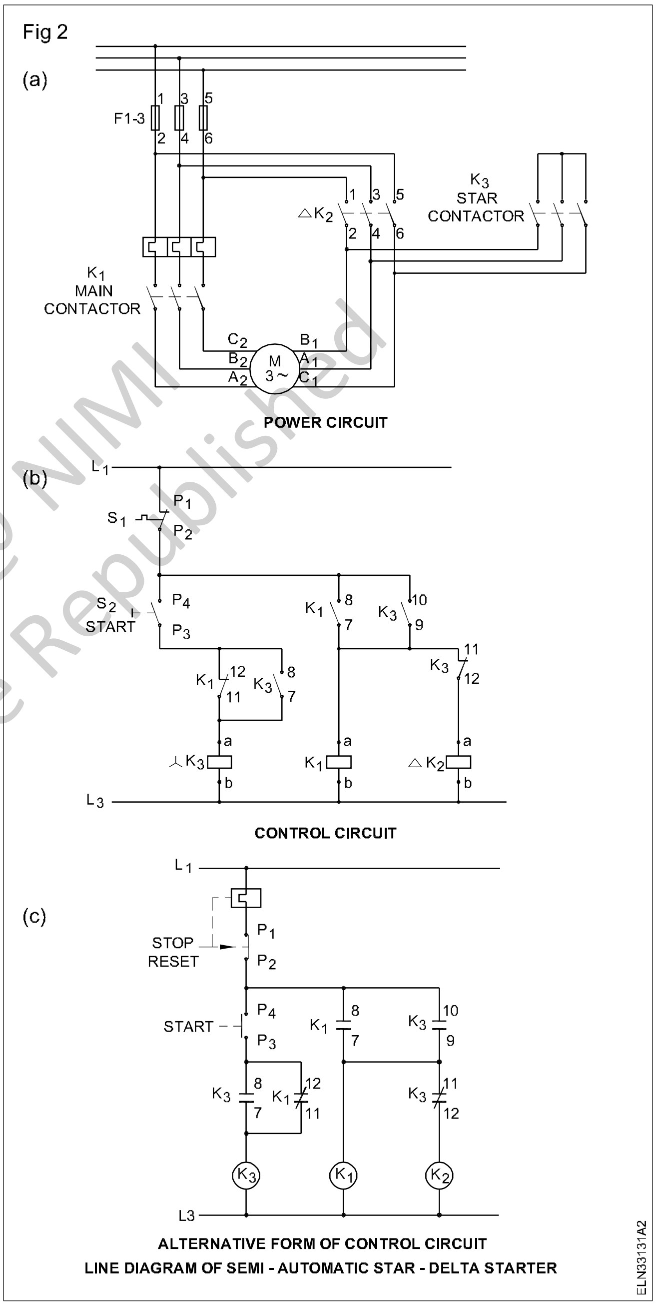
The proper use of manual star-delta starter demands a special skill in handling the starter. The sluggish operation of the manual lever often causes damage to the moving and fixed contacts in a manual star-delta starter.

The contactors are employed for making and breaking the main line connections. Fig 1 shows the wiring diagram and Fig 2 shows the line diagram of power circuit and the control circuit.



Operation: Refer to the control circuit and power circuit diagrams shown in Fig 2. When the start button S_2 is pressed the contactor coil K_3 energises through P_4, P_3 and K_1 normally closed contact 12 and 11. When K_3 closes, it opens the normally closed contact K_3 between 11 and 12 and makes contact between 10 and 9 of K_3. The mains contactor K_1 energies through P_4, 10 and 9 of K_3. Once K_1 energises the NO contact of K_1 point 8 and 7 establishes a parallel path to K_3 terminals 10 and 9.

The star contactor K_3 remains energised so long as the start button is kept pressed. Once the start button is released, the K_3 coil gets de-energised. The K_3 contact cannot be operated because of the electrical interlock of K_1 and normally closed contacts between terminals 12 and 11.



When the K_3 contactor get de-energised the normally closed contact of K_3 between terminals 11 and 12 establishes contact in the contactor K_2 - coil circuit. The delta contactor K_2 closes.

The operator has to observe the motor starting and reaching about 70% of the synchronous speed for satisfactory starting and running of the induction motor.

Figure 2c shows the alternative form of drawing control circuit.

Automatic star-delta starter

Objectives: At the end of this lesson you shall be able to
- **state the applications of automatic star-delta and overload relay setting**
- **describe the operations of automatic star-delta starter.**

Applications : The primary application of star-delta motors is for driving centrifugal chillers of large central air-conditioning units for loads such as fans, blowers, pumps or centrifuges, and for situations where a reduced starting torque is necessary. A star-delta motor is also used where a reduced starting current is required.

In star-delta motors all the winding is used and there are no limiting devices such as resistors or auto-transformers. Star-delta motors are widely used on loads having high inertia and a long acceleration period.

Overload relay settings : Three overload relays are provided on star-delta starters. These relays are used so that they carry the motor winding current. This means that the relay units must be selected on the basis of the winding current, and not the delta connected full load current. The motor name-plate indicates only the delta connected full load current, divide this value by 1.73 to obtain the winding current. Use this winding current as the basis for selecting and setting the motor winding protection relay.

Operation : Fig 1 shows the line diagram of the power circuit and the control circuit of the automatic star-delta starter. Pressing the start button S-energises the star contactor K_3. (Current flows through K_4T NC terminals 15 & 16 and K_2 NC terminals 11 & 12). Once K_3 energises the K_3 NO contact closes (terminals 23 & 24) and provide path for the current to close the contactor K_1. The closing of contactor K_1 establishes a parallel path to start button via K_1 NO terminals 23 & 24.

Fig 1

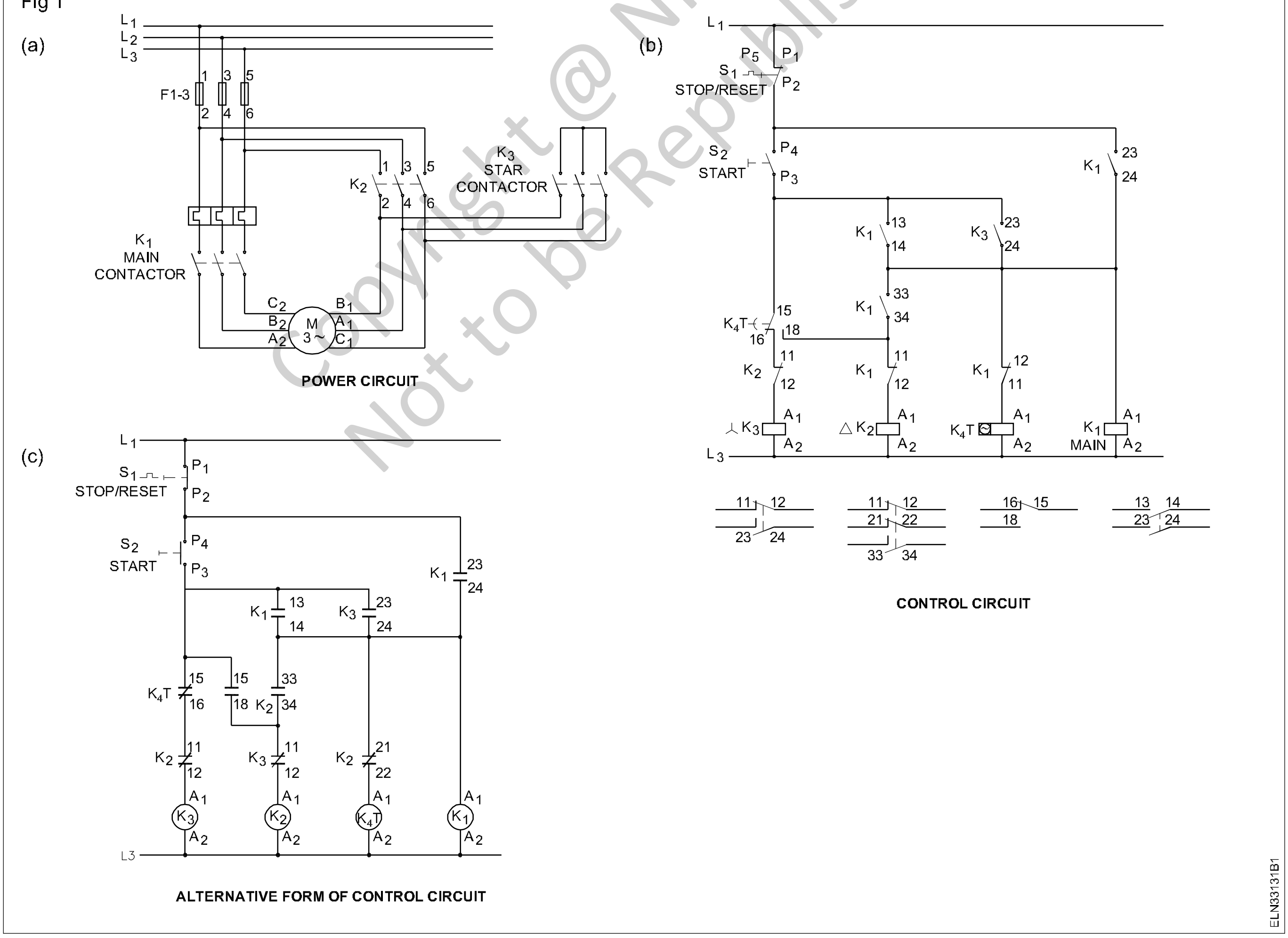
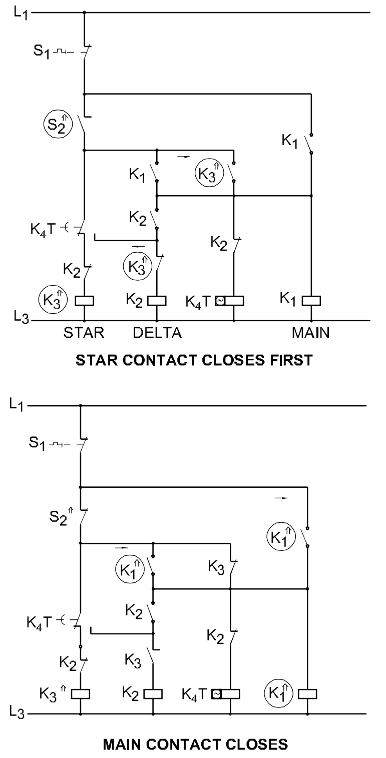


Fig 2 shows the current direction and closing of contacts as explained above.

Fig 2



→ INDICATES THE DIRECTION OF MOVEMENT OF CONTACT
⇑ INDICATES CLOSING OF CONTACTOR

Similarly Fig 3 shows the action taking place after the timer relay operating the contact K_4T.

Time delay contact changes opening star contact.

Fig 4 shows the connections established while the motor is running in delta with the contactors K_1 and K_2 closed.

Delta contact closes.

Fig 3

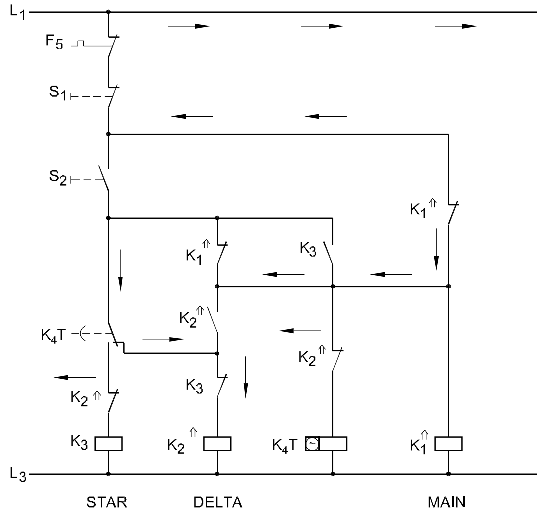
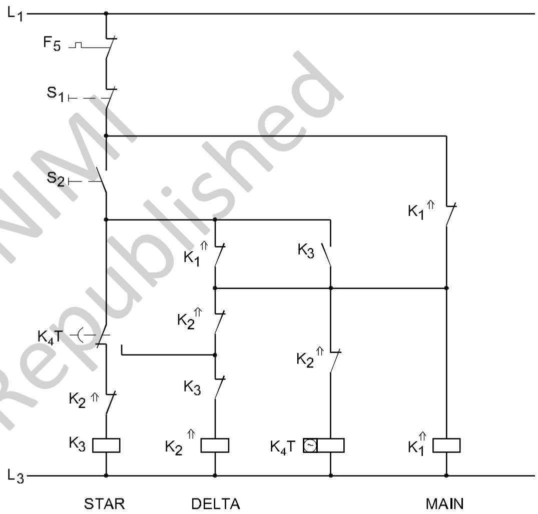


Fig 4

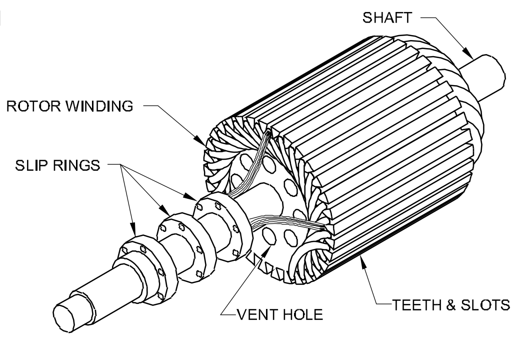


Three-phase, slip-ring induction motor

Objectives: At the end of this lesson you shall be able to
- **explain briefly the construction and working of a three-phase, slip-ring induction motor**
- **explain how the starting torque is high due to insertion of rotor resistance**
- **state the characteristic of the slip-ring induction motor**
- **compare the slip-ring induction motor with the squirrel cage induction motor.**

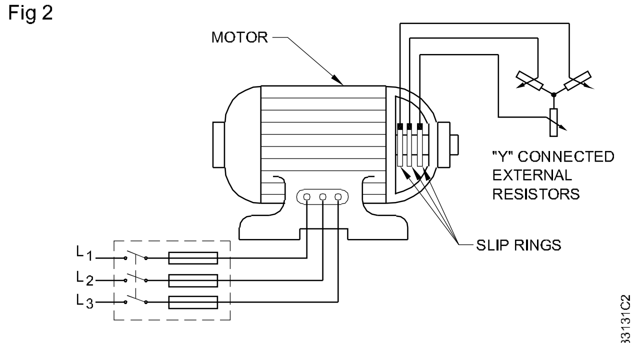
Construction : The slip-ring induction motor could be used for industrial drives where variable speed and high starting torque are prime requirements. The stator of the slip-ring induction motor is very much the same as that for a squirrel cage motor but the construction of its rotor is very much different. Stator windings can be either star or delta connected depending upon the design. The rotor consists of three-phase windings to form the same number of poles as in a stator. The rotor winding is connected in star and the open ends are connected to three slip-rings mounted in the rotor shaft, as shown in Fig 1. The rotor circuit is, in turn, connected to the external star-connected resistances through the brushes, as shown in Fig 2.

Fig 1



WOUND ROTOR FOR SLIP RING INDUCTION MOTOR

Fig 2



CIRCUIT FOR A WOUND - ROTOR INDUCTION MOTOR

Working : When the stator-winding of the slip-ring motor is connected to the 3-phase supply, it produces a rotating magnetic field in the same way as a squirrel cage motor. This rotating magnetic field induces voltages in the rotor windings, and a rotor current will flow through the closed circuit, formed by the rotor winding, the slip-rings, the brushes and the star-connected external resistors.

At the time of starting, the external resistors are set for their maximum value. As such, the rotor resistance is high enabling the starting current to be low. At the same time, the high resistance rotor circuit increases the rotor power factor, and thereby, the torque developed at the start becomes much higher than the torque developed in squirrel cage motors.

As the motor speeds up, the external resistance is slowly reduced, and the rotor winding is made to be short-circuited at the slip-ring ends. Because of the reduced rotor resistance, the motor operates with low slip and high operating efficiency. The motor could be started for heavy loads with higher resistance or vice versa. However at increased rotor resistance, the motor's slip will be greater, the speed regulation poorer and it will have low efficiency. The resistance in the external circuit could be designed and varied to change the speed of the slip-ring motor between 50 to 100 percent of the rated speed. However, the I^2R losses in the rotor due to increased resistance is inevitable.

Starting torque : The torque developed by the motor at the instant of starting is called the starting torque. In some cases it is greater than the normal running torque whereas in some other cases it is somewhat less.

Let E_2 be the rotor emf per phase at standstill

X_2 be the rotor reactance per phase at standstill and R_2 be the rotor resistance per phase.

Therefore $Z_2 = \sqrt{(R_2)^2 + (X_2)^2}$ = rotor impedance per phase at standstill.

Then $I_2 = \frac{E_2}{Z_2}, \cos\theta_2 = \frac{R_2}{Z_2}$

Standstill or starting torque $T_{st} = K_1 E_2 I_2 \cos q_2$ or

$$T_{st} = K_1 E_2 \times \frac{E_2}{\sqrt{(R_2)^2 + (X_2)^2}} \times \frac{R_2}{\sqrt{(R_2)^2 + (X_2)^2}}$$

If the supply voltage V is constant, then the flux, f and hence E_2 is constant.

Therefore $T_{st} = K_2 \frac{R_2}{Z_2}$ where K_2 is another constant.

The starting torque of such a motor is increased by adding external resistance in the rotor circuit. The resistance is progressively cut out as the motor gain speed.

Rotor emf and reactance under running condition : When the starter is stationary i.e. S = 1, the frequency of the rotor emf is the same as that of the stator supply frequency. The value of emf induced in the rotor at standstill is maximum because the relative speed between the rotor and the rotating stator flux is maximum.

When the rotor starts running, the relative speed between the rotor and the rotating stator flux is decreased. Hence the rotor induced emf is also decreased. The rotor emf become zero if the rotor speed become equal to the speed of stator rotating flux.

Hence, for a slip (s), the rotor induced emf will be s times the induced emf at standstill.

Therefore, under running condition $E_r = sE_2$.

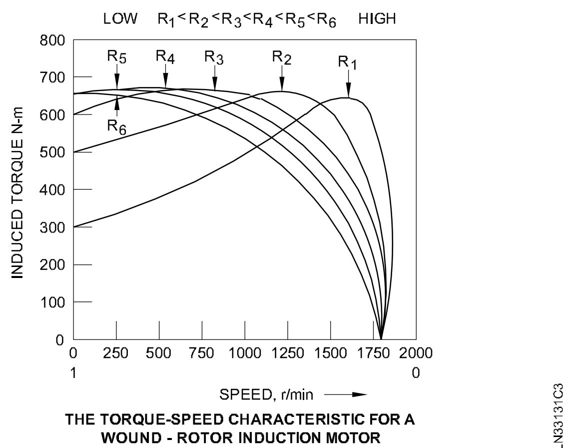
The frequency of induced emf will likewise become $f_r = sf_2$ where f_2 is the rotor current frequency at standstill.

Due to decrease in frequency of the rotor emf, the rotor reactance will also decrease.

Therefore $X_r = sX_2$.

Characteristic and application of slip-ring induction motor: Insertion of higher, external resistance alters the starting torque to a higher value, as shown in Fig 3, by the torque speed characteristic.

Fig 3



THE TORQUE-SPEED CHARACTERISTIC FOR A WOUND - ROTOR INDUCTION MOTOR

By inserting the suitable value rotor resistance, the speed of the slip ring motor could be controlled inspite of power loss in resistance.

As shown in the curve, higher, external resistance improves the starting torque to a higher value. However the maximum torque remains constant for the variation of the rotor resistance.

By these curves, it is clear that the slip-ring motor could be used to start heavy loads by insertion of high resistance in the rotor to facilitate higher starting torque. At the same time the running efficiency of the motor could be achieved by cutting out the external resistance when the motor picks up its speed.

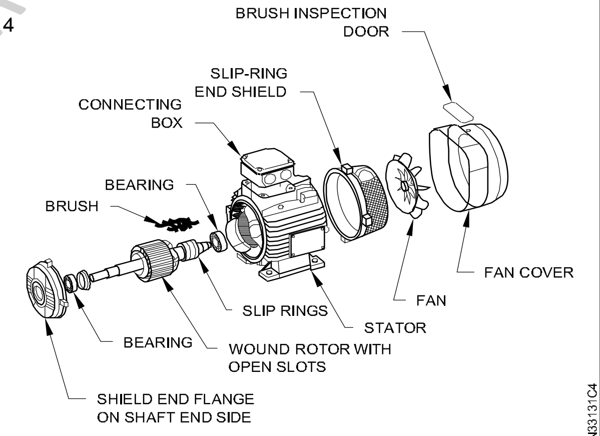
This motor could be used for drive which demands a higher starting torque and also a variable speed control - like compressors, conveyors, cranes, hoists, steel mills and printing presses.

Comparison between squirrel cage and slip-ring induction motors is given below:

Sl. No.	Property	Squirrel cage	Slip-ring motor
1	Rotor construction	Bars are used in rotor. Squirrel cage rotor is very simple, rugged and long lasting. No slip-rings.	Winding wire is used. Wound rotor requires attention Slip-ring and brush gear need frequent main-tenance.
2	Starting	Can be started byDOL star-delta, auto-transformer starters.	Rotor resistance starter is required
3	Starting torque	Low	Very high
4	Starting current	High	Low
5	Speed variation	Not easy, but could be varied in larger steps by pole-changing or smaller incre- -mental steps through thyristors or by frequency variation.	Easy to vary speed,but speed change through pole-changing is not possible. Speed change possible by - insertion of rotor resistance - using thyristors - using frequency variation - injecting emf in the rotor circuit - cascading
6	Acceleration on load	Just satisfactory	Very good
7	Maintenance	Almost nil	Requires frequent maintenance
8	Cost	Low	Comparatively high

Fig 4 shows the exploded view of the slip ring induction motor.

Fig 4



PARTS OF 3 PHASE SLIP RING INDUCTION MOTOR

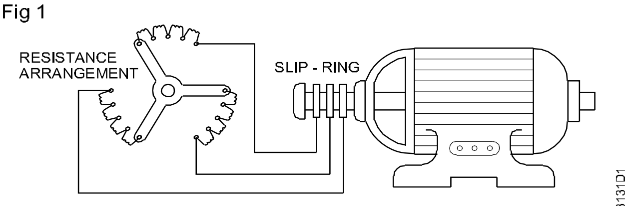
Resistance starter for 3-phase, slip-ring induction motor

Objective: At the end of this lesson you shall be able to

- **explain the rotor resistance starters used for a 3-phase, slip-ring induction motor.**

Slip-ring induction motors are started with full-line voltage across the stator winding. However, to reduce the heavy rush of the starting current, a star-connected external resistance is added in the rotor circuit as shown in Fig 1. The external resistances are cut out, and the rotor winding ends are shorted once the motor picks up its speed.

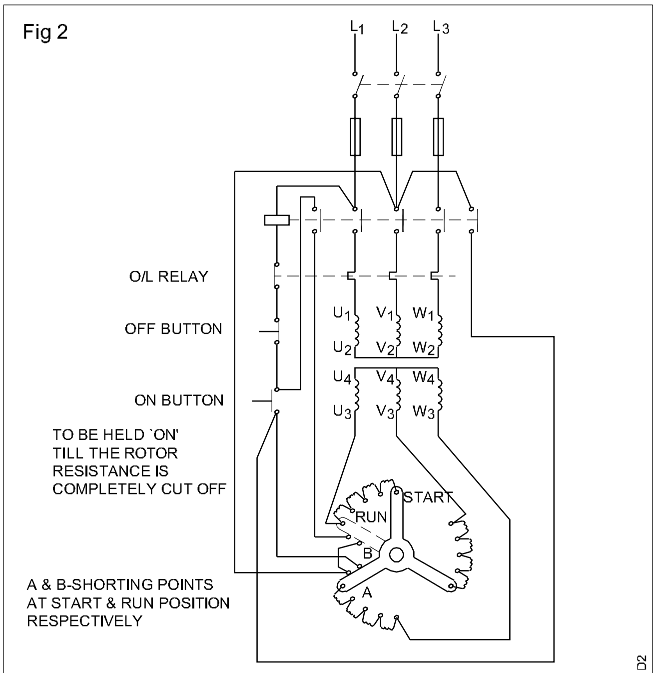
Fig 1



SLIP RING INDUCTION MOTOR WITH RESISTANCE STARTER

If such a manual starter is used, there is a possibility that someone may apply full voltage to the stator when the rotor resistance is in a completely cut-out position, resulting in heavy rush of the starting current and poor starting torque. This could be eliminated by the use of a protective circuit in the resistance starter; thereby motor cannot be started until and unless all the rotor resistances are included in the rotor winding. Such a semi-automatic starter is shown in Fig 2.

Fig 2



ROTOR RESISTANCE STARTER FOR SLIP RING INDUCTION MOTOR

By pressing the 'ON' button, the contactor will close, only when the shorting point 'A' at the rotor resistance is in a closed position. This is possible only when the handle is in the start position. Once the motor starts running, the handle of the rotor resistance should be brought to 'run' position to cutout the rotor resistance.

The position of the handle clearly indicates that at the start position, the contact 'A' is in the closed position, and at the run position, contact 'B' is in the closed position, but both cannot close at the same time. The 'ON' push-button needs to be held in the pushed-position till the handle is brought to the run-position. During the run-position, the handle contact 'B' closes the no-volt coil circuit, and the pressure on the 'ON' button can be released.

In general, for small machines, the rotor resistance is air-cooled to dissipate the heat developed during starting. For larger machines, the rotor resistance is kept in an insulating oil tank for cooling. The starter shown is intended to start the motor only. As speed regulation through the rotor resistance needs intermediate positions, they are specially designed and always oil-cooled.

Method of measurement of slip in induction motor

Objectives: At the end of this lesson you shall be able to
- **explain the method of measurement of slip by actual motor speed**
- **describe the method of measurement of slip by comparing motor and starter frequencies**
- **explain the method of measurement of slip by stroboscope method.**

Measurement of slip

Following are the methods used for finding the slip of an induction motor

(i) By actual measurement of motor speed: This method requires measurement of actual motor speed N and calculation of synchronous speed N_s. N is measured with the help of a speedometer and N_s calculated from the knowledge of supply frequency and the number of poles of the motor (Since an induction motor does not have salient poles, the number of poles is usually inferred from the no-load speed or from the rated speed of the motor). Then slip can be calculated by using the equation

$S = (N_s - N) \times 100 / N_s$

(ii) By comparing rotor and stator supply frequencies: This method is based on the fact that $s = f_r/f$. Since f is generally known, s can be found if frequency of rotor current can be measured by some method. In the usual case, where f is 50 Hz, f_r is so low that individual cycles can be easily counted. For this purpose, a DC moving coil preferably of centre-zero milli-voltmeter, is employed as described below:

a) In the case of a slip-ring motor, the leads of the centre zero milli-ammeter is connected to adjacent slip-rings as they revolve (Fig 1). Usually, there is sufficient voltage drop in the burshes and their short-circuiting strap to provide an indication on the milli-ammeter. The current in the milli-ammeter follows the variations of the rotor current and hence the pointer oscillates about its mean zero position. The number of complete cycles made by the pointer per second can be easily counted (it is worth remembering that one cycle consists of a movement from zero to a maximum to the right, back to zero and on to a maximum to the left and then back to zero).

   As an example, consider the case of a 4-pole motor fed from a 50-Hz supply and running at 1,425 rpm. Since N_s = 1,500 rpm its slip is 5% or 0.05. The frequency of the rotor current would be $f_r = S_f$ = 0.05 x 50 = 2.5 Hz which (being slow enough) can be easily counted.

b) For squirrel-cage motors (which do not have slip-rings) it is not possible to employ the centre zero milli ammeter.

iii) By Stroboscopic Method: In this method, a circular metallic disc is taken and painted with alternately black and white segments. The number of segments (both black and white) is equal to the number of poles of the motor. For a 6-pole motor, there will be six segments, three black and three white, as shown in Fig 2a.

Fig 1

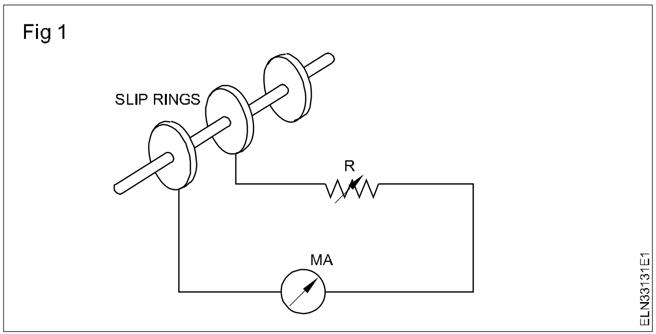
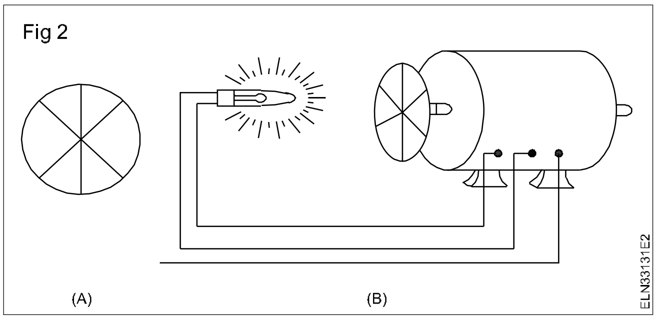


Fig 2

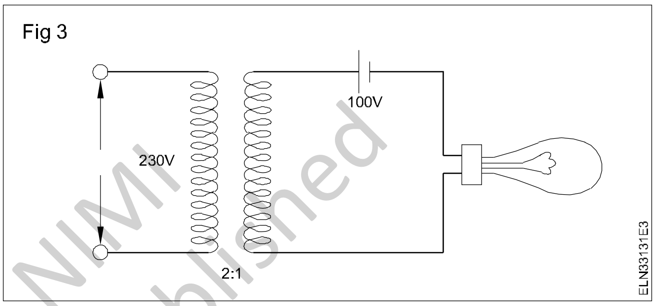


The painted disc is mounted on the end of the shaft and illuminated by means of a neon-filled stroboscopic lamp, which may be supplied preferably with a combined d.c. and a.c. supply although only a.c. supply will do (When combined d.c. and a.c. supply is used, the lamp should be tried both ways in its socket to see which way it gives better light.). The connections for combined supply are shown in Fig 3 whereas Fig 2b shows the connections for single supply only. It must be noted that with combined d.c. and a.c. supply, the lamp will flash once per cycle (It will flash only when the two voltages add and remain extinguished when they oppose). But with a.c. supply, it will flash twice per cycle.

Consider the case when the revolving disc is seen in the flash light of the bulb which is fed by the combined d.c. and a.c. supply.

If the disc were to rotate at synchronous speed, it would appear to be stationary, Since in actual practice, its speed is slightly less than the synchronous speed, it appears to rotate slowly backwards.

Fig 3



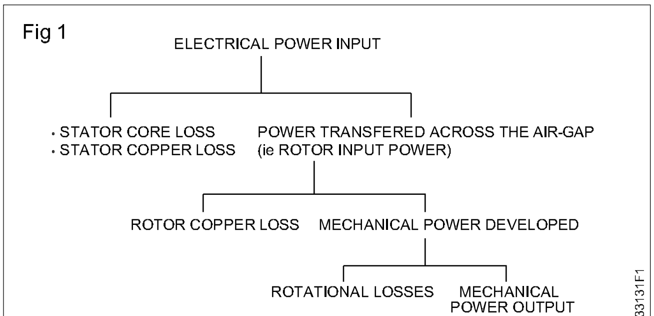
Efficiency - characteristics of induction motor- no load test - blocked rotor test

Objectives: At the end of this lesson you shall be able to
- **state the power flow diagram of an induction motor indicating the losses**
- **calculate the efficiency from the given data.**

When the three-phase induction motor is running at no-load, the slip has a value very close to zero. The torque developed in the rotor is to overcome the rotational losses consisting of friction and windage. The input power to the motor is to overcome stator iron loss and stator copper loss. The stator iron loss (consisting of eddy current and hysteresis) depends on the supply frequency and the flux density in the iron core. It is practically constant. The iron loss of the rotor is, however, negligible because the frequency of the rotor currents under normal condition is always small.

If a mechanical load is then applied to the motor shaft, the initial reaction is for the shaft load to drop the motor speed slightly, thereby increasing the slip. The increased slip subsequently causes I_2 to increase to that value which, when inserted into the equation for torque calculation (i.e $T = K\phi_s I_2 \cos \phi_s$), yields sufficient torque to provide a balance of power to the load. Thus an equilibrium is established and the operation proceeds at a particular value of slip. In fact, for each value of load horsepower requirement, there is a unique value of slip. Once slip is specified then the power input, the rotor current, the developed torque, the power output and the efficiency are all determined. The power flow diagram in a statement form is shown in Fig 1. Note that the loss quantities are placed on the left side of the flow point. Fig 2 is the same power flow diagram but now expressed in terms of all the appropriate relationships needed to compute the performance.

Fig 1



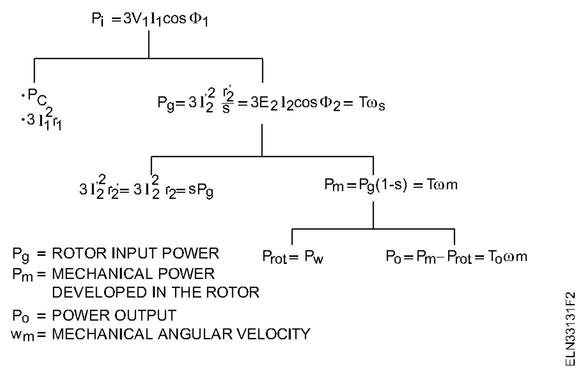
Torque, Mechanical power and Rotor output : Stator input P_i = stator output + stator losses.

The stator output is transferred fully inductively to the rotor circuit.

Obviously, rotor input P_g = stator output.

Rotor gross output, P_m = rotor input P_g - rotor cu. losses.

Fig 2



This rotor output is converted into mechanical energy and gives rise to the gross torque T. Out of this gross torque developed, some is lost due to windage and friction losses in the rotor, and the rest appear are useful torque T_o.

Let n r.p.s be the actual speed of the rotor and if it is in Nm, then

T x 2πn = rotor gross output in watts, P_m.

$$\text{Therefore, } T = \frac{\text{rotor gross output in watts, } P_m}{2\pi\, n} \text{ N.m}$$

The value of gross torque in kg.m is given by

$$T = \frac{\text{rotor gross output in watts}}{9.81 \times 2\pi\, n} \text{ Kg m}$$

$$= \frac{P_m}{9.81 \times 2\pi\, n} \text{ Kg m}$$

If there were no copper losses in the rotor, the rotor output will equal the rotor input and the rotor will run at synchronous speed.

$$\text{Therefore, } T = \frac{\text{rotor input } P_g}{2\pi\, n_s}$$

From the above two equation we get,

Rotor gross output = P_m = Tw = T x 2πn

Rotor input = P_g = TW_s = T x $2\pi n_s$

The difference between the two equals the rotor copper loss.

Therefore, rotor copper loss = s x rotor input

= s x power across air gap

= sP_g.

$$\text{Also rotor input, } P_g = \frac{\text{rotor copper loss}}{s}$$

Rotor gross output P_m = Input P_g - rotor cu.loss

= (1 - s) P_g

$$\text{or } \frac{\text{rotor gross output, } p_m}{\text{rotor input, } p_g} = 1 - s$$

rotor gross output. Pm = (1 - s)P_g

$$\text{Therefore rotor efficiency} = \frac{n}{n_s}$$

Example

The power input to a 4-pole, 3-phase, 50 Hz. induction motor is 50kW, the slip is 5%. The stator losses are 1.2 kW and the windage and friction losses are 0.2 kW. Find (i) the rotor speed, (ii) the rotor copper loss, (iii) the efficiency.

Data given

No. of poles	P = 4
Frequency	f = 50 Hz
Phases	= 3
Input power	= 50kW
% Slip	s = 5%
Stator losses	= 1.2 kW
Friction & Windage losses	= 0.2 kW

Find:

Rotor speed	= N
Rotor copper loss	= s x input power to rotor
efficiency	= η

SOLUTION

$$\text{Synchronous speed} = N_s = \frac{120f}{p} = \frac{6000}{4} = 1500 \text{ rpm}$$

$$\text{Fractional slip} = s = \frac{N_s - N_r}{N_s}$$

$$\frac{5}{100} = \frac{1500 - N_r}{1500}$$

$$75 = 1500 - N_r$$

Therefore, rotor speed, Nr = 1500 - 75 = 1425 rpm.

Input power to rotor = (50 - 1.2)kW

Rotor copper loss = s x input power to rotor

= 0.05 x 48.8

= 2.44 kW.

Rotor output = Rotor input - (Friction and windage loss + rotor cu.loss)

= 48.8 - (0.2 + 2.44)

= 46.16 kW

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{44.56 \times 100}{50} = 92.32\%.$$

Characteristics of squirrel cage induction motor

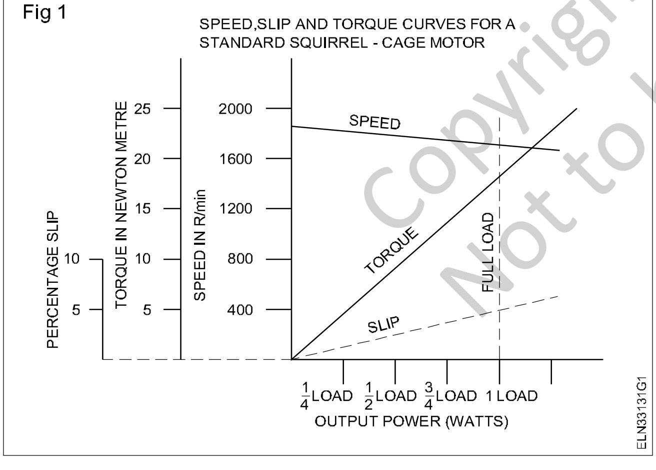
Objective: At the end of this lesson you shall be able to
- **describe the characteristics and application of a 3-phase squirrel cage induction motor.**

The most important characteristic of the induction motor is the speed torque characteristic which is also called the mechanical characteristic. A study of this characteristic will give an idea about the behaviour of the motor in load conditions. As the torque of the motor is also dependent on the slip, it will be interesting to study the characteristic of the squirrel cage induction motor to find the relationship between load, speed, torque and slip.

Speed, torque and slip characteristics : It has already been made clear that the rotor speed of a squirrel cage motor will always lag behind the synchronous speed of the stator field. The rotor slip is necessary in order to induce the rotor currents required for the motor torque. At no load, only a small torque is required to overcome the motor's mechanical losses, and the rotor slip will be very small, say about two percent. As the mechanical load is increased, however, the rotor speed will decrease, and hence, the slip will increase. This increase in slip inturn increases the induced rotor currents, and the increased rotor current in turn, will produce a higher torque to meet the increased load.

Fig 1 shows the typical speed torque and slip characteristic curves for a standard squirrel cage motor. The speed curve shows that a standard squirrel cage motor will operate at a relatively constant speed from no load to full load.

Fig 1



Since the squirrel cage rotor is constructed basically of heavy copper/aluminium bars, shorted by two end rings, the rotor impedance will be relatively, low and hence, a small increase in the rotor induced voltage will produce a relatively large increase in the rotor current. Therefore, as the squirrel cage motor is loaded, from no-load to full load, a small decrease in speed is required to cause a relative increase in the rotor current. For this reason, regulation of a squirrel cage motor is very good. But the motor is often classified as a constant speed device.

The slip curve shows that the percentage slip is less than 5% load, and is a straight line.

Since the torque will increase in almost direct proportion to the rotor slip, the torque graph is similar to the slip graph which also has a straight line characteristic as shown in Fig 1.

Relationship between torque, slip rotor resistance and rotor inductive reactance : It was stated earlier that torque is produced in an induction motor by the interaction of the stator and the rotor fluxes. The amount of torque produced is dependent on the strength of these two fields and the phase relation between them. This may be expressed mathematically as

$T = K\,\phi_s I_R \cos\phi$

where T = torque in Newton metre

K = a constant

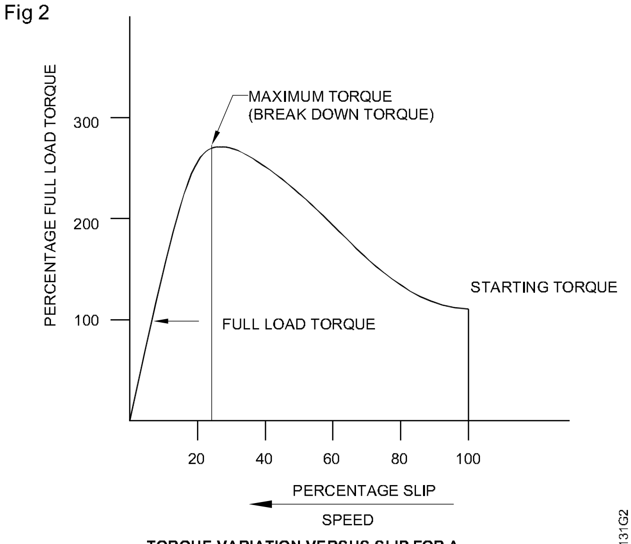
ϕ_s = stator flux in weber

I_R = rotor current in ampere

$\cos\phi$ = rotor power factor

From no load to full load, the torque constant (K), the stator flux (ϕ_s) and the rotor power factor ($\cos\phi$) for a squirrel cage motor will be practically constant. Hence the motor's torque will vary almost directly with the induced rotor current (I_R) since the rotor current inturn will vary almost directly with its slip. Variation of the torque of a squirrel cage motor is often plotted against its rotor slip as shown in Fig 2.

Fig 2



TORQUE VARIATION VERSUS SLIP FOR A STANDARD SQUIRREL - CAGE MOTOR

The increase in the rotor current, and hence, the increase in the rotor torque for a given increase in the rotor slip is dependent on the rotor power factor. The rotor resistance for a squirrel cage motor will be constant. However, an increase in slip will increase the rotor frequency, and the resulting inductive reactance of the rotor from no load to full load and even upto 125 percent of rated load, the amount of rotor slip for a standard squirrel cage motor is relatively small and the rotor frequency will seldom exceed 2 to 5 Hz. Therefore, for the above range of load the effect of frequency change on impedance will be negligible, and as shown in Fig 2, the rotor torque will increase in almost a straight relationship with the slip.

Inbetween 10 to 25 percent slip the squirrel cage motor will attain its maximum possible torque. This torque is referred to as the maximum breakdown torque, and it may reach between 200 and 300 percent of the rated torque as shown in Fig 2. At the maximum torque, the rotor's inductive reactance will be equal to its resistance.

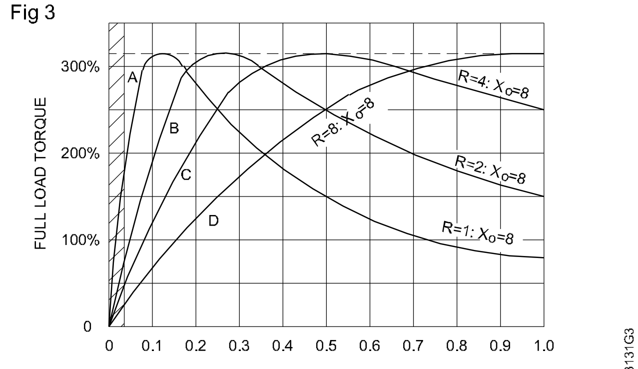
However, when the load and the resulting slip are increased much beyond the rated full load values, the increase in rotor frequency, and hence, the increase in rotor reactance and impedance become appreciable. This increase in rotor inductive reactance and the resulting decrease in rotor power factor will have two effects; first, the increase in impedance will cause a decrease in the rate at which the rotor current increases with an increase in slip, and second, the lagging rotor power factor will increase; that means, the rotor flux will reach its maximum sometime after the stator peak flux has been swept by it. The out-of-phase relationship between these two fields will reduce their interaction and their resulting torque. Hence, if the motor load is increased beyond the breakdown torque value, the torque falls rapidly due to the above two effects and the motor operation becomes unstable, and the motor will stall.

Effect of rotor resistance upon the torque/slip relationship: Fig 3 shows the relationship between torque and slip when the rotor resistance is changed. The shaded portion of the curve shows the actual operating area. Curve A for an induction motor with low rotor resistance, say 1 ohm, Curve B is for 2 ohm, Curve C is for 4 ohm and Curve D for 8 ohm.

Breakdown torque : In all these cases the standstill inductive reactance of the rotor is the same, say 8 ohm. From the curves it is clear that the maximum (breakdown) torque is the same for the four values of R. Further it is also clear that the maximum torque occurs at greater slip for higher resistance.

Starting torque : At the time of starting, the fractional slip is 1, and the starting torque is about 300% of the full load torque for the rotor having maximum resistance as shown by curve D of Fig 3, and at the same time the rotor having low resistance will produce a starting torque of 75% of the full load torque only, as shown by curve A of Fig 3. Hence, we can say that an induction motor having high rotor resistance will develop a high torque at the time of starting.

Fig 3



FRACTIONAL SLIPS TORQUE/SLIP CURVES FOR AN INDUCTION MOTOR

Running torque : While looking at the normal operating region in the shaded portion of the graph, it will be found the torque at running is appreciably high for low resistance rotor motors and will be conspicuously less for high resistance rotor motors.

As squirrel cage induction motors will have less rotor resistance, their starting torque is low but running torque is quite satisfactory. This is partly compensated by the double squirrel cage motors which produce high starting and normal running torque. On the other hand, the slip ring induction motor, due to its wound rotor, has the possibility of inclusion of resistance at the time of starting and reducing the same while running.

Application of squirrel cage induction motor : Single squirrel cage motors are used widely in industries and in irrigation pump sets where fairly constant speed is required. This motor has fairly high efficiency, costs less and is found to be robust in construction.

Double squirrel cage induction motors are used in textile mills and metal cutting tool operations where high starting torque is essential.

No-load test of induction motor

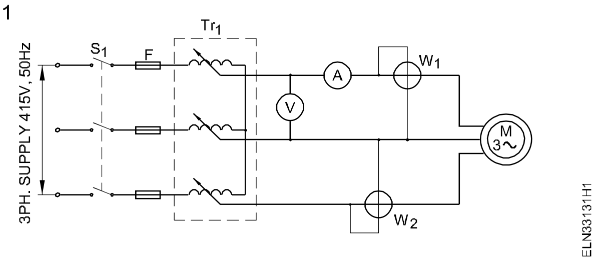
Objectives: At the end of this lesson you shall be able to
- **determine the constant (mechanical and iron losses of induction motor) by no-load test**
- **calculate the total equivalent resistance per phase.**

No-load test

The induction motor is connected to the supply through a 3-phase auto-transformer (Fig 1). The 3-phase auto-transformer is used to regulate the starting current by applying low voltage at the start, and then gradually increased to rated voltage. The ammeter and voltmeters are selected based upon the motor specification. The no-load current of the motor will be very low, up to 30% of full load.

As the power factor of the motor on no-load is very low, in the range of 0.1 to 0.2, the wattmeters selected are such as to give a current reading at low power factor. The wattmeter full scale reading will be approximate equal to the product of the ammeter and voltmeter full scale deflection values.

Fig 1



The calculation is done as follows to determine the constant losses of the induction motor.

At no-load, the output delivered by the motor is zero. All the mechanical power developed in the rotor is used to maintain the rotor running at its rated speed. Hence the input power is equal to the no-load copper loss plus iron losses and mechanical losses.

Calculation

V_{NL} is ® line stator voltage

I_{NL} is ® line current

P_{NL} is ® Three-phase power input.

The input power consists of the core loss P_c, friction and windage loss $P_{(rot)}$, and the stator copper loss.

$$P_{NL} = P_c + P_{rot} + 3\, I^2_{NL}\, R_S$$

This permits the sum of rotational loss to be evaluated.

$$P_{rot + C} = P_{NL} - 3\, I^2_{NL}\, R_S$$

where the stator resistance Rs per phase obtained from a resistance measurement at the stator terminal.

In star connection $R_S = R/2$.

Delta connection $R_S = 2/3\ R$.

Blocked rotor test

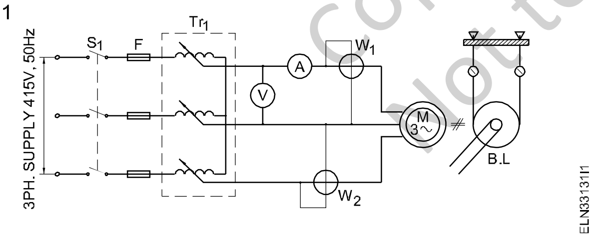
Objectives: At the end of this lesson you shall be able to

- **determine the full load copper loss of a 3-phase induction motor by blocked rotor test**
- **calculate the total equivalent resistance per phase and efficiency.**

The connections are made similar to that of the no-load test. In this case the ammeter is selected to carry the full load current of the motor. Wattmeters will be of a suitable range and its power factor is 0.5 to unity.

An auto-transformer is used to give a much lower percentage of the rated voltage. The rotor is locked by a suitable arrangement such that it cannot rotate even if the supply is given to the motor. One such arrangement is shown in Fig 1. The belt is over-tightened on the pulley to prevent rotation.

Fig 1



As the rotor is in a locked condition it is equivalent to the short circuit secondary of a transformer. Therefore, a small induced voltage in the rotor cage winding will be sufficient to cause a large current to flow in the cage.

It is very essential to limit the supply voltage to a value less than 5% at start and then gradually increase until the starter current is equal to the full load current. The frequency of the starter supply voltage is maintained at normal rated supply frequency.

The method of calculating the copper losses from the result is illustrated through the example given below.

Example

A 5 HP 400V, 50 Hz, four-pole, three-phase induction motor was tested and the following data were obtained.

Blocked rotor test: $V_s = 54$. $P_s = 430$, $I_s = 7.5$ A.

The resistance of the stator winding gives a 4 V drop between the terminals' rated DC current flowing.

Find the power factor at short circuit and R_e and X_e and full load copper loss.

Given:

Output	= 5 HP
Voltage	= 400 V
Frequency	= 50 Hz.
Blocked rotor voltage, V_S	= 54 V
Power P_S,	= 430 W
Current, I_S	= 7.5 A

Find:

Power factor at short circuit	= $\cos \theta_S$
Equivalent resistance, R_e/phase	
Equivalent reactance X_e/phase	
Full load copper loss	= $3I^2R_e$.

Known:

$$W_S = \sqrt{3}\, V_S I_S \quad \cos \varnothing_S$$

Equivalent impedance $Z_e = \frac{V_s}{\sqrt{3} I_s} = \sqrt{R_e^2 + X_e^2}$

R_e = equivalent resistance $= \frac{P_s}{3I_s^2}$

X_e = equivalent reactance $= \sqrt{Z_e^2 - R_e^2}$

Solution:

$W_S = \sqrt{3}\, V_S I_S \ \text{Cos} \varnothing_S$

$\text{Cos}\phi_s = \frac{W_s}{\sqrt{3}\, V_s I_s}$

$\text{Cos}\,\phi_S = \frac{430}{1.72 \times 54 \times 7.5}$

$= \frac{430}{696.6}$

$= 0.61$

Equivalent resistance R_e/phase $= \frac{P_s}{3 \times I_s{}^2}$

$= \frac{430}{3 \times (7.5)^2}$

$= \frac{430}{168.75} = 2.5\Omega$

X_e = equivalent reactance/phase $= \sqrt{Z_e^2 - R_e^2}$

$Z_e = \frac{54}{\sqrt{3} \times 7.5} = \frac{54}{12.90} = 4.1\Omega.$

$X_e = \sqrt{4.1^2 - 2.5^2} = \sqrt{16.81 - 6.25}$

$= \sqrt{10.56} = 3.24\Omega.$

Full load copper loss $= 3\, I^2 R_e$

$= 3 \times 7.5^2 \times 2.5 = 421.875$ watts

Answer

i $\cos\phi_s = 0.61$

ii Equivalent resistance R_e/phase = 2.5 Ω

iii Equivalent reactance X_e/phase = 3.24 Ω

iv Full load copper loss = 421.875 watts

Efficiency from no-load and blocked rotor test

Objective: At the end of this lesson you shall be able to
- **determine the efficiency at full load.**

Example

A 5 HP 220V, 50 Hz four-pole, three-phase induction motor was tested and the following data were obtained.

No load test = V_{NL} = 220V, P_{NL} = 340 W, I_{NL} = 6.2 A

Blocked rotor test = V_{BR} = 54V, P_{BR} = 430W,

I_{BR} = 15.2 A

Application 4V DC across two stator terminals causes the rated current flow with stator (assume star connection). Determine the efficiency at full load.

Assuming star connection DC resistance/phase = R/2

SOLUTION:

$R_1 + R_2$ = 4/15.2 = 0.263 W

Resistance/phase = 0.263/2 = 0.1315 Ω

Effective AC resistance $R_s = 1.4\, R_{ph}$

= 1.4 x 0.1315

= 0.1841 Ω

$R_{(rot + c)} = P_{NL} - 3I^2_{NL} R_s$

= 340 - 3 x 6.2² x 0.1841

= 340 - 21.23

= 318.77 W(constant loss)

Copper loss $= 3I^2 R_e$ = 430 W

Output = 5 x 735.5 = 3677.5 W

$\text{Efficiency} = \frac{3677.5}{3677.5 + 318.77 + 430} = \frac{3677.5}{4426.2}$

= 0.830

% efficiency = 0.830 x 100

i.e. = 83%.

Effect of external resistance in slip ring motor rotor circuit

Objective: At the end of this lesson you shall be able to
- **explain the effect of introducing additional rotor resistance in an induction motor.**

We have seen that the slip-ring induction motor is started by controlling resistance in the form of a rheostat connected in star. By increasing the rotor resistance, the rotor current is reduced at starting. Hence the starter current is also reduced. The starting torque is high because of improvement in the rotor power factor.

The introduction of external resistance in the rotor circuit is applicable to slip-ring motors only. The motor speed is reduced by introducing an external resistance in the rotor circuit.

We know that the torque under running condition is

$T \alpha E_r I_r \cos \phi_2$

or $T \alpha \phi I_r \cos \phi_2$ because $E_r \alpha \phi$

where E_r = rotor emf/phase under running condition

I_r = rotor current / phase under running condition

$E_r = s E_2$

Therefore

At normal speeds close to synchronous speed, the sX_2 is small and hence negligible with respect to the value of R_2.

Hence T as/R_2

It is obvious that for a given torque, slip can be increased, that is, speed can be decreased by increasing the rotor resistance. This method is used to control the speed of a slip-ring motor.

One serious disadvantage of this method of speed control is that with the increase in rotor circuit resistance, I^2R losses also increases. Thus the operating efficiency of the motor decreases. This method of speed change is used only where such changes are needed for short periods only.

Auto-transformer starter

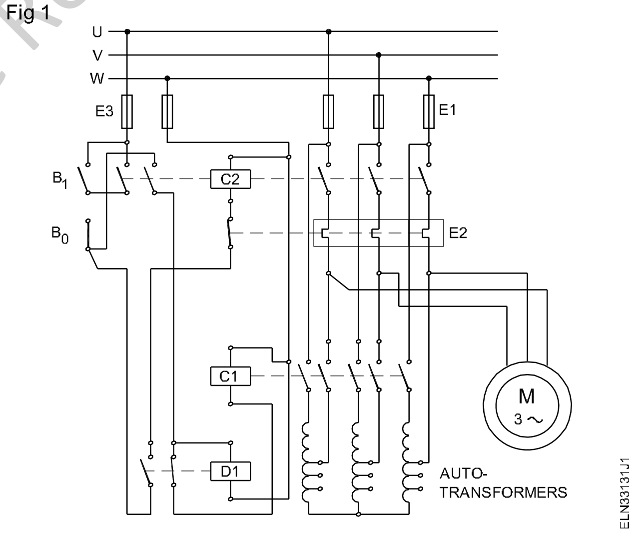
Objectives: At the end of this lesson you shall be able to
- **explain the construction and operation of auto-transformer starter**
- **explain power circuit and control circuit of auto-transformer starter.**

Auto-transformer starter

By connecting series resistances reduced voltage is obtained at the motor leads. It is simple and cheap, but more power is wasted in the external series resistances.

In auto transformer starting method the reduced voltage is obtained by taking tappings at suitable points from a three phase auto -transformer as shown in Fig 1. The auto transformers are generally tapped at 55, 65, 75 percent points. So that the adjustment at these voltages may be made for proper starting torque requirements. Since the contacts frequently break, large value of current acting some time quenched effectively by having the auto-transformer coils immersed in the oil bath.

Fig 1



The power circuit of the auto-transformer is shown in Fig 2a and control circuit of auto-transformer is shown in Fig 2b.

Auto-transformer starter - operation

In this type of starter reduced voltage for starting the motor is obtained from a three-phase star connected auto-transformer. While starting, the voltage is reduced by selecting suitable tappings from the auto-transformer. Once the motor starts rotating 75% of its synchronous speed, full line voltage is applied across the motor and the auto-transformer is cut off from the motor circuit.

Fig 3 shows the connection of an auto-transformer starter. To start the motor the handle of the starter is turned downward and the motor gets a reduced voltage from the auto-transformer tappings. When the motor attains about 75% of its rated speed the starter handle is moved upward and the motor gets full voltage. The auto-transformer gets disconnected from the motor circuit.

Fig 2

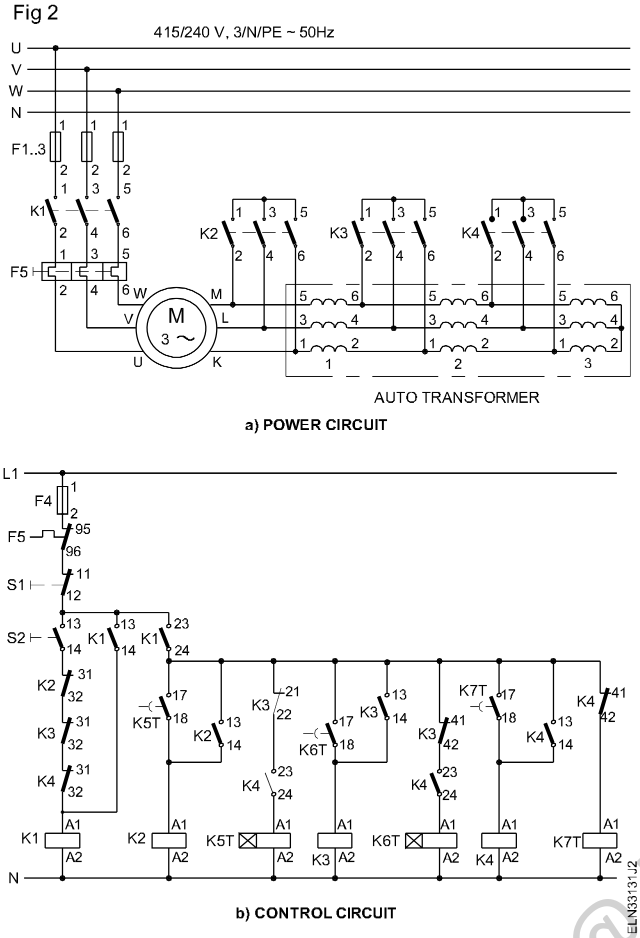
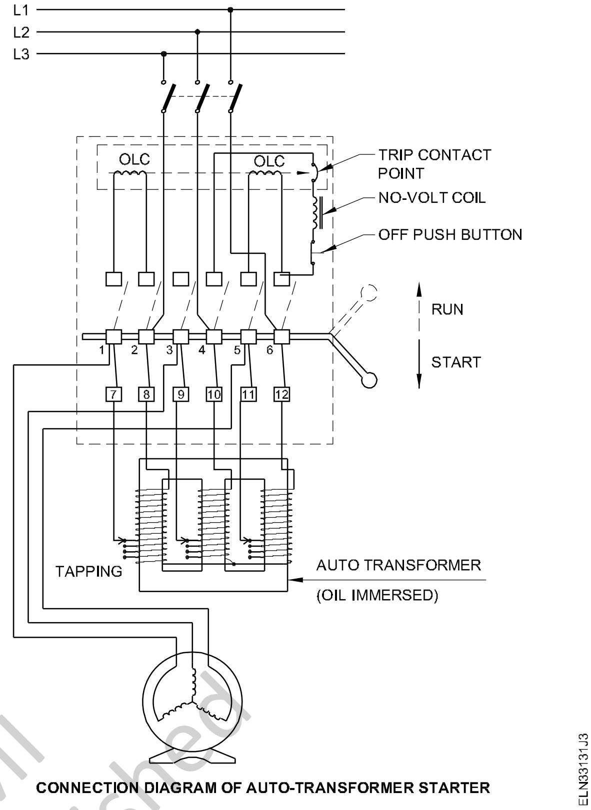


Fig 3



Hand operated auto-transformer starters are suitable for motors from 20 to 150 hp whereas automatic auto-transformer starters are used with large horse-power motors upto 425 hp.

Single phasing preventer/phase failure relay

Objectives: At the end of this lesson you shall be able to
- **define single phasing**
- **state the effects of single phasing**
- **explain the necessity of a single phasing preventer**
- **classify the single phasing preventers**
- **explain the installation procedure**
- **explain the procedure for troubleshooting and servicing of single phasing preventer.**

Single phasing preventer/phase failure relay : When one of the three lines of a three-phase supply system fails or opens, the load current flows between the other two lines only and the fault is known as single phasing.

Effect of single phasing: The effect of single phasing is different with different types of loads as follows

- In 3-phase heating loads, the heat produced decreases to around 50%; at the same time it does not harm the equipment.
- In three-phase motors, the effect of single phasing is different on different occasions. i) During starting, if single phasing occurs, the motor fails to start or stalls as proper rotating magnetic field is not created. But the motor draws a very large current and motor windings gets heated up. ii) During running, if single phasing occurs, the motor may or may not run depending upon the load condition and the phase in which supply is available will draw a large current and the winding is likely to burn out due to overheating.

Necessity of single phasing preventor/phase failure relay: If two phases of the supply to a three-phase induction motor are interchanged, the motor will reverse its direction of rotation. This action is called phase reversal. In the operation of elevators and in many industrial applications, phase reversal may result in serious damage to the equipment and injury to people using the equipment. In other situations, if a fuse blows or a wire connected to the motor breaks while the motor is running, the motor will continue to operate on two phase but will experience serious overheating. To protect motors against these conditions of phase failure, a sinlge phase preventor is used.

Types of preventors: Single phasing preventors are available in three types.

- Mechanical
- Current sensing
- Voltage sensing

Single phasing preventor - mechanical type : One type of single phasing preventor is incorporated with bimetal relays which opens the NVC circuit similar to that of normal OLR. This type of single phasing preventor is slow in operation and, also not fully reliable, and hence, not preferred nowadays.

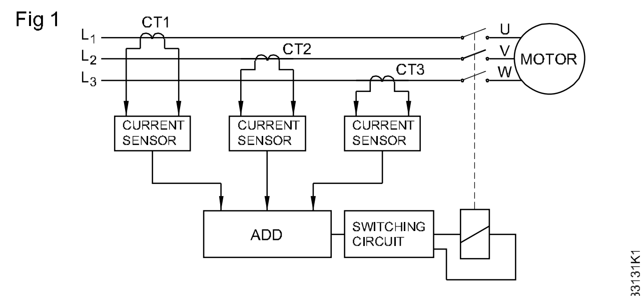
The second type of mechanical phase failure relay uses coils connected to two lines of the three-phase supply. The currents in these coils set up a rotating magnetic field that tends to turn a copper disc clockwise. This clockwise torque actually is the resultant of two torques acting in opposite direction. Out of two torques, one polyphase torque tends to turn the disc clockwise, and one single-phase torque tends to turn the disc anti-clockwise.

The disc is kept from turning in the clockwise direction by a projection resting against a stop. However, if the disc begins to rotate in the anti-clockwise direction, the projecting arm will move a toggle mechanism to open the starter and disconnect the motor from the line. In other words, if one line is opened, the poly-phase torque disappears and the remaining single-phase torque rotates the disc in anti-clockwise direction. As a result, the motor is disconnected from the line. In the case of phase reversal, the poly-phase torque helps the single-phase torque to turn the disc anti-clockwise, and again, the motor is disconnected from the line.

Single phasing preventers - current sensing : It operates on the principle of equal currents with balanced loads developing secondary voltage on current transformers. These secondary voltages are so connected so as to add and the added voltage is rectified, filtered and sensed and applied to operate a relay which operate to close the NVC circuit of the starter.

Fig 1 shows the block diagram of a current sensing single phasing preventor.

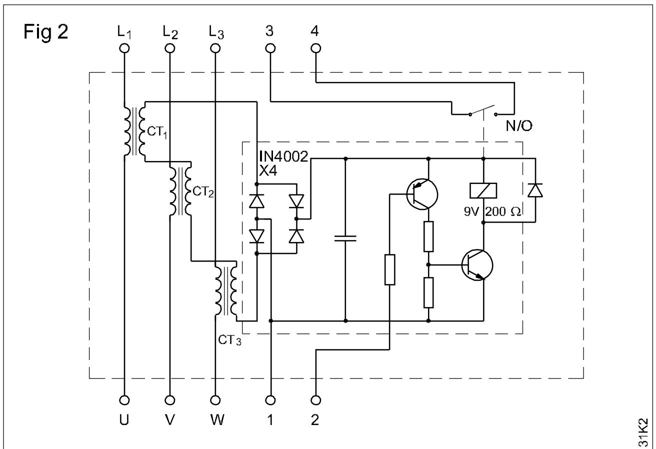
Fig 1



SINGLE PHASING PREVENTOR

Fig 2 shows a typical circuit diagram of current sensing single phase preventor. The terminals 1 and 2 are used if any time delay circuit is to be introduced. Otherwise they are kept shorted.

Fig 2



TYPICAL CIRCUIT DIAGRAM OF CURRENT SENSING SINGLE PHASING PREVENTOR

Terminals 3 and 4 are connected in series with the NVC circuit of starter. The relay will not operate if the motor draws a current lesser than the specified value or the circuit is unbalanced thereby keeps the motor off.

This type of single phasing preventors are suitable only where the motors run with a constant load such as pump motors, compressor motors etc. It also serves as dry run protection unit as and when the motor is out of load, such as a pump running without water, the load current decreases and the circuit senses and trips the motor circuit.

Single phasing preventer - voltage sensing : In an AC three-phase supply the order in which three -phase voltages reach the maximum value is known as phase sequence. The phase voltage reaches their maximum positive value one after another at 120° in clockwise known as positive phase sequence and in anti-clock wise known as negative phase sequence. In the case of phase reversal or unbalanced voltages or no voltage in a line it results in a super-imposition of negative phase sequence over the normal positive phase sequence of supply voltages. This negative sequence is filtered by a resistance capacitance or resistance, capacitance and inductor network and de-energise the relay in the voltage the sensing single phasing preventor.

Fig 3 and Fig 4 shows the block diagram and circuit diagram of a typical voltage sensing single phasing preventor. In this a resistance, capacitance network is utilized to sense the negative phase sequence. When phase sequences and voltages are correct, no voltage will be generated across the filtered output i.e. across capacitor. C_4 in the circuit which drives the transistor Q_1 to cut off transistor Q_2 to drive the relay.

When the negative sequence occurs due to unbalanced supply voltage or phase reversal, a voltage is developed across the capacitor C_4 which drives the transistor Q_1 to saturation and transistor Q_2 to cut off. This results in switching off the relay circuit.

Some of the single phasing preventors are provided with the facility to adjust unbalanced settings. For example when the relay is found to operate very frequently for the set value, the unbalanced pre-set can be changed by operating the pre-set P_5 in Fig 4.

Fig 3

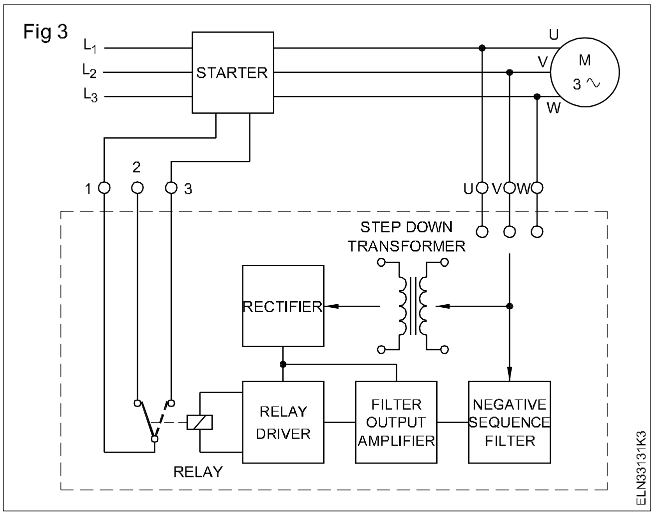
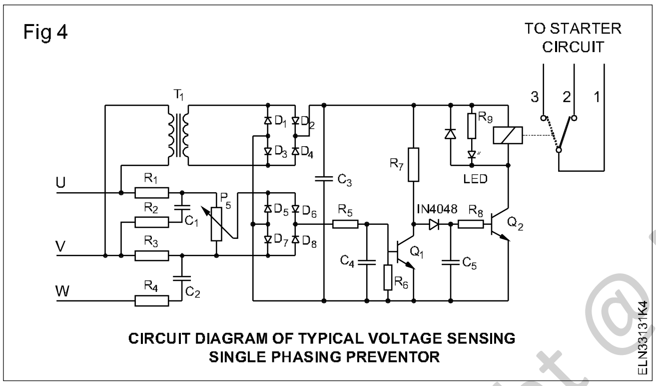


Fig 4



CIRCUIT DIAGRAM OF TYPICAL VOLTAGE SENSING SINGLE PHASING PREVENTOR

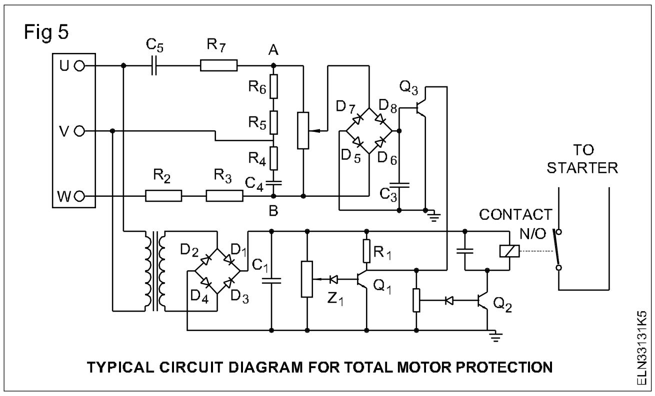
Single phasing preventor with over-voltage and under voltage cut off (Total motor protection) : When a motor is fed with reduced voltage, the motor draws excess current to drive the load and with an over -voltage, also it draws excess current. To protect the motor from under-voltage or over-voltage and also from single phasing a preventor with over and under voltage protection is used for total motor protection.

Fig 5 shows an arrangement of over-voltage and under - voltage cut off circuit along with single phasing preventor.

In the circuit transistor Q_1 serves as over-voltage cut off and transistor Q_2 serves as under-voltage cut off where- as transistor Q_3 serves as single phasing preventor.

Installation of single phasing preventor : Installation and connection of single phasing preventor shall be done as recommended by the manufacturer. Preferably single phasing preventors shall be located nearer to the equipment and not subjected to abnormal vibration. Care should be taken to locate the unit away from a heat generating source such as oven, furnace etc.

Fig 5



TYPICAL CIRCUIT DIAGRAM FOR TOTAL MOTOR PROTECTION

A single phase preventor shall be connected with the supply line and starter to the appropriate terminals and circuits.

Some of the commonly used single phasing preventors and their connection with starter are shown in Figs 6 & 7 for your reference.

Fig 6

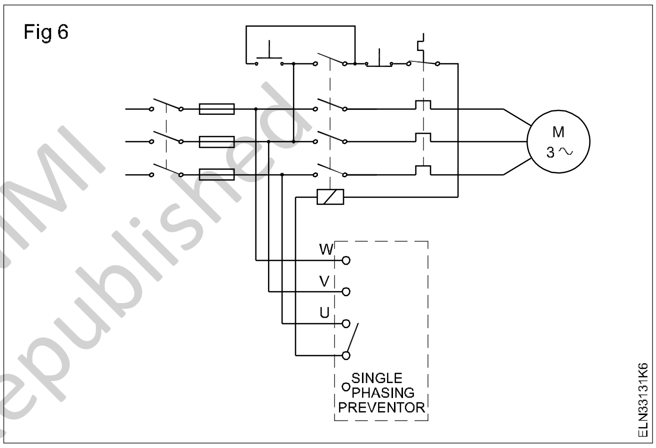
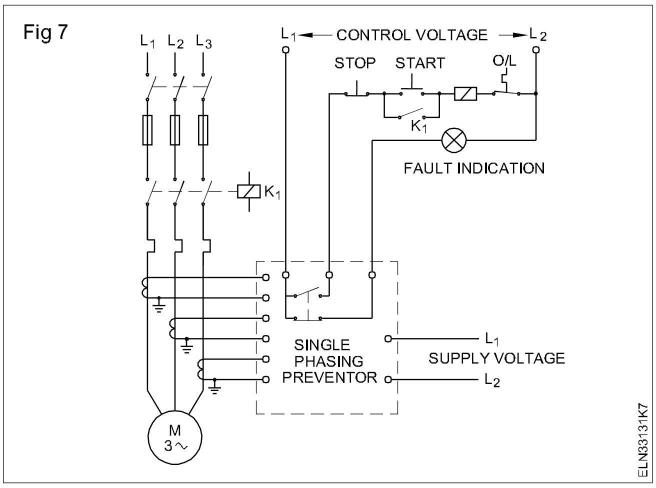


Fig 7



Troubleshooting and maintenance of single phasing preventor : The arrangement of components and their circuits of single phasing preventors vary from one make to another make as well as from one type to another type.

It is preferred to follow the manufacturer's recommendations for troubleshooting and maintenance of single phase preventors. A few general guide lines for troubleshooting of single phase preventors are given in the Table-1.

Table 1

S.No.	Symptoms	Possible causes	Remedy
1.	Starter with single phase preventor does not start.	No supply. Low supply voltage.	Check and resume supply. Verify and correct the voltage.
		Unbalanced line voltages.	Verify and correct.
		Improper phase sequence.	Reverse the phase sequence by interchanging any two incoming lines.
		Single phasing	Check and rectify.
		No control circuit voltage.	Check and rectify.
2.	Starter with single phase preventor does not hold on.	Low supply voltage. Unbalanced line voltages.	Verify and correct. Verify and correct.
		Single phasing.	Verify and correct.
		Improper phase sequence.	Reverse the phase sequence.
		Defect in single phase preventor electronic circuit.	Check, repair or replace.
		Relay of single phase preventor is not energised.	Check, rectify or replace.
		Improper function of relay contacts.	Check, rectify or replace.
		Open in holding circuit.	Check and correct.
3.	Starter with single phase preventor trips frequently.	Abnormal fluctuations in line voltages.	Check and rectify.
		Improper settings or unbalanced settings.	Adjust the unbalanced settings.
		Loose contact in supply lines/ control circuit.	Check and rectify.

Braking system of motors

Objectives: At the end of this lesson you shall be able to
- **state the necessity of braking system for motors**
- **list and explain each type of braking system.**

Necessity of braking system

The term braking comes from the term brake. The brake is an equipment to reduce the speed of any moving or rotating equipment, like vehicles, locomotives etc. The process of applying brakes can be termed as **braking.**

The term braking in two parts **i) Mechanical braking** and the **ii) Electrical braking.** In mechanical braking the speed of the machine is reduced solely by mechanical process but in electrical braking the whole process is depended on the flux and torque directions. Each type of electrical braking is the reversal of the direction of the flux. **Braking** is the process of reducing speed of any rotating machine. The application of braking is in factories, industrial areas or be it in locomotives or vehicles. Everywhere the use of mechanical and electrical brakes is inevitable.

Types of braking

Brakes are used to reduce or cease the speed of motors. There are various types of motors available (DC motors, induction motors, synchronous motors, single phase motors etc.) and the specialty and properties of these motors are different from each other, hence this braking methods also differs from each other. Braking can be divided in to three methods mainly, which are applicable for almost every type of motors.

1 Plugging type braking

2 Regenerative Braking

3 Dynamic braking.

1 Plugging type braking: In this method the terminals of supply are reversed, as a result the generator torque also reverses which resists the normal rotation of the motor and as a result the speed decreases. During plugging external resistance is also introduced into the circuit to limit the flowing current. The main disadvantage of this method is that here power is wasted.

2 **Regenerative braking:** Regenerative braking takes place whenever the speed of the motor exceeds the synchronous speed. This braking method is called regenerative braking because here the motor works as generator and supply itself is given power from the load, i.e. motors. The main criteria for regenerative braking is that the rotor has to rotate at a speed higher than synchronous speed, only then the motor will act as a generator and the direction of current flow through the circuit and direction of the torque reverses and braking takes place. The only disadvantage of this type of braking is that the motor has to run at super synchronous speed which may damage the motor mechanically and electrically, but regenerative braking can be done at sub synchronous speed if the variable frequency source is available.

3 **Dynamic braking:** Another method of reversing the direction of torque and braking the motor is dynamic braking. In this method of braking the motor which is at a running condition is disconnected from the source and connected across a resistance. When the motor is disconnected from the source, the rotor keeps rotating due to inertia and it works as a self -excited generator. When the motor works as a generator the flow of the current and torque reverses.

Method of speed control of 3 phase induction motor

Objectives: At the end of this exercise you shall be able to
- **list the speed control methods from stator and rotor side**
- **explain the speed control methods of 3 phase induction motor.**

In 3 phase induction motor, speed can be controlled from both stator and rotor side

1 Speed control methods from stator side
  - By changing the applied voltage
  - By changing the applied frequency
  - By changing the number of stator poles

2 Speed control from rotor side
  - Rotor rheostat control
  - Cascade operation
  - By injecting EMF in rotor circuit

1. Speed control from stator side

a) By changing the applied voltage: Torque equation of induction motor is

$$T = \frac{k_1 s E_2^2 R_2}{\sqrt{R_2^2 + (s X_2)^2}}$$

$$= \frac{3}{2\pi N_s} \frac{s E_2^2 R_2}{\sqrt{R_2^2 + (s X_2)^2}}$$

Rotor resistance R_2 is constant and if slip s is small then sX_2 is so small that it can be neglected. Therefore, $T \alpha$

sE_2^2 where E_2 is rotor induced emf and $E_2 \alpha V$

And hence $T \alpha V^2$, thus if supplied voltage is decreased, torque decreases and hence the speed decreases.

This method is the easiest and cheapest, still rarely used because-

1 A large change in supply voltage is required for relatively small change in speed.

2 Large change in supply voltage will result in large change in flux density, hence disturbing the magnetic conditions of the motor.

b) By changing the applied frequency: Synchronous speed (N_s)of the rotating magnetic field of induction motor is given by,

$$N_s = \frac{120f}{P} \text{rpm}$$

where, f = frequency of the supply and P = number of stator poles.

Thus, synchronous speed changes with change in supply frequency, and thus running speed also changes. However, this method is not widely used. This method is used where, only the induction motor is supplied by a generator (so that frequency can be easily changed by changing the speed of prime mover).

c) Changing the number of stator poles: From the above equation, it can be also seen that synchronous speed (and hence, running speed) can be changed by changing the number of stator poles. This method is generally used for squirrel cage induction motors, as squirrel cage rotor adapts itself for any number of stator poles. Change in stator poles is achieved by two or more independent stator windings wound for different number of poles in same slots.

For example, a stator is wound with two 3phase windings, one for 4 poles and other for 6 poles.

for supply frequency of 50 Hz

i) Synchronous speed when 4 pole winding is connected, Ns = 120 x (50/4) = 1500 RPM

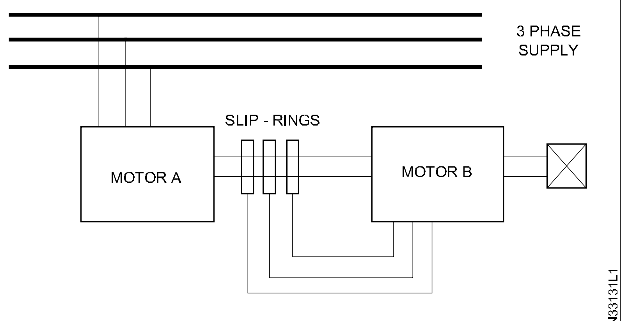
ii) Synchronous speed when 6 pole winding is connected, Ns = 120 x (50/6) = 1000 RPM

2 Speed control from rotor side

a) Rotor rheostat control: This method is similar to that of armature rheostat control of DC shunt motor. But this method is only applicable to slip ring motors, as addition of external resistance in the rotor of squirrel cage motors is not possible.

b) Cascade operation: In this method of speed control, two motors are used. Both are mounted on a same shaft so that both run at same speed. One motor is fed from a 3phase supply and other motor is fed from the induced emf in first motor via slip-rings. The arrangement is as shown in Fig 1.

Fig 1



CASCADE OPERATION

Motor A is called main motor and motor B is called auxiliary motor.

Let, N_{s1} = frequency of motor A

N_{s2} = frequency of motor B

P_1 = number of poles stator of motor A

P_2 = number of stator poles of motor B

N = speed of the set and same for both motors

f = frequency of the supply

Now, slip of motor A, $S_1 = (N_{s1} - N) / N_{s1}$.

Frequency of the rotor induced emf in motor A, $f_1 = S_1 f$. Now, auxiliary motor B is supplied with the rotor induce emf therefore, $N_{s2} = (120f_1) / P_2 = (120S_1 f) / P_2$. Now putting the value of $S_1 = (N_{s1} - N) / N_{s1}$

$$N_{s2} = \frac{120f\,(N_{s1} - N)}{P_2 N_{s1}}$$

At no load, speed of the auxiliary rotor is almost same as its synchronous speed. i.e. $N = N_{s2}$. From the above equations, it can be obtained that

$$N = \frac{120f}{P_1 + P_2}$$

With this method, four different speeds can be obtained

1 When only motor A works, corresponding speed = $N_{s1} = 120f / P_1$

2 When only motor B works, corresponding speed = $N_{s2} = 120f / P_2$

3 If cumulative cascading is done, speed of the set = $N = 120f / (P_1 + P_2)$

4 If differential cascading is done, speed of the set = $N = 120f (P_1 - P_2)$

c) By injecting EMF in rotor circuit: In this method, speed of induction motor is controlled by injecting a voltage in rotor circuit. It is necessary that voltage (emf) being injected must have same frequency as of slip frequency. However, there is no restriction to the phase of injected emf. If we inject emf which is in opposite phase with the rotor induced emf, rotor resistance will be increased. If we inject emf which is in phase with rotor induced emf, rotor resistance will decrease. Thus, by changing the phase of injected emf, speed can be controlled. The main advantage of this method is a wide range of speed control (above normal as well as below normal) can be achieved. The emf can be injected by various methods such as Kramer system, Scherbius system etc.

Fundamental terms used in AC winding

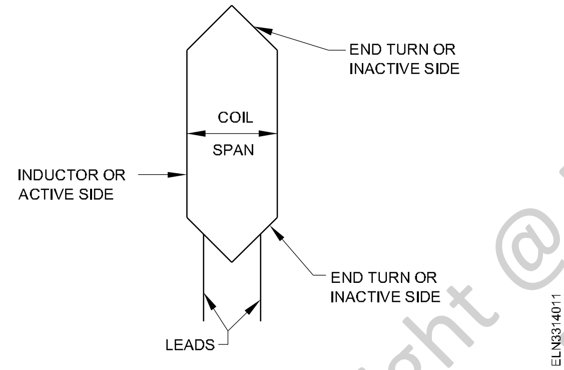
Objectives: At the end of this lesson you shall be able to
- **state the terms used in AC winding**
- **explain the different types of AC winding.**

Fundamental terms used in AC Winding: Before taking up AC winding, the trainee should be familiar with the terms used in AC winding as explained in the following paragraphs.

Coil : A number of turns connected in series is called a coil. A coil has two active sides and two inactive sides.

Turn: It is the closed path of the conductor which is formed by connecting the two inductors under two dissimilar poles N and S. (Fig 1)

Fig 1



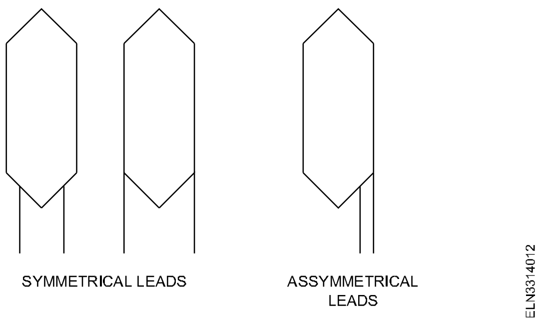
Active side of a coil : It is that part of the coil which lies in the slots of the core. It is also known as an inductor. (Fig 1)

Inactive side of a coil : It is the portion of the coil which joins the two active sides of a coil. (Fig 1)

Leads of a coil : These are the two ends of a coil which are used for the connection. Leads are also known as jumpers which may be symmetrical or unsymmetrical as shown in Fig 2.

Pole pitch : The distance between the centre of two adjacent opposite poles is called the pole pitch. Pole pitch is measured in terms of slots or coil sides.

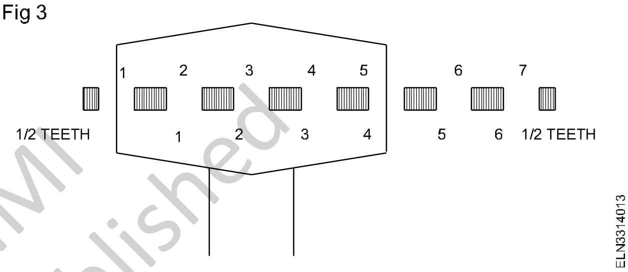
Fig 2



$$\text{Pole pitch} = \frac{\text{No. of slots in the stator}}{\text{No. of poles}}$$

Coil pitch/span and coil throw : The distance between the two active sides of a coil under adjacent dissimilar poles is called coil pitch/span. Fig 3 shows the coil pitch/span and coil throw (i.e. coil pitch/span = 4 and coil throw is 1-5).

Fig 3



Pitch factor : Winding pitch need not be equal to the pole pitch. If the pole pitch and winding pitch are equal, the winding is called full pitched winding. If the winding pitch is less than the pole pitch, the winding is called fractional pitch winding or short pitch winding. While rewinding, the original winding pitch should not be changed. The machine designer would have chosen the winding pitch after considering the different factors required for the better performance of the machine. Any change in the original winding pitch of a machine will affect the performance of that machine. If the winding pitch is 4, then the coil throw is 1 to 5, and one side of the coil is placed in slot No.1 and the other side of the coil is inserted in slot No.5 as shown in Fig 3. Then the winding pitch is 5-1 = 4. The ratio between the winding pitch and pole pitch is called the pitch factor.

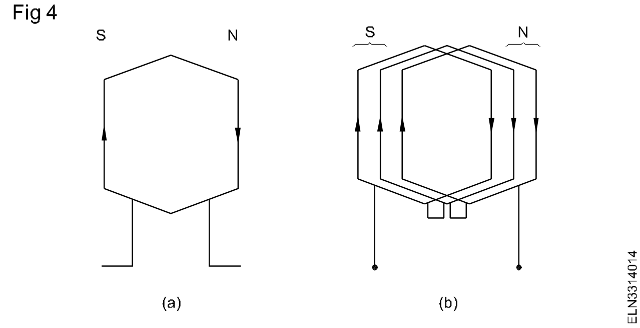
$$\text{Pitch factor} = \frac{\text{Winding pitch}}{\text{Pole pitch}}$$

Short pitch winding is usually used in almost all machines except variable speed motors. The reasons for adopting short pitch winding are given below.

1 Winding requires less copper.
2 Copper loss is less.
3 Efficiency of the machine is increased.
4 Winding occupies less space.
5 In alternators, the winding produces uniform sine wave.

Coil group : When you observe the direction of the current flow in a coil, you will see current in the two coil sides have opposite directions as shown in Fig 4(a).

Fig 4



Accordingly the current in a single coil produces two dissimilar poles. In an ordinary winding, according to the design, one or more coils may be connected in series to form a group as shown in Fig 4(b).(Three coils form one group) The total number of coil groups in a winding is equal to the number of phases multiplied by the number of poles.

Total No.of coil groups = No. of phases x No. of poles

$$\text{Coil group per phase} = \frac{\text{Total No. of coil groups}}{\text{No. of phases}}$$

Coil group per phase per pole =

$$\frac{\text{Total No. of coil groups}}{\text{No. of phases} \times \text{No. of poles}}$$

Further the number of coils in a group per phase per pole

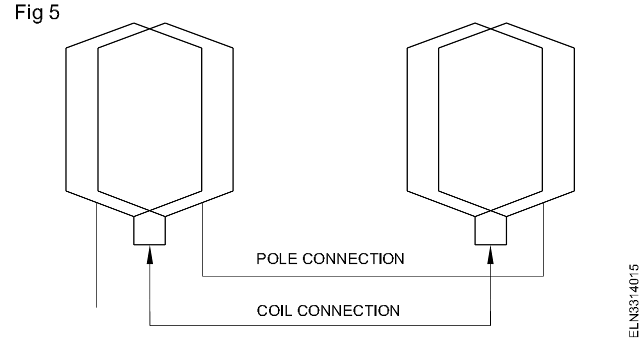
$$= \frac{\text{Total number of coils}}{\text{No. of phases x No. of poles}}$$

$$= \frac{\text{Total number of coils}}{\text{Total number of groups}}$$

Coil connections : The connection which joins a coil lead of one coil to the other coil lead of the same coil group is called ‘coil connection’ and is shown in Fig 5.

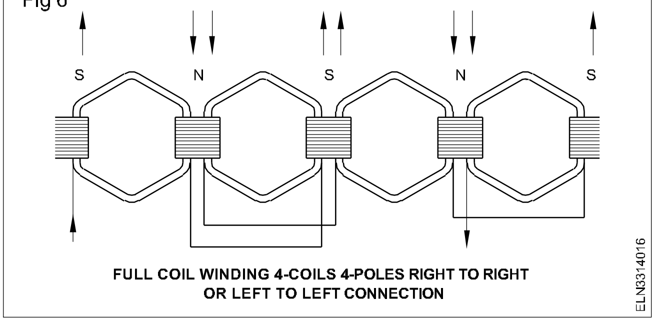
Pole connection : The connection which joins a coil group of one phase to another coil group of the same phase of the winding is called pole connection or group connection, and is shown in Fig 5.

Fig 5



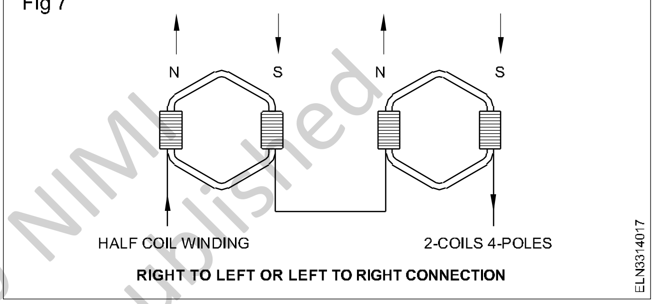
Whole-coil winding: A whole coil winding is one in which the number of coils per phase is equal to the number of poles in the machine. Refer to Fig 6.

Fig 6



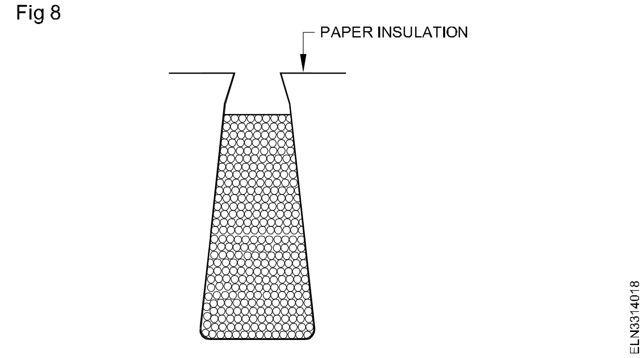
Half coil winding : A half coil winding is one in which the number of coils per phase is equal to half the number of poles in the machines. Half coil winding is generally done in the winding of ceiling fans, double speed motors etc. Refer to Fig 7.

Fig 7



Single layer winding : In single layer winding each slot contains only one coil side as shown in Fig 8 and the number of coils in the machine is equal to half the number of slots in the stator or armature. In single layer winding the coil pitch is usually taken in odd numbers.

Fig 8



Double layer winding : In double layer winding each slot contains two coil sides (i.e.one upper and one lower) as shown in Fig 9 and the number of coils is equal to the number of slots in the stator.

Balanced winding : When the coil groups contain the same number of coils per phase per pole the winding is termed as ‘balanced winding’. It is also known as ‘Even Group’ winding and is shown in Fig 10.

Unbalanced winding : If the coil group contains an unequal number of coils per phase per pole then the winding is called ‘unbalanced winding’. It is also sometimes called ‘odd group’ winding and is shown in Fig 11.

It is important that there must be an equal number of coils in each phase whether the winding is balanced or unbalanced as shown in Figs 10 and 11.

Fig 9

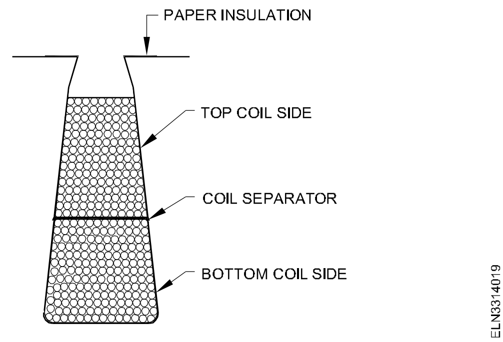
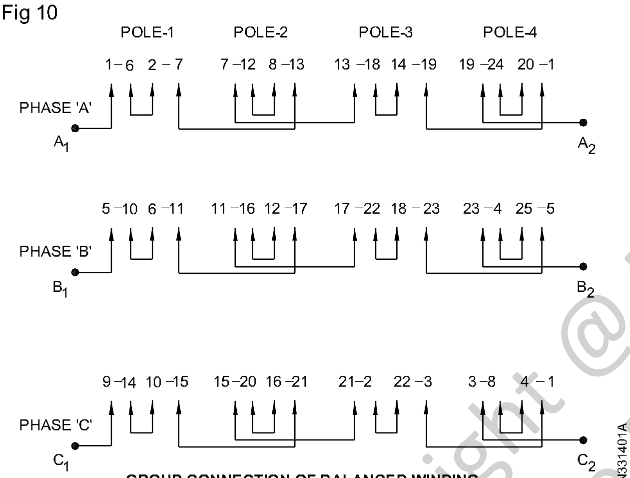
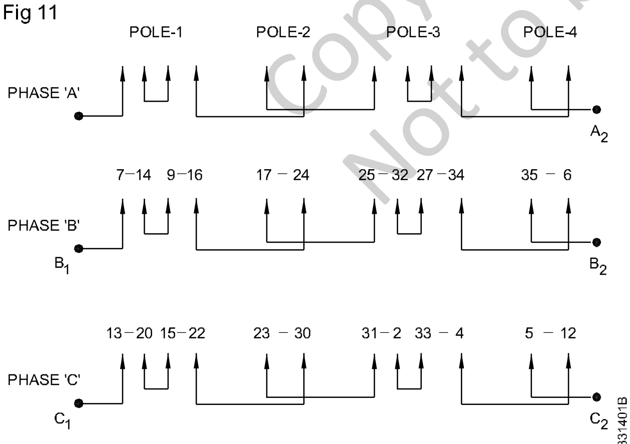


Fig 10



GROUP CONNECTION OF BALANCED WINDING

Fig 11



GROUP CONNECTION OF UNBALANCED WINDING

Concentrated winding : If in any winding the number of coils/pole/phase is one, then the winding is known as ‘concentrated winding’. In this winding each coil side occupies one slot.

Distributed winding : In this winding the number of coil/ pole/phase is more than one - arranged in different slots. In this case each coil has the same pole pitch.

Partially distributed winding: In this winding the coil sides do not occupy all the slots, but some slots remain empty and they are called dummy slots.

Fully distributed winding : It is a winding in which not a single slot remain empty.

Different types of AC Windings

The types of AC windings according to shape are as follows.

a Basket winding

b Concentric winding

c Skein winding

d Flat loop Non-overlapped winding

e Flat loop overlapped or chain winding

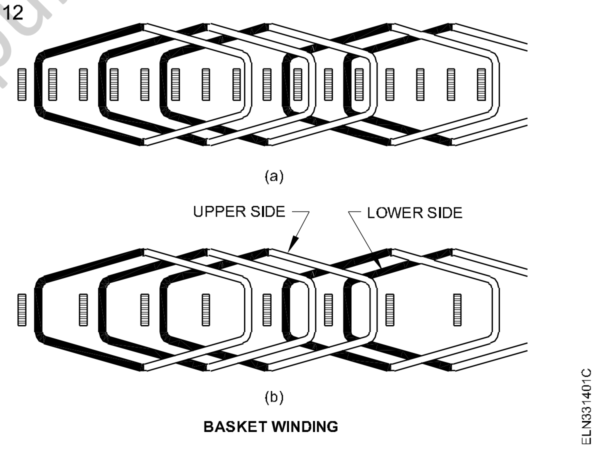
f Skew winding

g Diamond coil winding

h Involute coil winding

Basket winding : After the completion of the winding, the ends of the winding resemble the weaving of a basket and hence it is known as basket winding. Basket winding is of two types. a) Single layer basket winding as shown in Fig 12a, double layer basket winding as shown in Fig 12b.

Fig 12



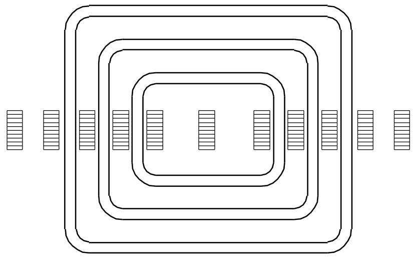
BASKET WINDING

Concentric (or box type) winding : This winding has two or more than two coils in a group, and the coils in each group have the same centre. In each group, the coil pitch is not equal, and, therefore, do not overlap each other.

In this winding the coil pitches are not equal and each coil of the group has a difference of 2 slots in its pitch. Though it requires more labour to insert coils due to different coil spans, the design allows more cooling space. This winding is usually provided in single phase motor winding. This is shown in Fig 13.

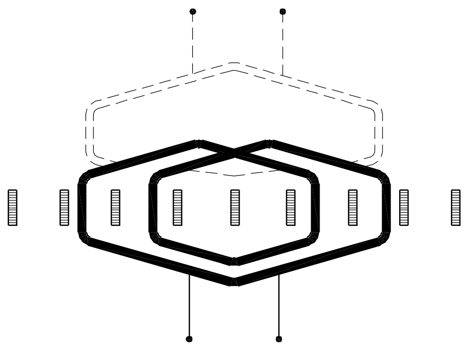
Skein winding : In skein winding, a long coil of sufficient length is first wound and then inserted in one slot. The remainder of the length is turned and inserted in the adjacent slots as shown in Fig 14.

Fig 13



CONCENTRIC WINDING

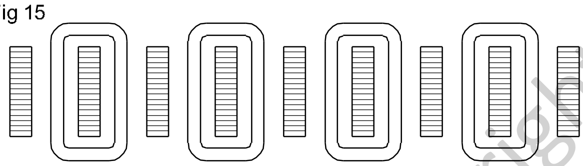
Fig 14



SKEIN WINDING

Flat loop non-overlapped winding : The coils of this winding do not overlap each other, and hence is known as 'flat loop non-overlap winding'. In such a winding each group has only one coil as shown in Fig 15.

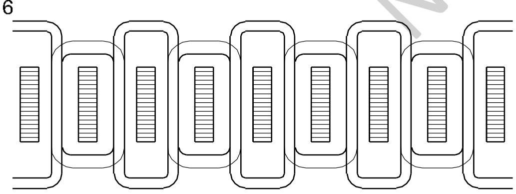
Fig 15



FLAT LOOP NON-OVER LAPPED WINDING

Flat loop overlapped or chain winding : In this winding, the number of coil/pole/phase is more than one having different pitches and the coils overlap each other in the form of a chain as shown in Fig 16.

Fig 16



FLAT LOOP OVERLAPPED WINDING OR CHAIN WINDING

Skew winding : The coil sides of this winding are unequal and as such allows greater space for heat radiation. This winding is shown in Fig 17.

Diamond coil winding : The shape of the coil used in this winding is just like a diamond as shown in Fig 18 and the coil occupies more space.

Involute coil winding : This type of coil is first made in the shape of a diamond coil and then it is pressed at inactive coil sides to attain a shape of involute coil as shown in Fig 19.

Fig 17

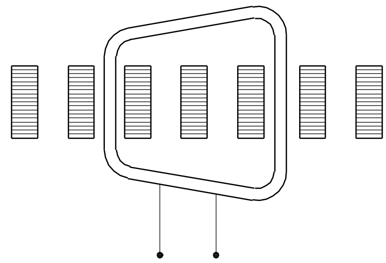


Fig 18

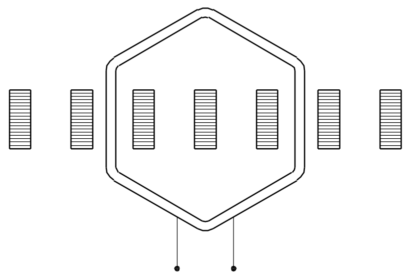
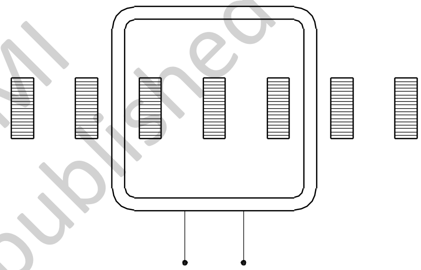


Fig 19



Electrical degrees: A pair of poles contain 360° electrical degrees. That is each pole has 180°. As such the number of electrical degrees in a motor depends upon the number of poles.

For 2 poles - 360° electrical degrees

For 4 poles - 720° electrical degrees

For 6 poles - 1080° electrical degrees

The slot angle could be calculated by the formula

$$\text{Slot angle} = \frac{180 \text{ x No. of poles}}{\text{Total No. of slots}}$$

Alternatively,

$$\text{Slot angle} = \frac{360 \text{ x pair of poles}}{\text{Total No. of slots}}$$

Phase dispalcement : For a single phase, the starting winding and running winding should be displaced by 90°. For example if the slot angle is 30°, the starting winding will be started in say, first slot and the running winding will be started in the fourth slot.

Example : The following is the insulation specification for Class 'B' motors.

Slot liner : One layer of 0.175 mm thick press paper with 0.25 mm thick fibre glass backed mica are used as a slot liner. This shall extend 10 mm beyond each end of the core.

Coil separator : In the case of multi-layer winding 0.375 mm thick press paper and fibre glass mica in combination are to be used and this should extend 10 mm beyond each end of the cores.

Wedge separator/packing strip : 0.375 mm thick melanex is used in between the slot liner and wedge. This should extend 10 mm beyond each end of the core.

Wedge : 2 mm or 3 mm vulcanised fibre is used. This should extend 6 mm beyond each end of the core.

Over hang inter-phase insulation : 0.25 mm varnished fibre glass cloth in the form of half moon is used as inter-phase insulation between coils of different phases. The separators after insulation should be bound with the coils by 0.15 mm varnished fibre glass chord.

Hand winding process

Objectives: At the end of this lesson you shall be able to
- **state the advantages of hand winding**
- **explain the method of hand winding.**

Hand winding may be used in split phase motors for both the starting and running winding. In this method, the winding wires are inserted in the slots, one turn at a time, starting with the inner coils until the winding operation is completed.

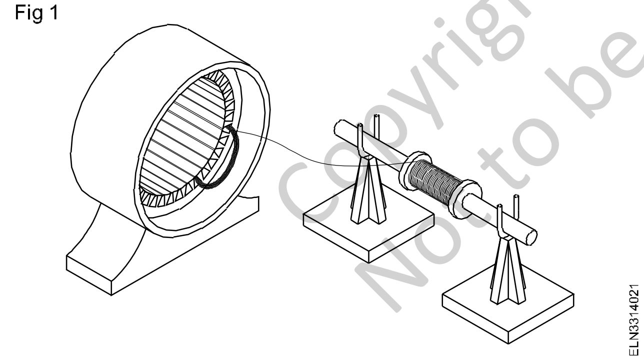
There are two main advantages in this method of winding.

1 A tight winding is possible, where the slot room is limited.

2 A winding former is not necessary.

The stator to be wound and the spool of winding wire are to be arranged as shown in Fig 1.

Fig 1



Assuming that the slots are properly insulated, the side of the stator where the connection end is to be placed is located and guide paper is placed in the respective slots.

The procedure for hand winding is as given below.

1 Set up the reel of selected size winding wire on a reel rack with a suitable tensioning device.

2 Insert the winding wire into a slot for the start of the inner coil having a smaller pitch.

3 Lace the winding wire through the identified slots according to the data, maintaining the tension.

4 After winding the designated turns in the first coil, continue the winding for the next larger coil according to the selected pole pitch.

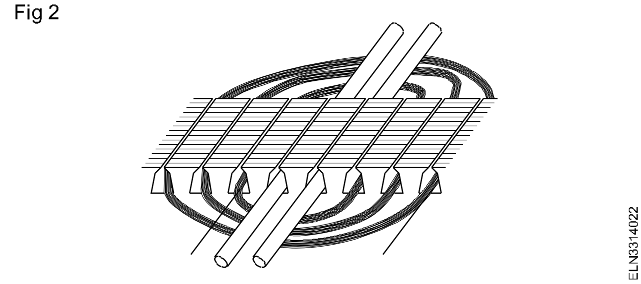
5 After winding the designated turns in the second coil, continue the winding for the next larger coil according to the selected pole pitch.

Complete the entire pole winding and take out the end connections.

6 Place wooden dowels as shown in Fig 2 in the empty slots to hold coils in position while winding.

7 Cut the wire and wedge the winding permanently in place if the slot contains only one coil side.

Fig 2



8 If the bottom coil side only is placed in the slots of the double layer winding, push temporary loose fitting wooden or fibre wedges in place for each slot until the stator is completed.

9 Remove the dowels.

10 Continue steps 2 to 9 for every pole until the bottom (main) winding of the stator is wound.

11 Set up a reel of the required size winding wire for the top (starting) winding.

12 Proceed to rewind the starting winding according to the collected data, following the above steps.

3 phase squirrel cage induction motor winding (single layer distributed winding)

Objectives: At the end of this lesson you shall be able to
- **explain the winding terms and calculations pertaining to single layer distributed type winding**
- **explain how to draw the end and coil connection diagrams**
- **state how to draw the ring and developed diagrams.**

Distributed type winding: The most common type of winding found in 3-phase motors is the distributed type winding. A distributed type winding is one in which the size of all the coils, coil pitch and shape will be the same as these coils are normally former wound. By virtue of the arrangement of these coils in slots, the coils overlap each other. Distributed winding may be of single or double layer type.

Single layer winding : Single layer winding is one in which there will be as many coils as half the number of slots. For example 6 coils in the case of 12 slots, 12 coils in case of 24 slots, 18 coils in the case of 36 slots and so on. In short, there will be only one coil side per slot.

Calculation for single layer distributed winding : The winding data of the distributed single layer winding will be within the following limitation. (As an example 3- phase, 24 slots, 12 coils, 4 poles is illustrated below).

I Grouping

i) $\text{No. of coils/phase} = \dfrac{\text{Total No. of coils}}{\text{No. of phases}}$

As in the example

No. of coils per phase = 12/3 = 4 coils/phase.

ii For whole coil connection

$$\text{No. of coils/phase/pole} = \frac{\text{Total No. of coils}}{\text{No. of phases x No. of poles}}$$

As in the example

$$\text{No. of coils/phase/pole} = \frac{12}{3 \times 4} = 1 \text{ coil/phase/pole}$$

iii) For half coil connection

$$\text{No. of coils/phase/pair of poles} = \frac{\text{Total No. of coils}}{\text{No. of phases x pair of poles}}$$

As in the example

$$\text{For each phase and pair of poles} = \frac{12}{3 \times 2} = 2 \text{ coils / phase / pair of poles}$$

For the example taken, half coil connection is possible for distributed winding by taking full pitch and placing coil in alternate two slots., but it is not in practice. Hence whole coil connection is taken as an example.

II Pitch

$$\text{Pole pitch} = \frac{\text{Total No. of slots}}{\text{No. of poles}}$$

As in the example, pole pitch = 24/4 = 6 slots.

ii) Coil pitch

In AC winding the relation between the coil pitch and the pole pitch is given below.

a) Coil pitch = Pole pitch	Then the winding is called full pitch winding.
b) Coil pitch < Pole pitch	Then the winding is called fractional pitch - short chorded winding.
c) Coil pitch > Pole pitch	Then the winding is called as fractional pitch - long chorded winding.

Further, if the winding is double layer, all the above 'a', 'b' and 'c' are possible. But for single layer distributed winding as the coils should be placed in alternate slots only, the coil pitch ought to be in odd number.

As in the example, coil pitch = pole pitch = 24/4 = 6 slots.

Here 6 is an even number and winding cannot be of full pitch, so the next alternative is to select a fractional pitch. Therefore the coil pitch can be taken either as 5 or 7. Normally AC windings should either have full pitch or short chorded fractional pitch. Hence a suitable pitch is taken of 5 slots.

iii) Coil throw

The coil throw for coil pitch '5' as in the example is 1 - 6.

III Electrical degrees

i) Total electrical degrees = 180^o x No. of poles

(180^o is the distance between poles)

ii) $\text{Slot distance} = \dfrac{180^0 \text{ x No. of poles}}{\text{No. of slots}}$

As in the example: Slot distance = (180x4)/24 = 30^o

IV Phase displacement

i) For three-phase winding, displacement between the phases should be 120^o.

ii) Phase displacement in terms of slots = 120^o/slot distance

As in the example, $120^o/30^o$ = 4 slots

V Winding sequence

In three-phase winding the distance between the starting end of one phase to the starting end of another phase should have 120^o electrical degrees. Hence we should arrange the winding such that

'A' phase starts from say 1st slot

'B' phase starts from 1st slot + 120^o and

'C' phase starts from 1st slot + 120^o + 120^o.

As in the above example, 'A' phase starts from say 1st slot

'B' phase should start from 1+4 = 5th slot

'C' phase should start from 1+4+4 = 9th slot.

VI Arrangement of coils

As the winding is in a single layer, the coil shall be placed in alternate slots i.e. if one coil side of coil number one is placed in slot number one which is an odd number, the other coil side of the first coil should be laid in an even number slot. Hence placement of coils should start in slot numbers 1,3,5,7,9 and so on leaving the slot numbers 2,4,6,8 and so on to receive the other coil sides of the coils.

As in the example the 12 coils are to be laid in slots (pitch = 5 slots)

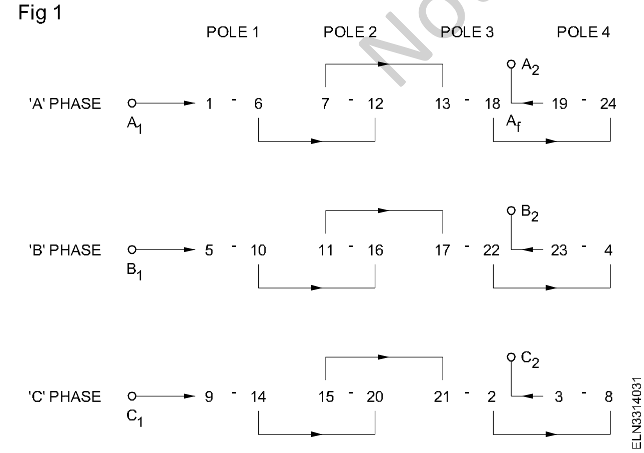
1-6, 3-8, 5-10, 7-12, 9-14, 11-16, 13-18, 15-20,

17-22, 19-24, 21-26(2), 23-28(4).

VII End connections

As discussed, for grouping of coils in normal practice, the end connections shall be whole coil connection. As in the example in Fig 1.

Fig 1



VIII Coil connections

In whole coil connection, the connection of the coil group shall be from finish to finish and start to start for the group of coils.

There are several ways of connecting the coils in groups. Fig 2 shows one method and Fig 3 shows another method. However, you are advised to check the formation of the poles with the help of a ring diagram and clock rule. The procedure is explained in the subsequent paras.

Fig 2

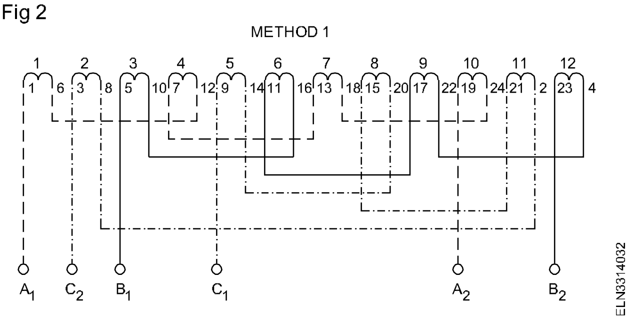
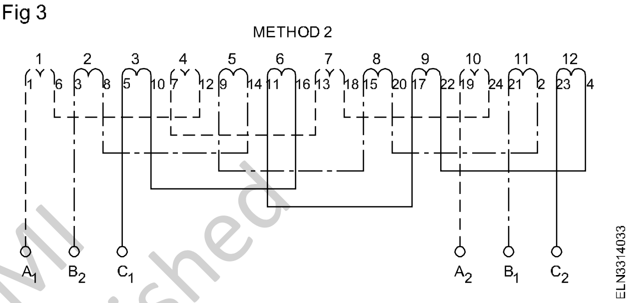


Fig 3

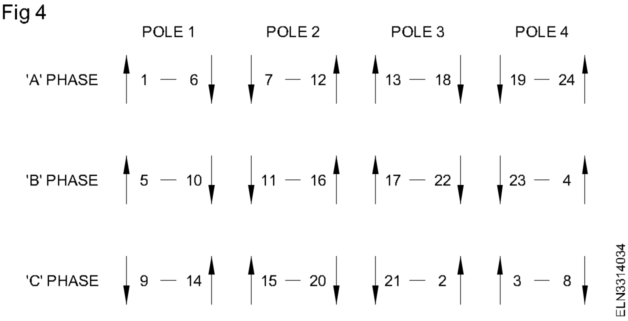


XI Ring diagram

Cross check the end connections as follows. Write the end connection table and mark the direction of current using the clock rule. Note that when three-phase supply is given to the windings, and if two phases carry current inward , the third phase will carry current outward.

Referring to method 1 shown in Fig 2, the current direction in the coil sides could be marked as shown in Fig 4.

Fig 4



Now arrange the slots in the sequential order and mark the direction of current in the slots accordingly by arrows which ultimately shall represent production of the required number of poles as shown in Fig 5.

Developed winding diagram: The development winding diagram will give a clear picture of the coil sides in relevant slots grouping, coil end connections and lead termination. A 24 slots, 12 coil, 4 pole, 3 phase single layer distributed winding development diagram is shown in Fig 6 for your guidance.

Fig 5

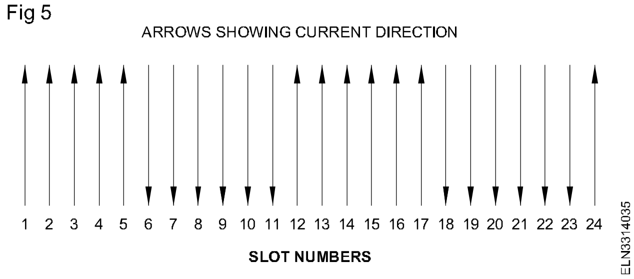
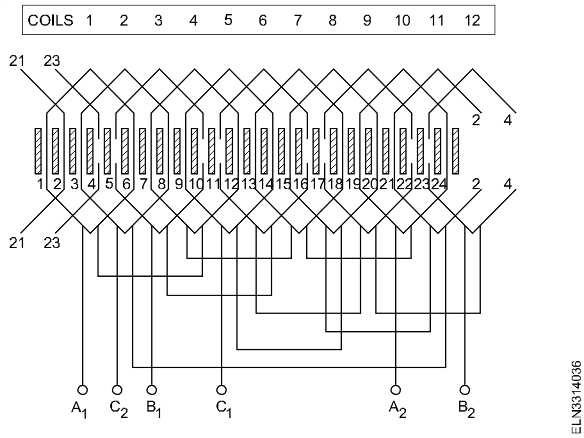


Fig 6



Method of placing coils in a basket or distributed winding

Objectives: At the end of this lesson you shall be able to

- **state the various methods employed to prepare gang or group of coils**
- **explain the method of placing coils in the single layer basket winding**
- **explain the method of placing coils in a double layer basket winding.**

The procedure outlined below is common for single or three-phase distributed winding. However this type of basket (distributed) winding is very popular in three phase motors.

The coils can be wound using a single former and then they can be interconnected by coil connections as shown in Fig 1. Most of the three-phase motors with the exception of very large ones with formed windings, use coils wound in groups as shown in Fig 2.

Fig 1

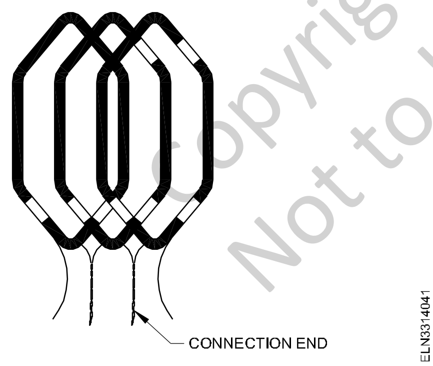
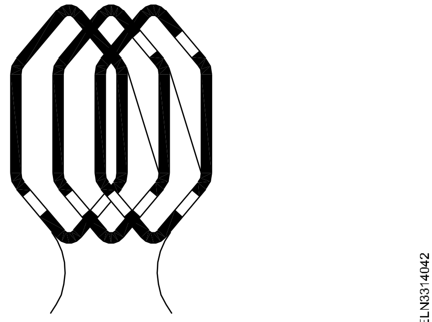


Fig 2



The number of coils in each group will depend on the number of phases and number of poles. This practice of winding coils in groups is called group or gang winding.

In group winding several coils are wound before the wire is cut. This saves time and space by eliminating the necessity of connecting coils to one another then soldering them and then insulating them.

Fig 3 shows a winding head mounted on a bench type coil winding drive. The wire is wound around six wheels mounted on a shaft. Other types of forms are also used. Fig 4 shows a coil winder for producing oval or round coils.

Fig 3

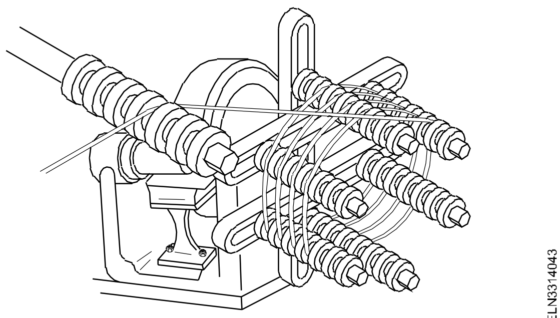
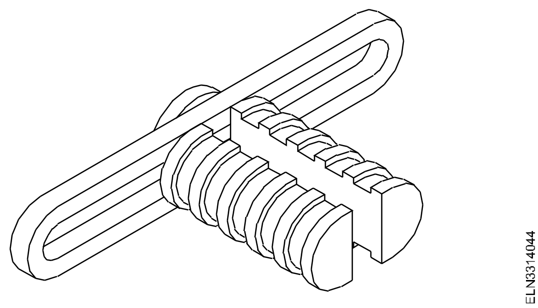
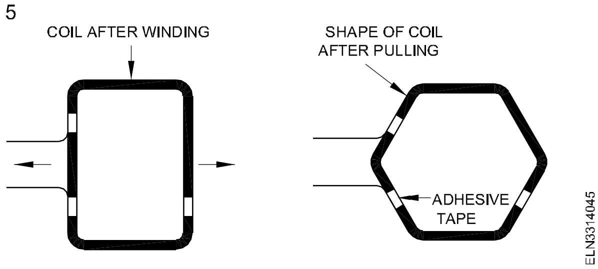


Fig 4



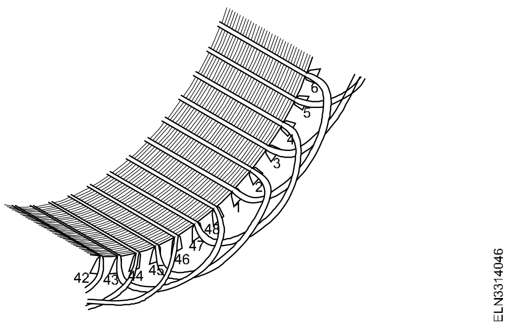
Coils for small motors may be wound in rectangular form and then two sides shaped into a diamond shape by pulling at the centre of the opposite ends as shown in Fig 5. Insertion of coils in single layer basket winding (formed individual coils).

Fig 5



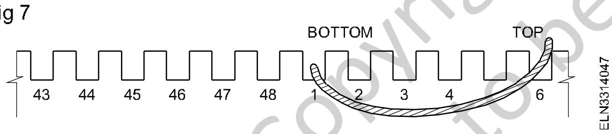
In single layer winding there are half the number of coils as there are slots. For example a machine with 12 coils and 24 slots will have single layer winding. The appearance of a single layer winding is shown in Fig 6 in which the coil pitch is 1-6. While placing coils in a single layer we have to place the coil sides in alternate slots only.

Fig 6



Let us take for example a 48 slot 24 coil 8 pole motor with the coil pitch of 1 to 6. Fig 7 illustrates the way in which the single layer winding is to be placed in the slot. This will be noticed from the diagrams there is only one coil side per slot. Fig 7 shows one coil side of the first coil placed in slot number 1.

Fig 7



Generally any slot can be identified as slot 1 with the help of chalk markings or a spot of paint. The other coil side of the same coil is left out on the core. This coil is called a throw coil. The left out coil side may lie in the right hand side as shown in Fig 7 or left hand side of the stator, when viewed from the connection end. However this depends upon the original winding pattern. The coil overhanging ends can be wrapped up to 2/3 of the length with a cotton tape of 0.175 mm thickness. To avoid the inserted coil turns from coming out of the slot while handling other coils, it is preferred to wedge temporarily the slot using a foot (Skill Information 1203) soon after the insertion of coil is over. In single layer winding the coil sides should be placed in alternate slots as shown in Fig 8.

In Fig 8 coil 1 is placed in slot No.1 and the other coil side of the same coil is left over the stampings. To avoid damage to the left out coil side, a leatheroid paper of width larger than the width of the core is placed between the core and the coil as shown in Fig 8. After placing the coil side in the slot use the awl to fold the insulation paper (slot liner) one side over the other, slip the separator paper over the folding and then slip the formed fibre or bamboo wedge over the top of the coil. The wedge should extend about 3 to 6 mm beyond the slot liner. The procedure is shown in Fig 9.

Fig 8

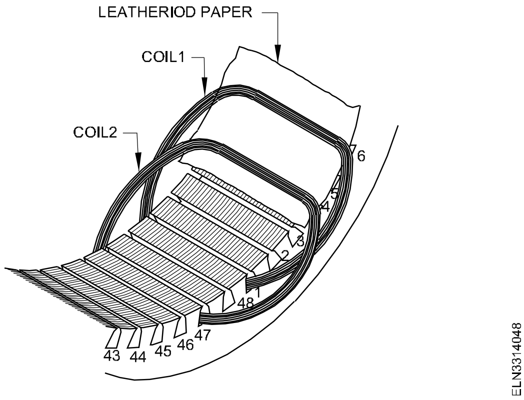
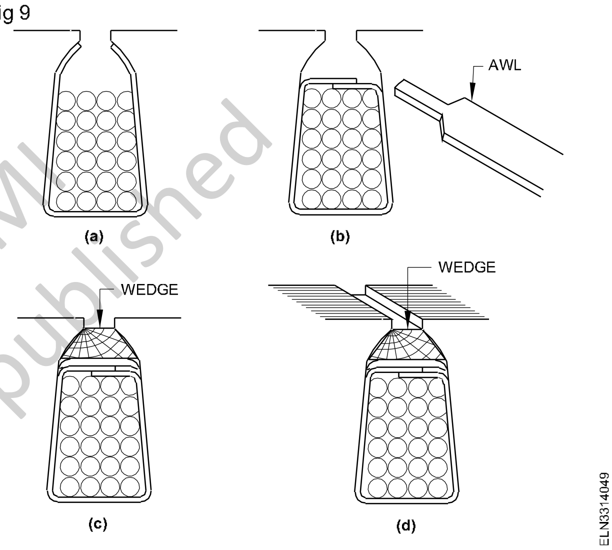


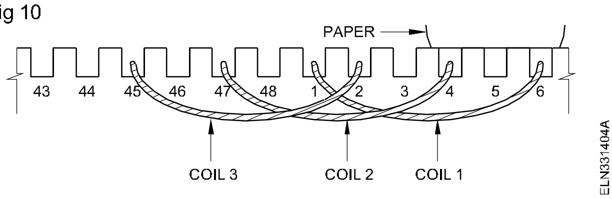
Fig 9



Some prefer to wedge the slots temporarily till all the coils are inserted and the winding is tested for grounding. Once the test results are o.k., then permanently wedge the slots.

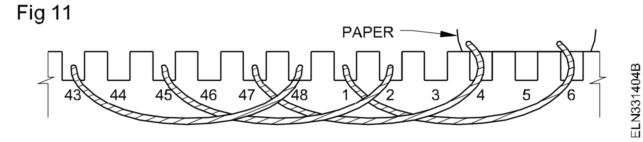
In the next step left coil side of coil 2 is placed in slot number 47 (leaving slot No.48 which is adjacent to slot No.1) and the right coil side of coil 2 is left in the core. (Fig 8) Next place left side of the coil 3 in slot number 45 and leave the right side of the coil over the core. Remember to extend the leatheroid paper insulation between the core and the coil. By examination it will be found that the left out (right) coil side of coil No.3 which has left coil side inserted in slot No.45 should be inserted in slot 2 according to the assigned coil pitch. Now insert the left out right coil side of coil 3 in slot No.2 as shown in Fig 10.

Fig 10



In general, unless the left out coil side of any coil falls, according to the assigned pitch, next to the occupied slot, proceed further to insert one coil side only. Again proceed to insert the left coil side of coil 4 in slot No.43 and the right coil side of coil 4 in slot No.48 as shown in Fig 11.

Fig 11



Proceed likewise to fill up the slots and complete the insertion of coils in the slots.

Insertion of coils in double layer (lap) winding

Let us consider a 3-phase machine with 24 slots, 24 coils, 4 poles and having a slot pitch of 1-6 and a coil pitch 1-12 in terms of coil sides.

ASSUMPTION: Individual coils numbering 24 are former wound and kept ready . Procedure given below is for the developed winding diagram shown in Fig 12.

Accordingly Fig 13 shows the numbered slots. Table 1 shows the position of the coil sides in the slots. The coil sides in the bottom are given odd numbers and the coil sides of top are given even numbers.

Fig 13

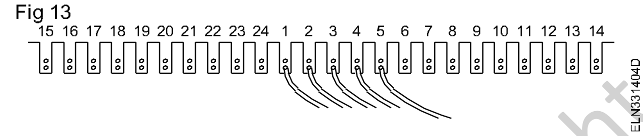
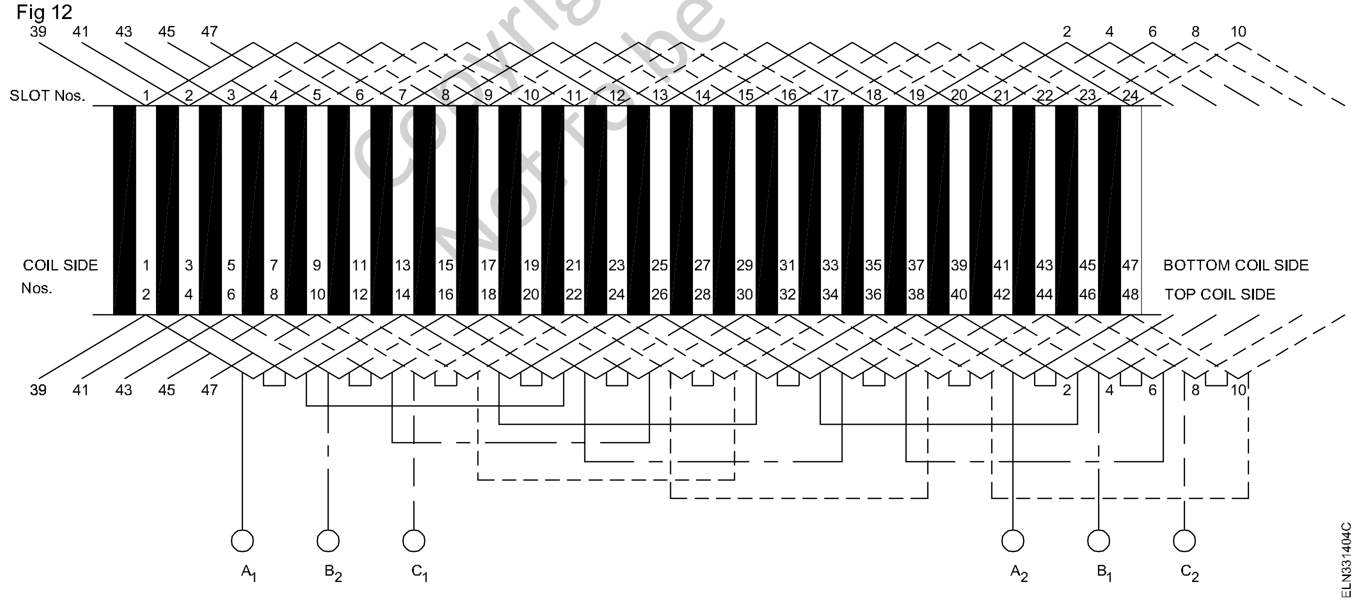


Table 1

Slot	Bottom	Top
1	1	2
2	3	4
3	5	6
4	7	8
5	9	10
6	11	12
7	13	14
8	15	16
9	17	18
10	19	20
11	21	22
12	23	24
13	25	26
14	27	28
15	29	30
16	31	32
17	33	34
18	35	36
19	37	38
20	39	40
21	41	42
22	43	44
23	45	46
24	47	48

Fig 12

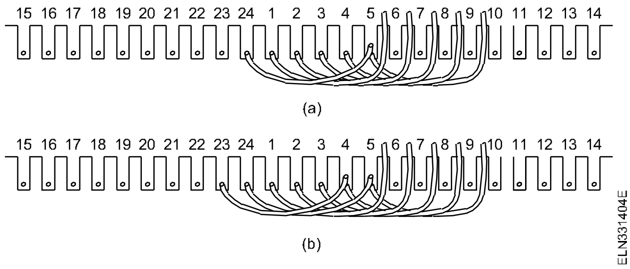


Winding is arranged such that looking from the connection end, the bottom coil is on the left side and the top coil sides is in the right side as shown in Figs 13 and 14.

Further the connection end of the winding in the stator is to be identified from the data with respect to the terminal box.

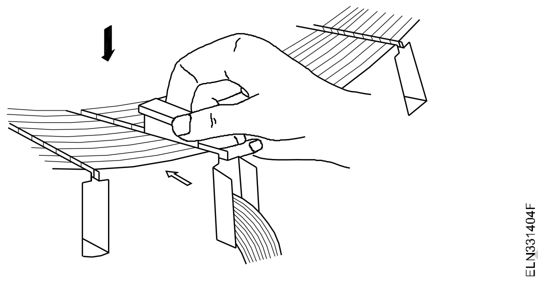
Referring to the developed diagram (Fig 12) and Table 1, if the bottom coil side 1 is inserted in slot 1, then the other coil side of the same coil which is 12, should be inserted in the slot number 6 as a top coil side. As such there should be a certain approved procedure to start the winding.

Fig 14



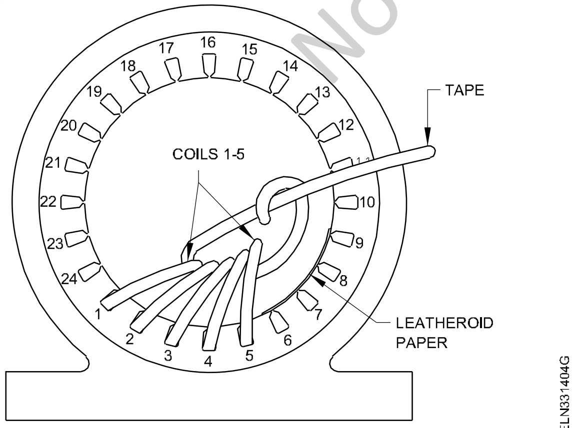
Proceed as, first insert one coil in slot number 5 and leave the other coil side on the core. Use a suitable fibre foot or wedge for slot 5 to secure the winding. (Fig 15). To avoid damage to the insulation in the process of winding, insert a thick leatheroid paper of a width larger than the core between the left out coil side and the core, as shown in Fig 8. Let the length of the leatheroid paper be sufficient enough to cover 5 coil sides at a stretch.

Fig 15



Insert the coils in slot numbers 4,3,2 and 1 in sequence as shown in Fig 13 and wedge them temporarily as shown in Fig 15. Let the other coil side lie on the core with the protected leatheroid paper between the coils and the core. These coils are called throw coils. For the protection of insulation of the throw coil you can tie the bunch of coil sides together with a cotton tape and tie the whole lot to the stator as shown in Fig 16. Remember to ensure the leatheroid paper is well kept between the bunched coils and the core.

Fig 16



Use of coil separation : Before inserting the top coil side over the bottom coil side of the same slot it is necessary to insulate the coil sides inside the slot by the use of coil seperators. This is because each coil side within one slot may belong to different phases and the voltage between them may be high.

To insulate the coil sides from each other within the slot follow the procedure shown in Fig 17 for both open and semi-closed slots. A creased separator or insulation paper of proper width, length and thickness (usually 0.25 to 0.375 mm) is used as insulation between the top and bottom coil sides in the slot. Slide an awl over the bottom coil side as shown in Fig 18a and press it over the bottom coil and slide the separator underneath the awl as shown in Fig 18b. Let the separator project about 10mm beyond the core on either side.

Fig 17

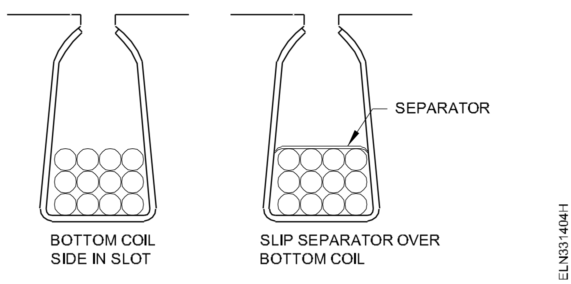
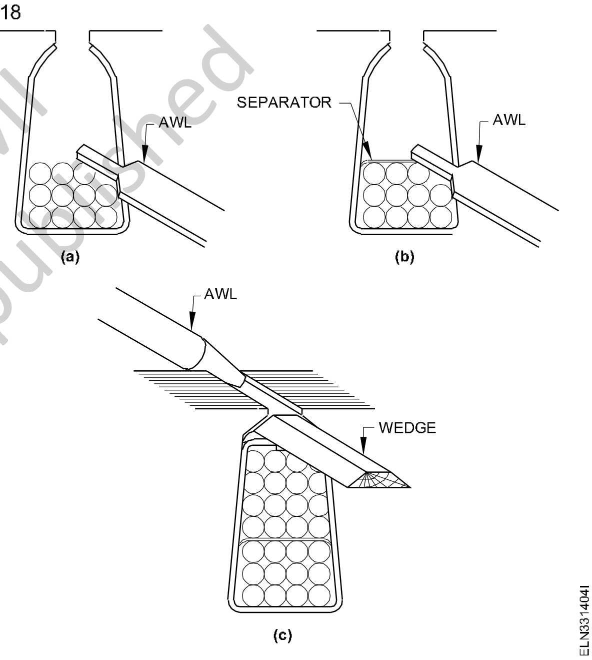


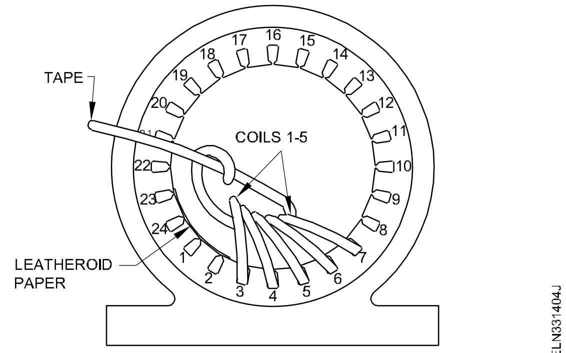
Fig 18



Method of overlapping : Now insert one coil side in slot number 24 (coil side 47) and the other coil side of the same coil (coil side 10) in slot number 5 as the top coil over the bottom coil side 9. Likewise insert another coil side 45 of a next coil in slot number 23 and the other coil side 7 of the same coil in slot number 4. Proceed likewise till you reach slot number 6. During this process as you reach near about the 10th slot or much earlier you will feel the hindrance of the throw coils which are tied to the stator. At that time untie the cotton tape from the stator and tie the bunch in the opposite side of the stator as shown in Fig 19 with a leatheroid paper in between the coils and the core.

While tieing the cotton tape see that the slot number 6 is easily approchable without any difficulty. After inserting the bottom coil side 11 in slot 6 insert the corresponding other coil side 22 in slot 11 as the top coil side. After inserting the top coil side fold the slot liners one side over the other, insert the separator and the wedge.

Fig 19

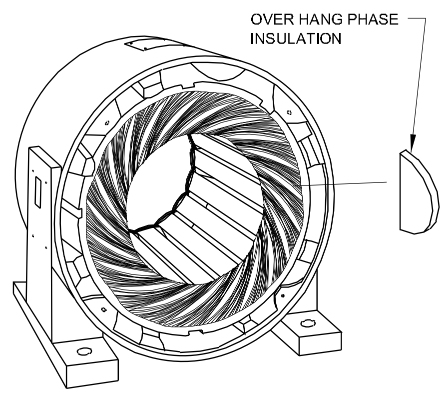


Now untie the throw coil bunch and release the free end of the coil in slot 5 and insert the same as top coil side in slot 10. Proceed likewise to insert the coils from slots 4,3,2 and 1 in the corresponding slots.

Overhang Insulation : Now cut and prepare the leatheroid paper to the shape of half moon as in the original which is to be used as phase insulation between the overhanging coils. According to the developed diagram coil sides 1 and 3 form the first phase, 5 and 7 the second phase and 9 and 11 form the 3rd phase. Identify these coils and start inserting the leatheroid paper between 3 and 5 as well as between 7 and 9.

Thus proceed to insert this phase insulation for the entire winding as shown in Fig 20. If you find the space between these coils is less, you may use a fibre wedge to prime the coils to facilitate insertion of the leatheroid paper. Do not use too much force which may crack the slot liner insulation and result in grounding the coils with the stator core.

Fig 20



End connections : There are three types of connections to be made - first the coil connection for coil grouping, second for connecting the coil groups in one phase, and thirdly connecting the lead wires. Better to proceed one by one in the above sequence. Any connection to be made in winding the wires should start with proper identification of the coil ends. For a beginner, it may be necessary to refer to the developed diagram, connection diagram, as well as the actual winding often to eradicate the confusion.

Three-phase induction motor winding (single layer - concentric type - half coil connection)

Objectives: At the end of this lesson you shall be able to
- **state the general requirements pertaining to the concentric type of winding in 3-phase motors**
- **state the merits and demerits of concentric type winding**
- **explain the preparation of a winding table for concentric type winding**
- **explain how to draw the end and coil connection diagrams**
- **explain how to draw the developed and ring diagrams.**

3-phase concentric winding : In general, concentric winding is found in single phase motors, and occasionaly, this type of winding is also used for 3-phase motors.

This concentric winding has to have two or more coils in a group consisting of different pitches. Further in 3- phase concentric winding, all the three phases consist of the same number of coils, and produce similar concentric poles. Stepped formers are used to prepare coils for concentric winding.

Merits and Demerits of concentric winding: This type of winding has some merits and demerits also.

Merits

1 This type of winding has more space for cooling.

2 No need of raising (lifting) the coil sides to interleave them during the winding.

3 It is easy to shape the coils uniformly.

4 Possible to save copper, because in distributed winding all the coils are of the same size; on the other hand in concentric winding, coil groups only will be uniform, but coils of different pitches in concentric form are used.

5 As there is no interleaving of the coil sides, the winding could be done by machine resulting in faster production.

6 It is easy to make the end connection.

7 Easy to wind, as there is no overlapping of coils.

Demerits

1 Skilled labour is required to insert the coils in the slots.

2 A stepped former is required.

3 Not as efficient as basket winding.

1 Grouping

The example given below will clarify the following:

a whether concentric type of winding is possible for a given stator

b If yes, whether it should be half coil or whole coil connnected winding.

Example

3-phase induction motor having 36 slots 12 coils 4 pole stator

We have

$$\text{No. of coils per phase} = \frac{\text{Total No. of coils}}{\text{No. of phases}}$$

$$= \frac{12}{3} = 4 \text{ coils/phase}$$

For whole coil connection

$$\text{No. of coils/phase/pole} = \frac{\text{No. of coils/phase}}{\text{No. of poles}}$$

$$= \frac{4}{4} = 1 \text{ coils/phase/pole}$$

As such there will be only one coil in a group. But concentric winding should have two or more coils in a group. In this case concentric winding is not possible. Alternatively grouping can be done for half-coil connection, i.e.

$$\text{No. of coils/phase/pair of poles} = \frac{\text{Total No. of coils}}{\text{No. of phase x No. of pair of poles}}$$

$$\text{As per the example } \frac{12}{3 \times 2} = 2 \text{ coils}$$

i.e. 2 coils/phase/pair of poles.

As per the above example, only half-coil connected concentric winding is possible whereas for the following example having data 48 slots, 24 coils, 4-pole, 3-phase stator winding both whole coil and half coil connections are possible. Hence it is necessary to trace the group connection very carefully before stripping the stator to determine whether the winding connection is whole coil or half coil.

2 Pitch

1 $$\text{Pole pitch} = \frac{\text{No . of slots}}{\text{No . of poles}}$$

$$\text{As per the example} = \frac{24}{4}\ 6 \text{ slots}$$

As the winding is concentric, there should be 2 or more pitches normally. According to the above example 2 pitches for half-coil connections are required.

Further it is necessary to have the average pitch equal i.e. to the pole pitch.

(i.e.) coil pitch = pole pitch ± 1

As per the example coil pitch is 6 ± 1.

Therefore outer coil pitch = 6 + 1 = 7

and inner coil pitch will be = 6 - 1 = 5

(i.e.) Coil throw = 1 - 8 and 1 - 6 In practice it is written as 1 - 8 and 2 - 7.

3 Electrical degrees

i Total electrical degrees = 180^o x No. of poles.

As per the example = $180^o \times 4 = 720^o$.

ii Slot distance in degrees $= \frac{180° \times 4}{\text{No.of slots}}$

$$= \frac{180° \times 4}{24} = 30°$$

4 Phase displacement

i For three-phase winding phase displacement should be equal to 120^o

ii Phase displacement in terms of slots

$$= \frac{120°}{\text{slot distance in degrees}}$$

$$\text{As per the example} = \frac{120°}{30°} = 4 \text{ slots}$$

5 Winding sequence

As per the example

A phase starts from 1st slot.

B phase starts from 1+4 = 5th slot and

C phase starts from 1+4+4 = 9th slot.

6 Arrangement of coils

As in the example 12 coils with pitches as 7 & 5 slots.

1-8,2-7; 5-12, 6-11; 9-16, 10-15; 13-20, 14-19; 17-24, 18-23; 21-4, 22-3.

Grouping of coils

The coil should start from every alternate 2 slots (i.e.) 2 slots for top sides and two slots for bottom sides. As per the example, coils start from 1 & 2, 5 & 6, 9 & 10, 13 & 14, 17 & 18, 21 & 22.

As the connection is half-coil type, with the help of one group of coils, 2 poles need to be created. Hence grouping is as follows:

A	B	C
1-8, 2-7	5-12, 6-11	9-16, 10-15
13-20, 14-19	17-24, 18-23	21-4, 22-3

In whole coil connection, the starting end connection is from the alternative groups (i.e.) if 'A' starts from the first group, 'B' starts from third group and 'C' starts from fifth group. Whereas in half-coil connection, the starting ends will be from continous group, if 'A' starts from the first group, 'B' starts from second group and 'C' starts from the third group. Refer to the developed diagram given in Fig 49.

7 End connections (Fig 1): Half coil connection.(End to start and start to end)

Coil connections : Half coil connection. (Fig 2)

In half coil connection, the connection of the coil group shall be from the finish end to the start end and then from the start end to the finish end of the group coils as shown in Fig 2.

Development diagram : Draw the development diagram showing the coil group and end connection. As an example a development diagram is shown in Fig 3.

Fig 1

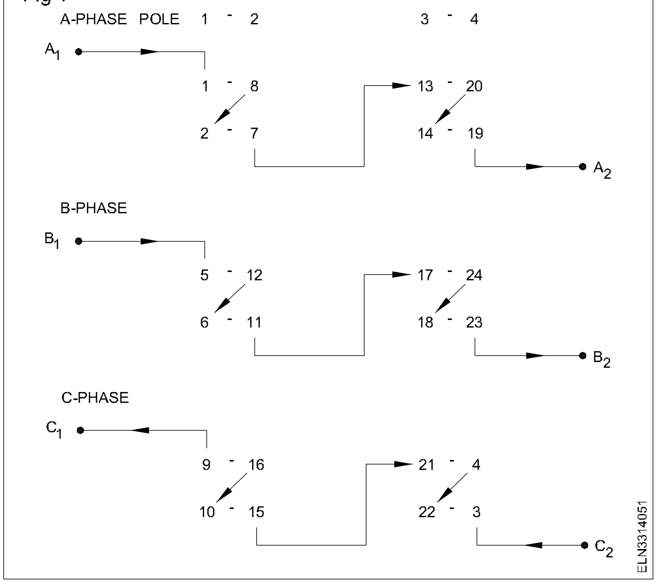


Fig 2

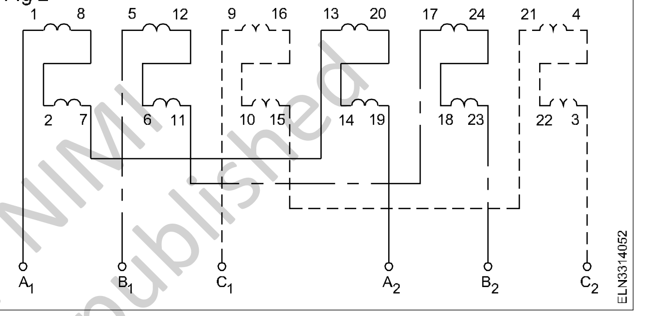
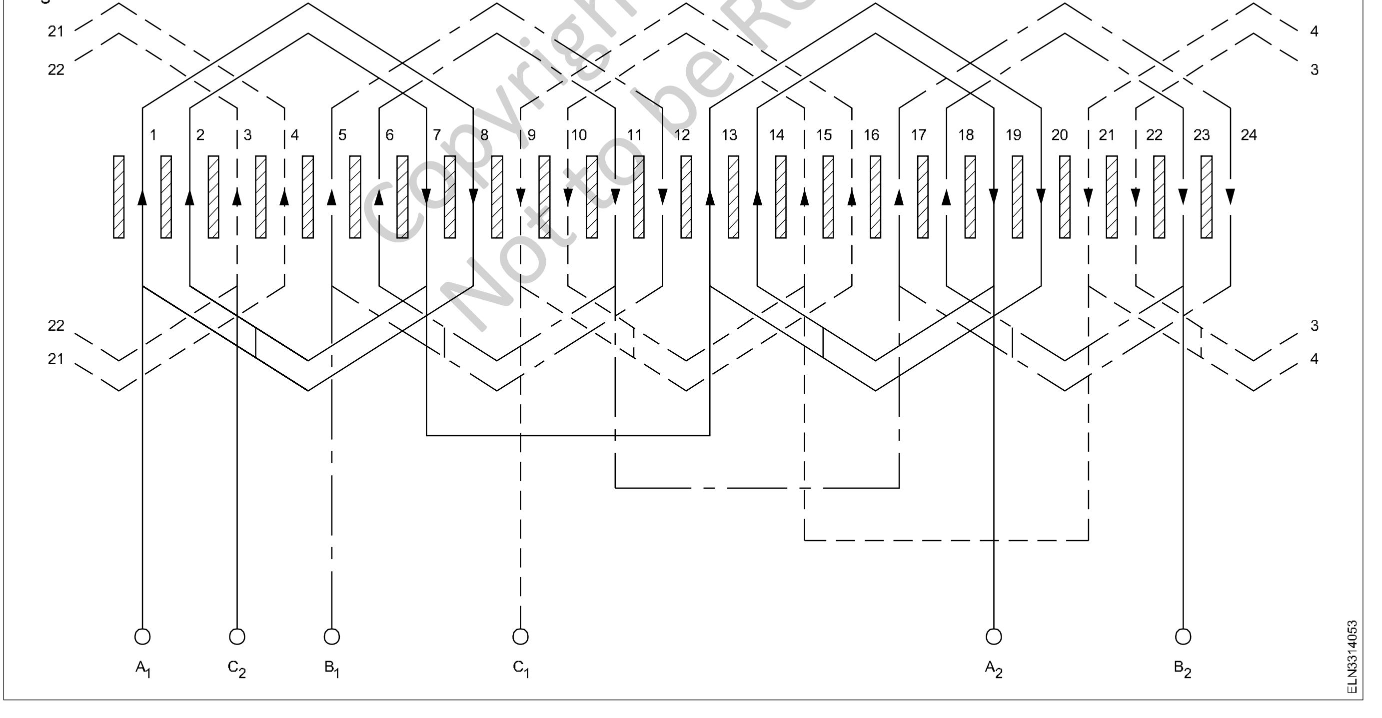


Fig 3



10 Ring diagram

Cross check the end connection with the help of the ring diagram as explained below. Write the end connection table and mark the direction of current using the clock rule. Note that when a three-phase supply is given to the windings at an instant, and if two phases carry current in one direction, the third phase carries current in the opposite direction as shown in Fig 4.

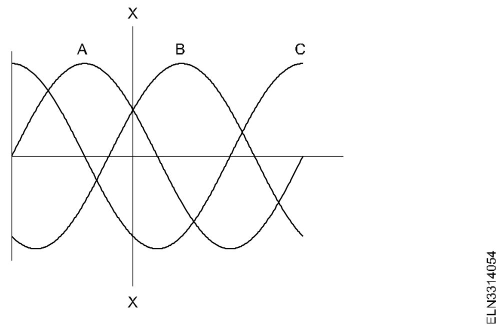
PHASE	P_1 & P_2	P_3 & P_4
A phase	↑1 - 8↓	↑13 - 20↓
	↑2 - 7↓	↑14 - 19↓
B phase	↑5 - 12↓	↑17 - 24↓
	↑6 - 11↓	↑18 - 23↓
C phase	↓9 - 16↑	↓21 - 4↑
	↓10 -15↑	↓22 - 3↑

Refer to Fig 4 in which at the instant shown in x-x we have phases A and B as positive polarity and C has negative polarity.

Mark the direction of current in the slot and it shall represent production of the required number of poles as per the example given below.

Whenever you come across a 3-phase induction motor having a single layer concentric type half coil winding follow the above mentioned procedure and prepare the winding table. Subsquently draw the end connection, development and ring diagrams.

Fig 4



↑	↑	↑	↑	↑	↑	↓	↓	↓	↓	↓	↓	↑	↑	↑	↑	↑	↑	↓	↓	↓	↓	↓	↓
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N						S						N						S					

3 phase squirrel cage induction motor - double layer distributed type winding

Objectives: At the end of this lesson you shall be able to
- **explain the meaning of double layer winding**
- **explain the winding terms and calculations pertaining to double layer distributed type winding**
- **draw the end and coil connection diagrams**
- **draw the ring and developed diagrams.**

There are different types of winding used in 3-phase AC motors. Some of the 3-phase windings are double layer, that is, there will be as many coils as the number of slots. For example 12 coils in the case of 12 slots, 24 coils in the case of 24 slots. 36 coils in the case of 36 slots, 48 coils in the case 48 slots.Further in the case of distributed winding the size of all the coils, pitch and shape will be the same as these coils are normally former wound. By virtue of the arrangement of these coils in slots, they overlap each other just like in a woven basket. This is also a type of distributed winding.

In double layer winding each slot contains two coil sides i.e. the bottom half contains the left hand coil side while the top half contains the right coil side of some other coil.

Calculations for double layer distributed winding : The winding data of the distributed double layer winding will be within the following limitations. As an example 3-phase double layer distributed winding for an induction motor having 36 slots 36 coils 4 poles is discussed below.

I Grouping

1 $$\text{No. of coils/phase} = \frac{\text{Total No. of coils}}{\text{No. of phase}}$$

As per the example,

$$\text{No. of coils/phase} = \frac{36}{3} = 12 \text{ coils per phase.}$$

2. $$\text{No. of coils/phase/per pole} = \frac{\text{Total no. of coils}}{\text{No. of phase x No. of poles}}$$

$$\text{No. of coils/phase/pole} = \frac{36}{3 \times 4} = 3 \text{ coils/phase/pole}$$

II Pitch

1 $$\text{Pole pitch} = \frac{\text{No. of slots}}{\text{No. of poles}}$$

As per the example, pole pitch $= \frac{36}{4} = 9$ slots

2 Coil pitch : Similar to the single layer winding the coil pitch can be short-chorded, long-chorded or equal to the pole pitch. The pitch of the double layer distributed winding may be odd or even number. As per the example, the pole pitch is equal to 36/4 = 9 slots and the no. of coils per group is 3. Hence the coil pitch may vary from 9 $\pm$ 3 that is 6,7 or 8 in the case of short corded winding, 9 in the case of full pitch winding and 10,11 or 12 in the case of long chorded winding. Hence the possible coil throws can be taken as

1 to 7 and 1 to 8 for short chorded winding

1 to 9 and 1 to 10 for full pitched winding

1 to 11, 1 to 12 and 1 to 13 for long chorded winding.

Normally the winding is designed for either short chorded or full pitch. Occasionally a long chord is used by the designer in double speed winding. The reason for not using long chorded winding is, it requires more chord length resulting in the requirement of more copper, and hence, increased heat losses.

3 Coil throw : According to the above example the coil throw for the coil pitch of 8 will be 1-9.

III Electrical degrees :

Total electrical degrees = 180^o x No. of poles

[180^o distance between poles]

$$\text{Slot distance in degrees} = \frac{\text{Total electrical degrees}}{\text{No. of slots}}$$

$$= \frac{180^\circ \text{ x No. of poles}}{\text{No. of slots}}$$

$$\text{As per the example } \frac{180 \text{ x } 4}{36} = 20^\circ$$

IV Phase displacement

i. For three-phase winding each phase winding should be displaced by 120 electrical degrees.

ii. Phase displacement in terms of slots =

$$\frac{120^\circ \text{ (Electrical)}}{\text{Slot distance in degrees}}$$

$$\text{As per the example } \frac{120^\circ}{20^\circ} = 6 \text{ slots}$$

V Winding sequence : In three-phase winding, the starting end of one phase winding to the starting end of the second phase winding should have a distance of 120 electrical degrees.

Hence if the 'A' phase starts say in the Ist slot then the 'B' phase should start from the Ist slot+120^o.

Further 'C' phase should start from the Ist slot+120^o+120^o.

As in the example 'A' phase starts from, say, 1st slot

'B' phase should start from 1+ 6 = 7th slot and

'C' phase should start from 1+ 6 + 6 = 13th slot.

VI Placing of the coils in double layer winding: As the winding is double layer, the laying of coils should start in adjacent slots.

That is the coils should be placed in slot 1, slot 2, slot 3 and so on.

As in the above example the arrangement of coils for the selected pitch 8 will be as given below:

Fractional pitch Short chorded winding

Pitch 8 **Coil throw 1-9**

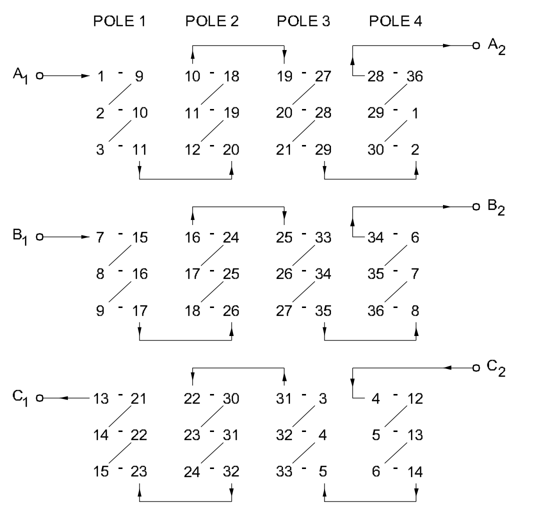
Pole	A-Group	C-Group	B-Group
P1	1-9, 2-10, 3-11	4-12, 5-13, 6-14	7-15, 8-16, 9-17
P2	10-18, 11-9, 12-20	13-21,14-22,15-23	16-24,17-25,18-26
P3	19-27, 20-28,21-29	22-30,23-31,24-32	25-33,26-34, 27-35
P4	28-36, 29-1, 30-2	31-3, 32-4, 33-5	34-6, 35-7, 36-8

Though the possible pitches are 6,7,8,9,10,11 and 12 the above example is given for the pitch equal to 8 only. Trainees are advised to write the table for other pitches to have a better understanding of the winding.

VII End connections : Draw the end connections as shown in Fig 1.

VIII Coil connections : In whole coil connection, the connection of coil groups shall be from the finish end to the finish end and the start end to the start end of the group of coils of the same phase. Either of the following two methods shown in Figs 2 and 3 could be followed.

Fig 1



GROUP AND PHASE CONNECTION OF WINDING

METHOD 1

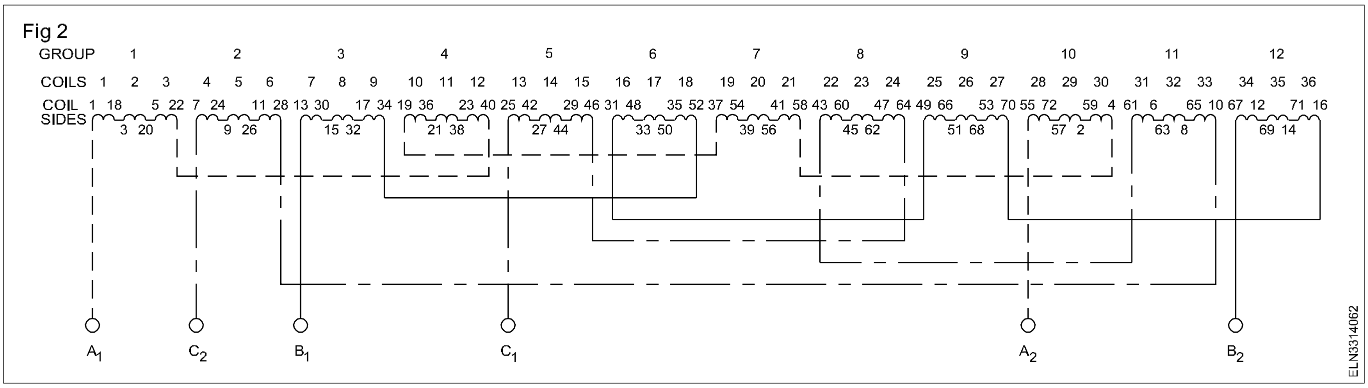


Fig 2

METHOD 2

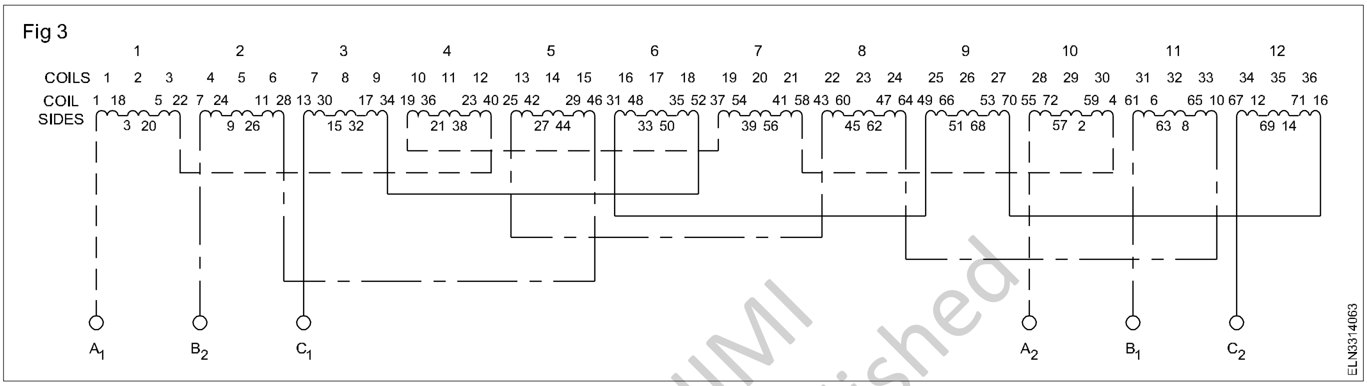


Fig 3

IX Cross check the end connections: Write the end connections table as illustrated below in Fig 4 and mark the direction of currents using the clock rule.

When three phase supply is given to the 3-phase winding, if two phases carry current inwards, the third phase will carry current outwards.

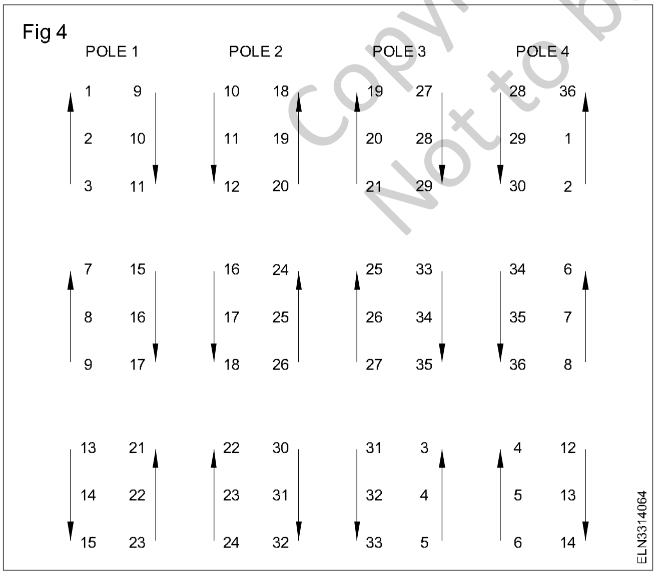


Fig 4

X Ring diagram

Mark the direction of current in the respective slots and then check the production of the required number of poles as shown with ring diagram. (Fig 5)

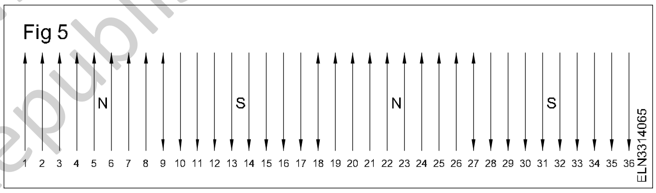


Fig 5

As per the above ring diagram, in all 4 poles are produced. One pole is produced at each of the area contained by the eight slots. In slots 9,18,27 and 36 coil sides carry current in the opposite directions and hence, the flux in those slots gets neutralized. This happens in the short chorded winding. Based on the above information draw the developed diagram.

XI Developed diagram

A developed diagram is shown in Fig 6 in which the connections are shown for the method 1 referring to Fig 2.

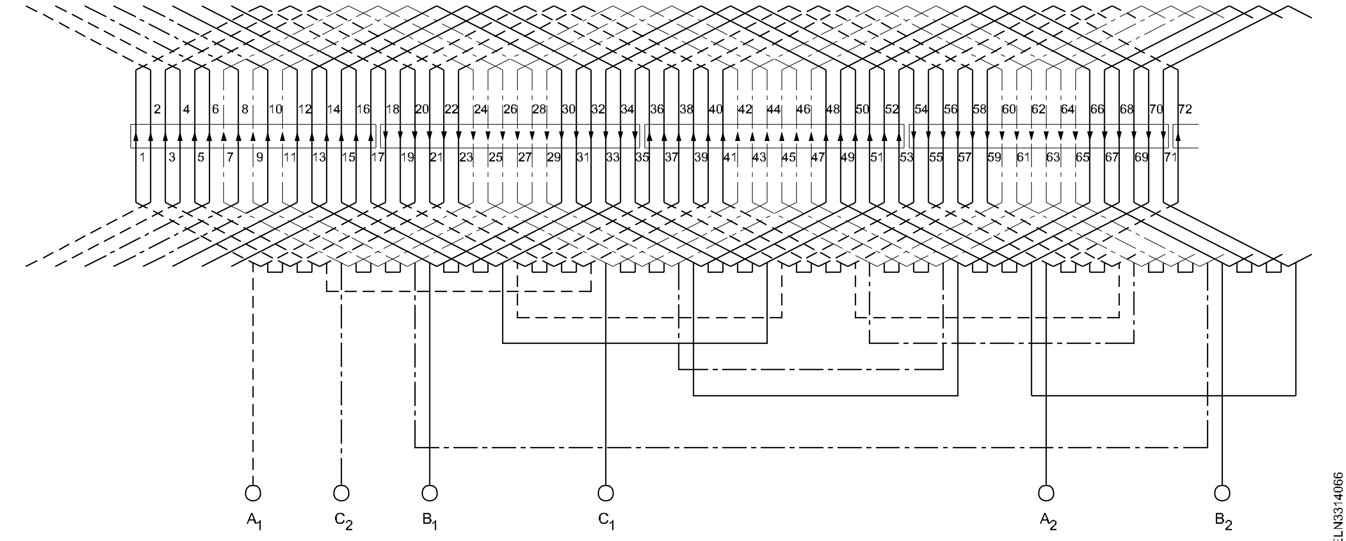
XII Fractional pitches

After the group and lead connections are over, the sleeved joints are to be tied with the overhang with the help of hemp threads. Follow the instructions contained in Ex.3.2.03 to complete the job.

Winding is then to be tested and varnished.

The motor is then to be assembled and test run for atleast eight hours to check its performance on no load. Wherever loading facilities are availabe the newly wound motor can be checked for its load performance.

Fig 6



Testing of windings

Objectives: At the end of this lesson you shall be able to
- **test the rewound motor for continuity and measure the coil resistance**
- **test the coils of the winding for short circuit using internal growler or voltmeter or ohmmeter**
- **test the winding for ground and insulation resistance**
- **test the winding for correct magnetic polarity using a magnetic compass or screwdriver or a search coil**
- **test the 3-phase winding for equal value of phase currents**
- **test the newly wound motor under no-load.**

After the motor is rewound the following tests are carried out in the windings.

1 Continuity test/resistance test.

2 Short circuit test/growler test.

3 Insulation resistance test.

4 Polarity test.

5 Unbalanced current test - for 3-phase winding.

6 No-load test.

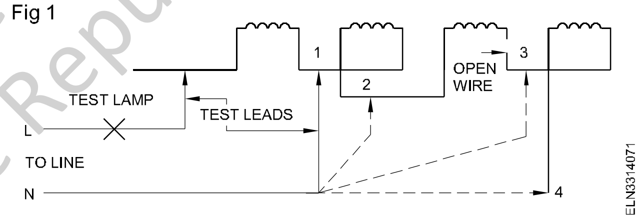
Continuity test/resistance test : This test is done to check up the continuity of each winding. If there is any open in the winding, it is to be rectified.

The usual cause of an open circuit in a winding is loose connection or break in the winding wire. The open circuit may be located by connecting one lead of the test lamp to one end of the winding and touching the other lead to the end of each coil end in sequence in the same phase.

Refering to Fig 1, if the lamp does not glow at point 3 but glows at point 2 then the third coil is faulty. If the lamp glows at 2 and 3 but not at 4 then the fourth coil is faulty. By repeating this process the coil which has the open circuit, can be identified.

Similarly, the other winding can also be tested for open circuit.

Fig 1



The resistance of each coil may be measured by a low range ohmmeter. The resistance of each coil must be the same. The high value of resistance or infinity value indicates open in the windings.

> **If there is any open in one coil, that coil can be bypassed and left out in the chain of windings. Then the motor can run, but if the open is in more than one coil, bypassing of the coil is not possible. This type of repairing is possible for small capacity motors where the winding has a large number of coils. Ex: Ceiling fans. But this procedure should be avoided as far as possible.**
>
> **If the polarity of one or two coils in a multiple pole fan motor is changed the fan will run slowly and produces more heat.**

Short circuit test/growler test : Two or more turns that contact each other electrically will cause a short circuit in the winding. This short circuit will cause excessive heat to be developed during the operation of the machine.

Short circuit can be detected by any one of the following methods.

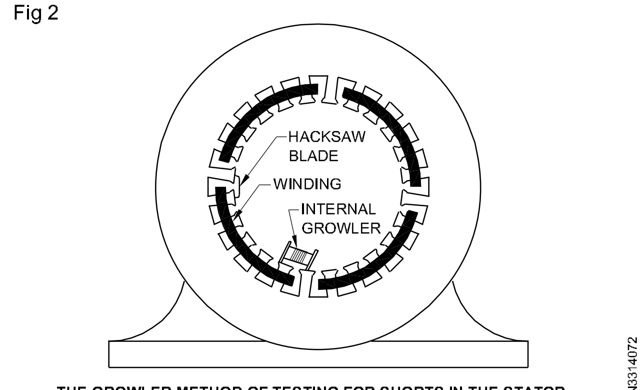
a Internal growler method

b Voltage drop test

c Ohmmeter method.

Internal growler method : The internal growler consists of a coil of wire wound on a laminated iron core and connected to 240V AC supply. After the stator is removed the growler is placed on the core of the stator and moved from slot to slot as shown in Fig 2. A shorted coil will be indicated by rapid vibration of a metal blade provided with the growler and in some types of internal growlers, glow of the neon lamp provided with the growler indicates short in winding.

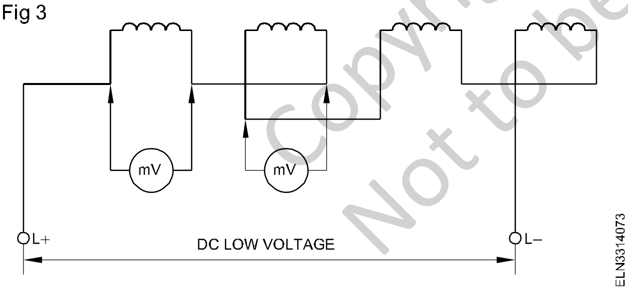
Fig 2



THE GROWLER METHOD OF TESTING FOR SHORTS IN THE STATOR

Voltage drop method : In this method the winding is connected to a low voltage DC supply as shown in Fig 3 and the voltage drop is measured across each coil by a millivoltmeter. The voltage drop across good coils will be the same whereas voltage drop across shorted coils will be low.

Fig 3



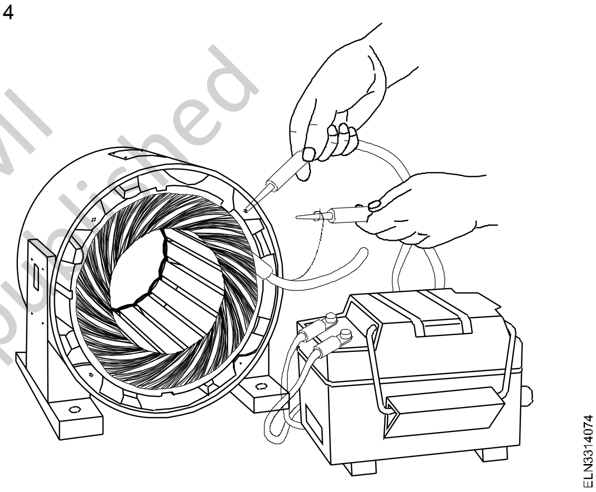
Ohmmeter method : For this method, measure the resistance of the each coil by a low range ohmmeter or Kelvin bridge or Post Office Box. All the coils should read the same value of resistance. The coil which reads lower resistance than the other coils or that which reads zero resistance is assumed to be shorted and needs replacement. On the other hand the coil which reads high resistance when compared to similar coils or which reads infinite value of resistance indicates open in that particular coil.

Ground test and insulation/resistance test : Grounded winding may cause a fuse to blow up or it may cause the winding to smoke, depending on the extent of the ground. It may give shock to persons when they come in contact with the frame which is not properly earthed.

The aim of this test is to check any direct connection between windings and earth(ground). For this, the neutral of the supply is connected to the body of the machine and the phase wire is connected through a series test lamp. The open end of the test lamp is touched to each end of the winding in sequence. If the lamp remains dark it means winding is not grounded and if it glows, the winding is earthed. This is a fast, rough practical method.

If a Megger is used for testing the grounded winding, one terminal of the Megger is connected to the body and other to the windings as shown in Fig 4. If the pointer of the Megger shows infinity, the winding is correct and there is no connection between the windings and the body. Insulation resistance between windings and the body of the machine is measured by a 500 volts Megger and the readings so obtained shall not be less than 1 Megohm in the case of 3-phase and single phase motors. For additional safety 2 megohms are necessary in the case of ceiling and table fans.

Fig 4



Polarity Test: Correct coil group connection in the winding ensures correct polarity. If there is any confusion in the coil group connections then the polarity test is necessary to be carried out to check proper polarity.

There are three methods recommended as explained below.

a Magnetic compass method

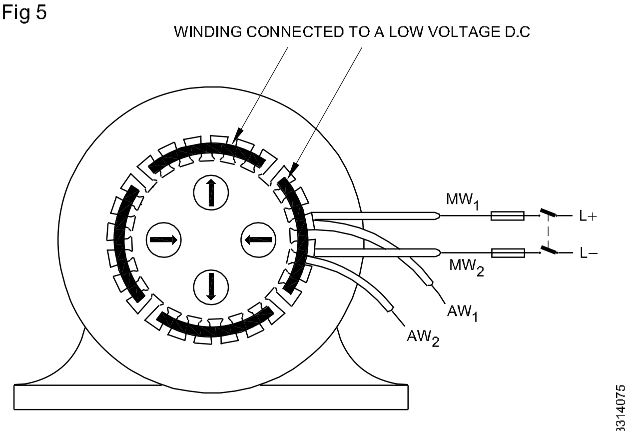
b Two screwdrivers method

c Search coil method

Magnetic compass method : In this method, the stator is placed in a horizontal position and a low DC voltage is applied to the winding. The compass needle is then held inside the stator and moved slowly from one pole area to another pole area as shown in Fig 5. The compass needle will reverse itself on each pole if the winding is correctly connected. If there is same direction of indication between two adjacent poles, a reverse pole is indicated.

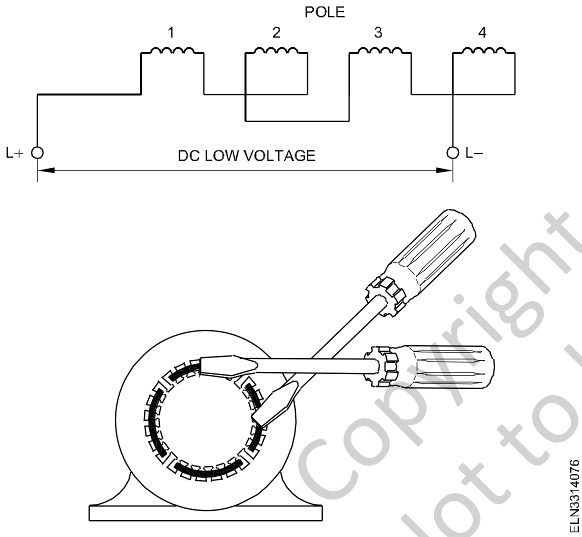
Two screwdrivers method : In this method, the stator is placed in vertical position and a low voltage DC is applied to winding in case of 3-phase to individual phase. A screwdriver is placed on the core at the centre of one pole area, and another on the next pole area centre. If in adjacent poles the polarity is correct the screwdrivers will be attracted as shown in Fig 6. If the polarity is incorrect the screwdrivers will repel each other. If it is found that one pole has wrong polarity, that can be corrected by reversing two lead connections of that coil group.

Fig 5



THE COMPASS METHOD OF TESTING FOR REVERSED POLES

Fig 6

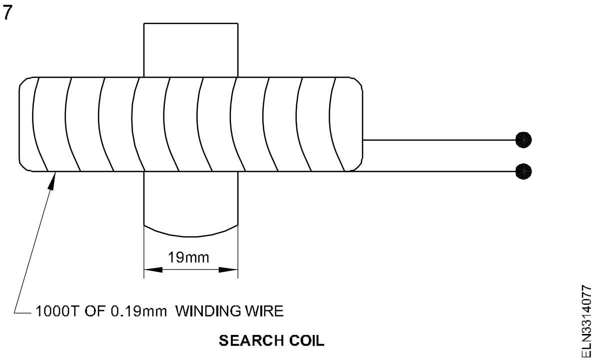


Polarity test by search coil method (Fig 7) : The search coil consists of a coil of 1000 to 2000 -turns. The iron core should have one end rounded. This coil is used for testing the polarity of the poles of the rewound stator.

A more reliable way is to use the search coil in conjunction with a centre-zero milli-voltmeter or galvanometer. (Fig 8) If the search coil is so made that one end of the core projects beyond the windings it can be used to polarise very small stators by placing the projecting end on each pole in turn without the coil itself entering the stator.

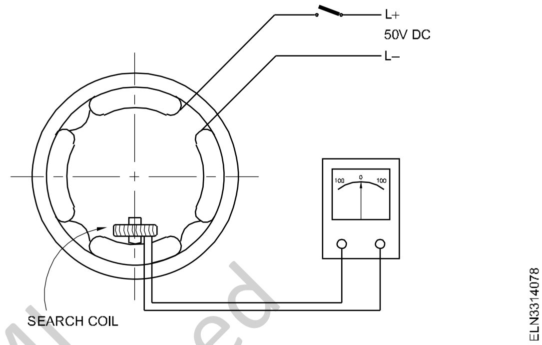
With the search coil core making contact with a pole, the switch is closed (Fig 8) and the galvanometer will give a kick either to the right or the left at the moment, the circuit is made. Mark the pole thus treated either R or L as the case may be with chalk.

Fig 7



SEARCH COIL

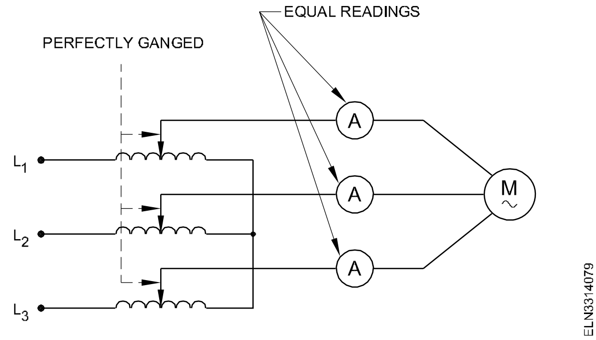
Fig 8



The next pole is marked in the same way according to the direction of the kick. It must be emphasised that all readings must be taken when the switch is made, because a reverse kick is seen when the switch is opened.

Unbalanced current test: In the case of three-phase winding reduced voltage is applied from a 3-phase auto-transformer to get nearly full load current as shown in Fig 9. In this test all the three phase currents measured should be the same. Even if the windings are good, ±3% variation of the current is permissible.

Fig 9



No-load test : After impregnation and assembly of motor, check the rotor for free rotation. Connect the motor to the rated supply voltage. Run the motor at no load and record the no-load voltage, current and speed of the motor. In no case these readings increase beyond name-plate values. Inspect the bearing sound and vibration. Normal sound without vibration is an indication of a good job. However, the perfection of the winding job could be ascertained only through a load test.

Insulating varnish and varnishing process in electric machines

Objectives: At the end of this lesson the you shall be able to
- **state the importance of varnishing the winding of a machine**
- **state the types of varnish, their characteristics and uses**
- **state the use of thinners**
- **explain the methods employed in preheating the winding**
- **explain the process of varnishing a winding.**

Importance of insulating varnish to the electrical machines : The hygroscopic (absorbing moisture) nature of many of the solid insulating materials used for general insulation has to be neutralised by varnish impregnation. Varnish will not allow the ingress of moisture to enter inside the winding layers by forming a cover and in many cases, works against the action of oils, acids, alkalies and heat. Insulating varnish is also necessary to bond conductors together especially in rotating machines. Heat dessipation from the windings is improved by the displacement of air by solid varnish between the conductors.

Types of Varnish: Four types of varnishes are commonly available to use with electrical windings. They are:

1 air-drying varnishes

2 baking varnishes

3 thermosetting varnishes

4 solventless varnishes.

Air drying varnish : This varnish consists of solid particles and a solvent. The varnish is dried by vaporisation of the solvent without heating. In comparison with baking varnishes, air-drying varnishes have low strength and high porosity(having too many small holes) because their films do not flow well enough to seal up the voids (gaps) left by the drying out of the solvent. Furthermore, they tend to deteriorate rather rapidly in the dip tank and during storage. The fastest drying types have a shellac spirit base and may be either clear or black. These can be used for emergency repair jobs or for touch-up work. Black asphalt-base varnishes are available, but these have only fair resistance to oil.

A number of oleoresinous (oil and resin base) varnishes, both black and clear, are available in the market. These varnishes dry by loss of the solvent and by oxidation and are more oil-resistant than the asphalt-base varnishes. Synthetic based air-drying varnishes are also used to some extent.

Baking varnishes - oleoresinous : Baking varnish also consists of solid particles and solvents. Varnishes of this type were more widely used before thermosetting varnishes were developed. They dry partly by polymerization and partly by oxidation, depending upon the drying oils they contain. Linseed oil varnishes dry almost entirely by oxidation; tung-oil varnishes dry both by oxidation and polymerization. Drying by oxidation causes a hard surface to form while the varnish is still wet underneath. This is the disadvantage of this type of varnish particularly in deep coils.

Thermosetting varnishes : These are heat-hardening, clear, synthetic varnishes which represent a vast improvement over ordinary baking varnishes, which depend upon oxidation for hardening. These varnishes are suitable for use either with Class B or Class E insulation.

Solventless varnishes : Recent developments indicate that in a few years satisfactory solventless varnishes (100 percent solids) may be commercially available; and these will be free of the poor shelf life characteristic and tank deterioration of the present solventless varnishes.

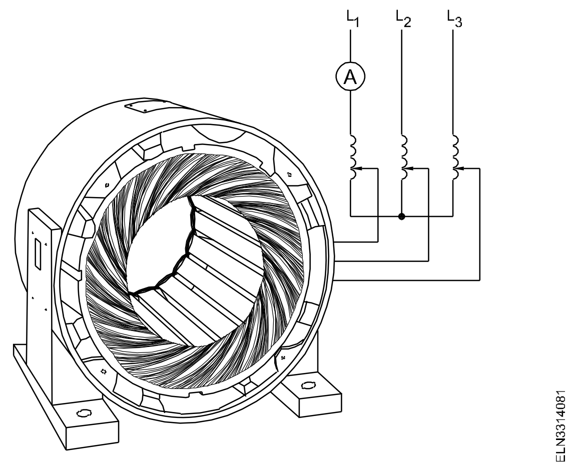
Varnish thinners: Thinners are used to adjust the viscosity and solid content of varnish to the desired amount. Addition of thinners should be done slowly, accompanied with rapid agitation of the varnish to obtain thorough mixing. In selection of thinners - specific recommendations for particular types of varnish should be obtained from the varnish manufacturer. The contents of thinners on the varnish should not exceed 60%.

Preheating : Preheating of winding before varnishing is done mainly to drive out the moisture in between the winding layers.

The winding should be completely dried before applying the varnish by any one of the following methods.

1 By applying a low voltage, about 20% of normal to the stator terminals through a 3-phase auto- transformer as shown in Fig 1 so that a current not greater than full load flows in the winding. The motor may be heated for 8 to 10 hours.

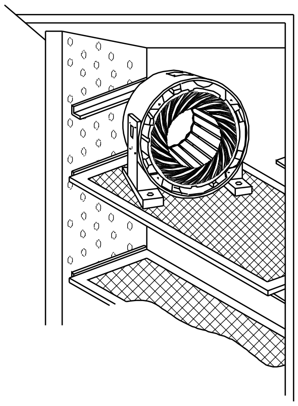
Fig 1



Close supervision is necessary as the heat generated by the winding is not easily dissipated.

2 The motor can be placed in an oven, as shown in Fig 2 but the temperature should not be allowed to exceed 90°C.

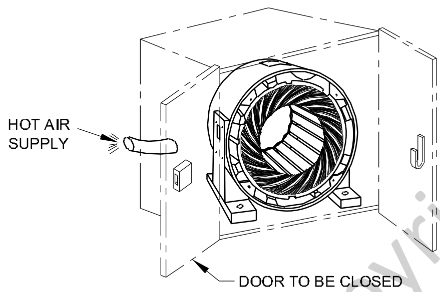
Fig 2



OVEN USED FOR DRYING THE WINDING

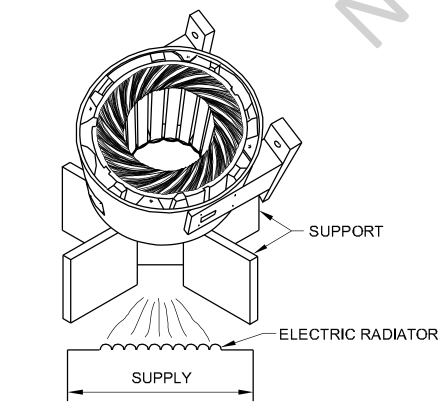
3 Hot air may be blown into the windings which is kept in a closed chamber as shown in Fig 3 but the air should be clean and dry and at a temperature of not more than 90°C.

Fig 3



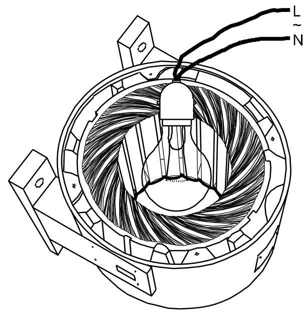
4 Coke braziers or electric radiators may be placed around the machine as shown in Fig 4.

Fig 4



5 Carbon filament lamps, placed inside the machine as shown in Fig 5, may be employed quite satisfactorily, but care should be taken that the hot bulb is not in contact with any part of the windings. If it is not possible to reach a sufficiently high temperature, the ventilation may be reduced by covering the stator with a tarpaulin.

Fig 5



The method of heating employed for drying out should be continuous and the process should be carefully watched to ensure that the windings do not attain a temperature sufficiently high to damage the insulation. The maximum safe temperature of the windings measured by thermometer is 90°C. At the same time the temperature should not be allowed to fall too low as this will cause re-absorption of moisture.

The insulation resistance is found to drop considerably as the motor warms up, the insulation resistance reaches the minimum, and then remain constant for some time, depending upon the dampness of the machine. As the drying process progresses further, the insulation resistance will gradually rise. The drying out should be continued as long as the insulation resistance rises, or until a sufficiently high value, i.e. not less than one megohm per 1000 volts at 75°C has been reached.

During the drying out period, reading of temperature and insulation resistance should be taken at least once an hour, in order to see how the drying out is progressing. The temperature of the motor should be kept constant as far as possible; otherwise the readings may be misleading.

After the winding is preheated, cool the job to a temperature of about 60°C before applying the varnish. This is important because the higher temperature would tend to seal the outer side with the varnish layer.

Varnishing process : Varnish is applied to the windings either by immersing the whole (wound) stator in the varnish tank or by pouring the varnish on the windings. In some cases varnish can also be applied with a painting brush.

Air-dry varnishes are natural drying; so allow the job to set at normal temperature atleast for 6 hours.

Impregnation : For impregnation follow the procedure recommended by the manufacturer of the varnish.

Impregnation process : The following is the impregnation procedure of class E motors. Use Class E impregnation varnish.

1 Preheat the job for eight hours in an oven at 85-100°C and measure the insulation resistance. If the insulation resistance is less than infinity continue the preheating process till the insulation resistance is infinity.

2 After preheating, allow the job to cool down to 60°C and dip it in the varnish tank. Dip the hot winding in vertical position in the varnish for one hour or for sufficient time for all the air bubbles to escape.

3 Drain the varnish from the job by lifting it over the tank in a cradle for about one hour till the varnish drains completely.

4 After draining, heat the job to 120°C for two hours and 140°C for a minimum of ten hours.

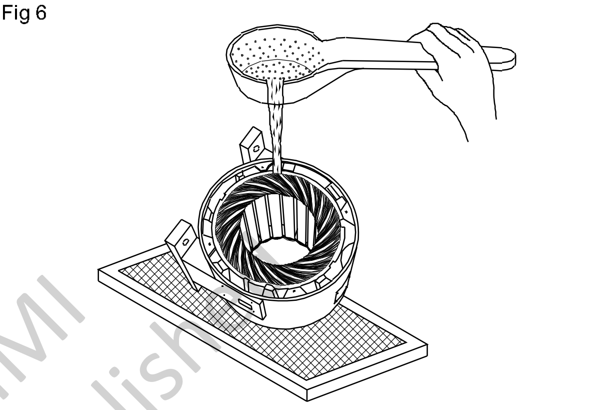
5 Measure the insulation resistance immediately after baking, and the value should not be less than 2 meg-ohms.

6 For second impregnation cool the job to 70°C after baking and repeat steps 2,3 and 4 as above.

In case there is no varnish tank to use, place the stator on a container filled with varnish and pour the varnish on it with a spoon as shown in Fig 6. In this case, pour the varnish sufficiently on it from the connection side and opposite of the connection side alternately by changing the position of the stator.

Varnish stripping : After the winding has been dipped and baked, it is often necessary to remove the excess varnish from such places as air gap surfaces or the end-shield fits, since there are no practical means for preventing the varnish from accumulating there. A rag saturated with the correct solvent for the varnish to be removed can be used to wipe off excess accumulation of the wet varnish. Baked varnish coatings can readily be stripped off from metallic surfaces if these surfaces are treated with a suitable masking compound before dipping. This compound is thinned with acetone for spraying or is maintained at a heavy molasses like consistency if it is to be applied by dipping or by brushing. After the thin coating has been dried for half an hour, the apparatus may be given the normal varnish impregnation and baked. After baking the masking compound will strip cleanly from the bare metal merely by inserting a knife or finer nail under it at one point. Both the varnish and the masking compound can be removed as a single intact film by peeling off the layer.

Fig 6



Method of connecting end connection, group connection, terminal leads, binding and forming the overhangs

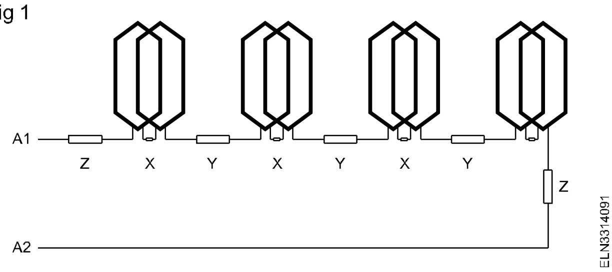
Objectives: At the end of this lesson you shall be able to
- **state the type of connections in winding**
- **explain the method of making coil end connections**
- **explain the method of making group (jumper) connections**
- **explain the method of connecting terminal leads**
- **explain the method of binding the end/terminal/lead connections with the winding**
- **explain the method of forming the overhangs.**

The procedure explained below is common for any winding.

End connections : There are three types of connections to be made in the windings. First for coil connection for coil group as shown by X, second for connecting the coil groups (jumper connection) in one phase as shown by Y and third by connecting the lead wires as shown by Z in Fig 1. Better to proceed one by one in the above stated sequence while winding.

Any connection to be made in winding wires should start with a proper identification of the coil ends. For a beginner, it may be necessary to refer alternatively to the developed diagram, connection diagram as well as the actual winding often to eradicate the confusion.After identifying the coil ends simply twist the ends to be joined temporarily as shown in Fig 2 and recheck the connection with respect to the developed diagram and the connection diagram.

Fig 1



After ascertaining the connections are correct, remove the enamel insulation with the help of sandpaper or a knife or by an electrically operated insulation remover. In all methods see that the wire is not nicked or bent often to avoid damage.

Method of coil connections : Check whether the enamel insulation is completely removed. Twist the wire together to a length of 20-25 mm and insert the PVC or empire sleeve as shown in Fig 3. Bend the joint towards the coil bunch and tie with a twine.

Fig 2

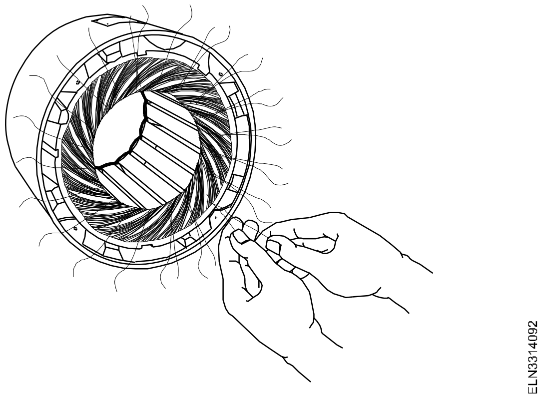
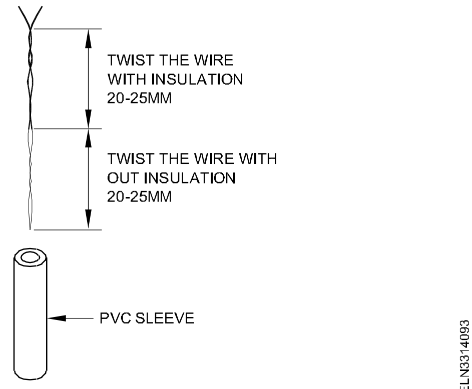


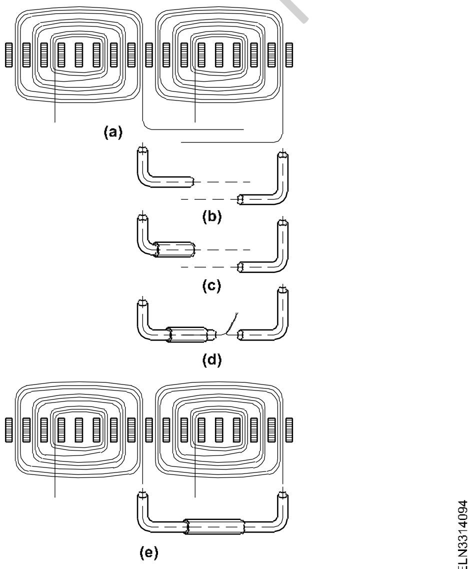
Fig 3



Method of group connections (jumper connections): Place the wire to be joined overlaping each other for 40 mm. Cut the extra length as shown in Fig 4a. Remove the enamel insulation to a length of 40 mm in the winding wires.

Insert a suitable PVC or empire sleeve of sufficient length inside the two wires to be joined as shown in Fig 4b. Over one of the sleeves insert another sleeve of larger size as shown in Fig 4c. Twist the wires together as shown in Fig 4d. Bend the joint on the wires and pull the 2nd sleeve insulation over the joint as shown in Fig 4e.

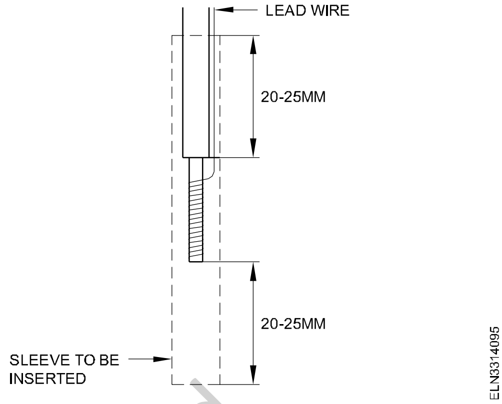
Fig 4



Method of lead connections : To connect the lead wire, strip the insulation of the cable to a length of about 25 mm and also remove the enamel insulation from the winding wire to that length. Clean both the wires and wind atleast 10 times of the winding wire over the lead wire tightly as shown in Fig 5.

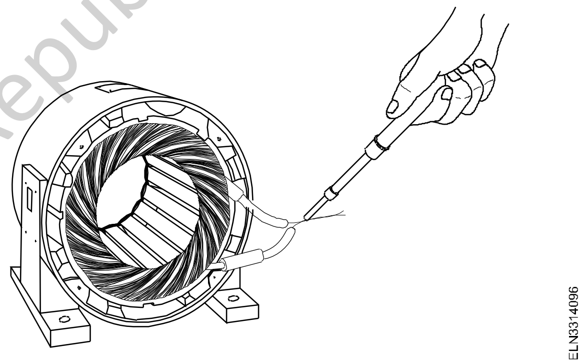
Use the PVC or empire sleeve to insulate the joint as shown in Fig 5.

Fig 5



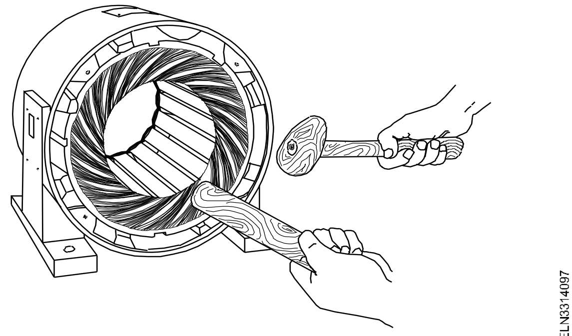
After testing the winding for correctness as outlined earlier in the end all the connections earlier made need to be soldered as shown in Fig 6 and then insulated by the sleeves.

Fig 6



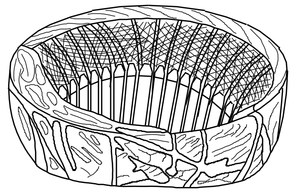
Shaping and binding the overhangs : After soldering and sleeving all the end connections, lay the jumper wires and lead wires in a symmetrical manner so that uniformity is maintained and the overhang looks neat. By a wooden or nylon mallet, gently tap the coil overhangs on both the sides into concentric ring. Use wooden or fibre roller for this as shown in Fig 7. At intervals check the overhang dimensions with the data taken earlier.

Fig 7



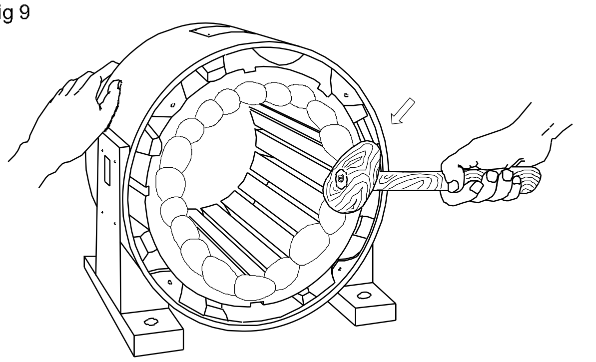
Bind the end connections, jumper and lead connections with the coil tightly with binding thread with suitable tape as in the original. (Fig 8)

Fig 8



After binding the connection leads with the overhangs, once again finally shape both the overhangs into concentric rings, so that they spread uniformly and do not touch the rotor. During the process check often whether sufficient gap is provided between the frame and end covers as in the original. (Fig 9)

Fig 9



Maintenance, service and troubleshooting in AC 3 phase squirrel cage induction motor and starters

Objectives: At the end of this lesson you shall be able to
- **list and state about the maintenance schedule of AC 3 phase motor**
- **list out the possible faults, causes and remedies in 3 phase motors**
- **explain the mechanical problems in motor, bearings and their remedies**
- **state the lubrication techniques on learning**
- **explain the troubleshooting of AC motor starters and maintenance of starters.**

Generally due to the rugged construction of the AC squirrel cage induction motor, it requires less maintenance. However to get trouble-free service and maximum efficiency, this motor needs a scheduled routine maintenance. As found in most of the industries the AC squirrel cage motor is subjected to full load for 24 hours a day and 365 days a year. Therefore the maintenance should be scheduled to have periodic maintenance for a selected area on daily, weekly, monthly, half yearly and yearly periods for increasing the working life of the motor and to reduce the break down time.

Maintenance schedule: Suggested maintenance schedule for the AC squirrel cage induction motor is given below as a guide.

Daily maintenance

- Examine earth connections and motor leads.
- Check motor windings for overheating. (Note that the permissible maximum temperature is above that which can be comfortably felt by hand.)
- Examine the control equipment.

In the case of oil ring lubricated machines

i) examine bearings to see that oil rings are working

ii) note the temperature of the bearings

iii) add oil if necessary

iv) check end play.

Weekly maintenance

- Check belt tension. In a case where this is excessive it should immediately be reduced and in the case of sleeve bearing machines, the air gap betweeen the rotor and stator should be checked.
- Blow out the dust from the windings of protected type motors, situated in dusty locations.
- Examine the starting equipment for burnt contacts where motor is started and stopped frequently.
- Examine oil in the case of oil-ring lubricated bearings for contamination by dust, dirt etc. (This can be roughly ascertained on inspection by the colour of the oil).

Monthly maintenance

- Overhaul the controllers.
- Inspect and clean the oil circuit breakers.
- Renew oil in high speed bearings in damp and dusty locations.
- Wipe brush holders and check the bedding of brushes of slip-ring motors.
- Check the condition of the grease.

Half-yearly maintenance

- Clean the winding of the motors which are subjected to corrosive or other such elements. Also bake and varnish if necessary.
- In the case of slip ring motors check slip rings for grooving or unusual wear.
- Renew grease in ball and roller bearings.
- Drain all oil bearings, wash with kerosene, flush with lubricating oil and refill with clean oil.

Annual maintenance

- Check all high speed bearings and renew if necessary.
- Blow out clean dry air over the windings of the motor thoroughly. Make sure that the pressure is not so high as to damage the insulation.
- Clean and varnish dirty and oily windings.
- Overhaul motors that are subject to severe operating conditions.
- In the case of slip ring motors, check the slip ring for pittings and the brush for wear. Badly pitted slip rings and worn out brushes should be replaced.
- Renew switch and fuse contacts if badly pitted.
- Renew oil in starters that are subjected to damp or corrosive elements.
- Check insulation resistance to earth and between phases of motor windings, control gear and wiring.
- Check resistance of earth connections.
- Check air gaps.

Records : Maintain independent cards or a register (as per specimen shown in trade practical) giving a few pages for each machine and record therein all important inspections and maintenance works carried out from time to time. These records shall show past performance, normal insulation level, gap measurements, nature of repairs and time between previous repairs, and other important information which would be of help for good performance and maintenance.

Faults which occur in AC 3-phase squirrel cage motor can be broadly divided into two groups

They are

1. Electrical faults
2. Mechanical faults.

In most of the cases both the faults may be individually present or both may be present, as one type of fault creates the other fault. The following charts give the cause, the test to be carried out and possible remedy.

Chart 1

Motor fails to start

S.No	Cause	Test	Remedy
1	Overload relay tripped.	Wait for overload coils to cool. Push the reset button if separately provided. In some starters the stop button has to be pushed to reset the overload relay.	If motor could not be started check the motor circuit for other causes as outlined in this chart.
2	Failure of power supply.	Test the power supply at the starter incoming terminals.	If the supply is present in the incoming terminals of the starter, check the starter for fault. If not, check the main switch and fuses. Replace the fuses if necessary or restore power supply.
3	Low voltage.	Measure the voltage at the mains and compare with the name-plate rating.	Restore normal supply or check the cables for underrating.
4	Wrong connection.	Compare the connection with the original diagram of the motor.	Still if motor does not start, reconnect, after disconnecting the connection of the motor.
5	Overload.	Measure the starting torque required by load.	Reduce load, raise tapping on auto-transformer, install a motor of a higher output.
6	Damaged bearings.	Open the motor and check the play of bearings.	Replace if required.
7	Faulty stator winding.	Measure current per phase and they should be equal, if required measure resistance per phase; check insulation resistance between winding and earth.	Repair the fault if possible or rewind stator.
8	Wrong control connections.	Check the control circuit and compare it with the circuit diagram.	Reconnect the control circuit according to the manufacturer's circuit diagram.
9	Loose terminal connections at mains or at starter or at motor.	Check the terminal connection of the main switch, starter and motor for discolouring and loose nuts.	Tighten the terminals.
10	Driven machine is locked.	Disconnect the motor from the load.	If the motor starts satisfactorily check the driven machine and rectify the defect.
11	Open circuit in stator or rotor.	Check visually and then with multimeter/megger.	Rectify the defect or wind.
12	Short circuit in stator winding.	Check the phases and coil groups with the help of an ohmmeter or use internal growler.	Repair the winding or rewind.

S.No	Cause	Test	Remedy
13	Winding is grounded.	Test with a Megger or test lamp.	If the fault is found, repair or rewind.
14	Bearing stiff.	Rotate the rotor by hand.	If the rotor is stalled, dismantle the motor and rectify the defect.
15	Overload.	Check the load and belt tension.	Reduce the load or loosen the tight belts.

Chart 2

Motor starts but does not share load (Runs at low speed when loaded.)

S.No	Cause	Test	Remedy
1	Too low a voltage.	Measure voltage at the motor terminals and verify it with the name-plate.	Renew bad fuses; repair circuit and remove the cause of low voltage, like loose or bad contacts in starter, switches, distribution box,etc.
2	Bad connection.	Check the connection and contact of starter for loose contact.	Remove the fault as required.
3	Too low or high tension on driving belt.	Measure the tension and verify it with the instruction of the manufacturer.	Adjust the belt tension.
4	Open circuit in rotor winding.	Examine the rotor bars and joints.	Re-solder the rotor bars.
5	Faulty stator winding.	Check for continuity, short circuit and leakage.	Repair the circuit if possible or rewind the stator.
6	Defective bearings.	Examine bearings for play.	Replace the bearings.
7	Excessively loaded.	Measure the line current of the motor and compare it with its rated current.	Reduce the mechanical load on the motor.
8	Low frequency.	Measure the line frequency with a frequency meter.	If the line frequency is low inform the supply authorities and get it corrected.

Chart 3

Motor blows off fuses

S.No	Cause	Test	Remedy
1	Incorrect size of fuses	Check the size of the fuse wire (it should be rated for 1½ times its normal current); connect the ammeter in the circuit and test for excess load current.	Replace the fuse wire if necessary; repair the motor if it is due to electrical fault of stator or rotor.
2	Low voltage	Measure the line voltage.	Remove the cause of low voltage.
3	Excessively loaded	Measure the line current and compare it with its rated current.	Rectify the cause of overload or install a motor of higher output rating.
4	Faulty stator winding	Check for open circuit, short circuit or leakage of the stator as explained earlier.	Repair the fault; if not possible then rewind the stator.
5	Loose connection in starter	Check for loose or bad connection in the starter because it may cause unbalancing of current.	Rectify the loose connection; loose all the contact points of the starter with sandpaper and align the contacts.
6	Wrong connection	Check the connection with the original diagram.	Reconnect the motor if it still does not start.

Chart 4

Over Heating of the motor

S.No.	Cause	Test	Remedy
1	Too high or low voltage or frequency.	Check the voltage and frequency at the terminal of the motor.	Rectify the cause of low or high voltage or frequency as the case may be.
2	Wrong connection.	Compare the connection with the given circuit diagram.	Reconnect the connection if required.
3	Open circuit in rotor.	Loose joints of rotor bars causeheat.	Resolder the joints of rotor bars and end rings.
4	Faulty stator winding.	Check for continuity, short circuit and leakage as stated before.	Remove the fault if possible; otherwise rewind the stator winding. Remove dirt and dust from them if any.
5	Dirt in ventilation ducts.	Inspect ventilation ducts for any dust or dirt in them.	Reduce the load or loosen the belt. Rectify the single phasing defect.
6	Overload.	Check the load and the belt.	If the defect is with the driven machine repair it. If the problem is with the bearing, investigate and repair or replace with new one.
7	Unbalanced electrical supply.	Check the voltage for single phasing. Check the connections and fuses. Remove the load and check the rotor for free rotation.	If required replace the motor designed for this purpose.
8	Motor stalled by driven machine or tight bearing.	Check the motor - starter contactor	Loose the machine bearing or grease the bearing or replace the bearing.
9	Motor when used for reversing heats up.	Check the connection	Check the manufacturer's instructions.

Mechanical problems in the motor: In general the squirrel cage induction motor is found to develop more mechanical troubles rather than electrical troubles. A thorough knowledge about the bearing and lubrication is a must for every electrician. As most of the faults which developed later in the squirrel cage motor are due to wrong selection of bearings, improper fittings of bearings and inefficient lubrication, it is essential that the electrician should have some knowledge with respect to the types of bearings, method of fitting or removal of the bearings and type of lubricants available in the market as explained below.

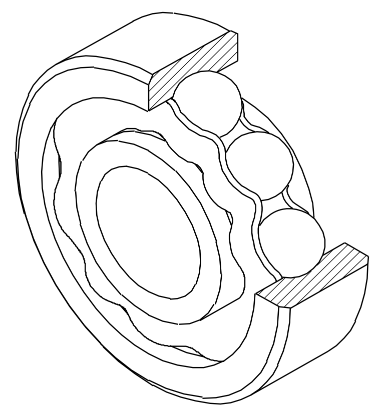
Ball or roller bearings : The electric motor is fitted with either a ball (Fig 1) or roller (Fig 2) bearing for easy rotation of the shaft.

As shown in Figs 1 & 2 these bearings have balls or rollers which prevent sliding friction by rolling between the races.

As bearings are used between stationary and revolving machine parts, such bearings have a stationary and a revolving race.

Handling the bearings : Bearings are precision-made of hard, brittle materials. But the working surfaces of bearings are either honed or very soft. If these surfaces are damaged, the bearing is ruined, therefore:

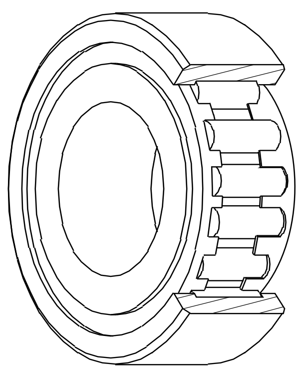
Fig 1



SINGLE ROW SNAP RING BALL BEARING

ELN3314111

Fig 2



CYLINDRICAL ROLLER BEARING

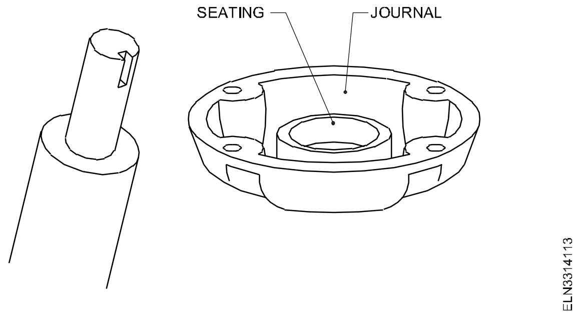
ELN3314112

- handle the bearings carefully to prevent damage
- keep the bearings wrapped until fitted, to keep out dirt
- protect the bearings against corrosion during storage, e.g. steel bearings must be oiled.

Installing bearings : Before any bearing is fitted:

- clean the journal or housing thoroughly and the seatings of the locating devices. (Fig 3)

Fig 3



- inspect the surfaces for damage; do not fit the bearings to damaged surfaces.
- Then coat the journal or housing with clean, light oil.

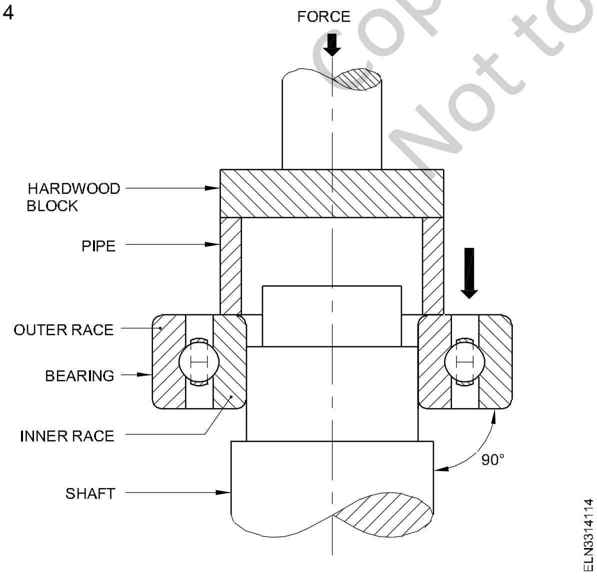
Take care to keep the oil clear of slip rings, brushes and the control gear of a motor.

While fitting the bearings to the shaft sufficient force has to be applied on the bearing. During the process to avoid damage to the bearings follow the procedure given below.

a) Force through arbor press.

Apply force through an arbor press to the inner race which is in contact with the housing as shown in Fig 4 by using a pipe and solid block of wood.

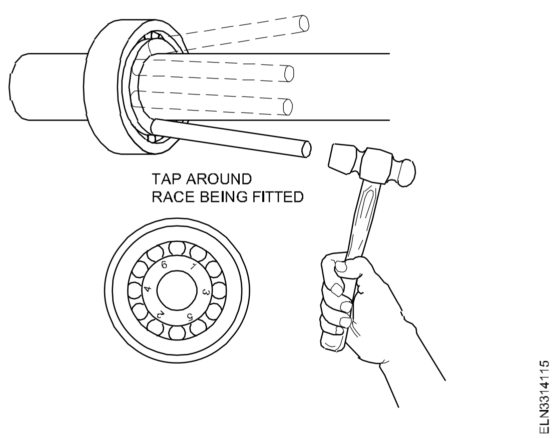
Fig 4



This is the best method, since the bearing can more easily be kept square to its seating.

b) Tapping bearings into place using a drift. (Fig 5)

Fig 5



Bearings should only be tapped into place when they cannot be pressed into position. Decide which is the most appropriate method.

Tap evenly around the race being fitted. Take care to keep the bearing square to seating. The method is useful when the seating is in an awkward situation. Take care to prevent foreign matter from entering the bearing.

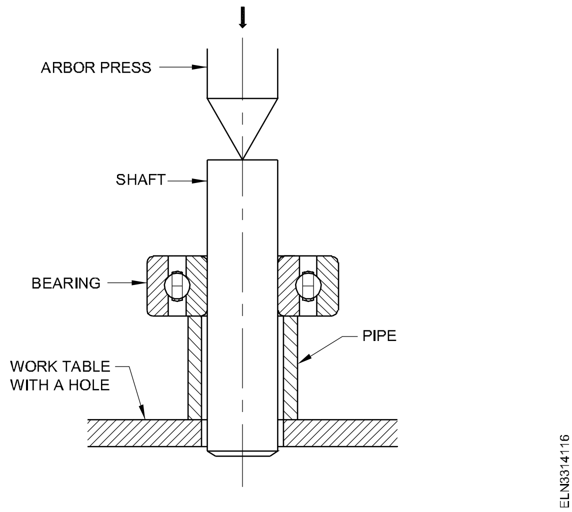
Tap the bearing home gently, stopping frequently to check that it is square.

Bearing removal techniques

a) Using an arbor press. (Fig 6)

Decide which is the best way to set the job up on the press. Apply the force evenly to remove the bearing.

Fig 6

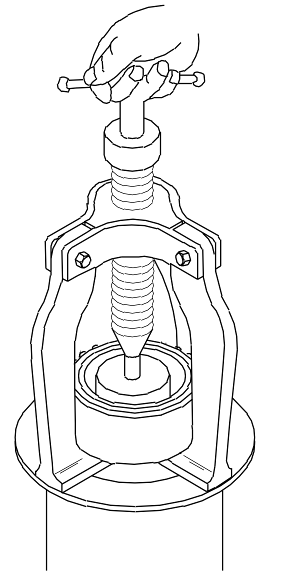


b) Using bearing puller. (Fig 7)

When using bearing pullers take care to keep the bearing square to the shaft. Screw-pullers are suitable for most purposes; take care to keep the puller square when turning the screw.

Locating faults in bearings : For checking any bearing, it should be cleaned well.

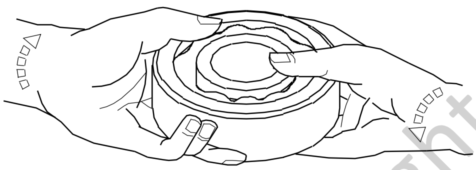
Fig 7



Ball bearings : Normally the ball bearings cannot be readily dismantled for close examination.

Wear : Check the wear of the ball bearing by holding the inner ring between the thumb and fore finger of one hand and holding the outer ring with the other hand . Holding the ball bearing twist the rings to and fro as indicated in Fig 8.

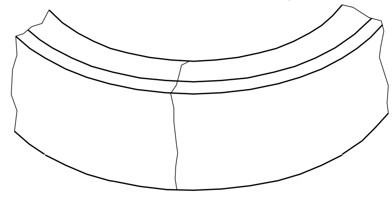
Fig 8



Any sign of movement indicates wear and the bearing needs to be replaced with a ball bearing of the same specification.

Break : Check the bearing for broken inner and outer rings which also indicate poor fitting, excessive load or wrong choice of bearing. (Fig 9)

Fig 9

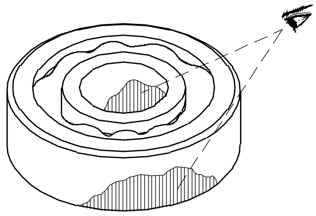


BROKEN RACES

Stains : Check the inner bore and the outer surface for the characteristic brown and black stains on a generally smooth and bright surface. (Fig 10) These marks indicate that movement has been taking place between the bearing, shaft and the housing due to poor fitting.

Roller bearing : After cleaning the bearing remove the inner ring and roller assembly from the outer ring.

Fig 10

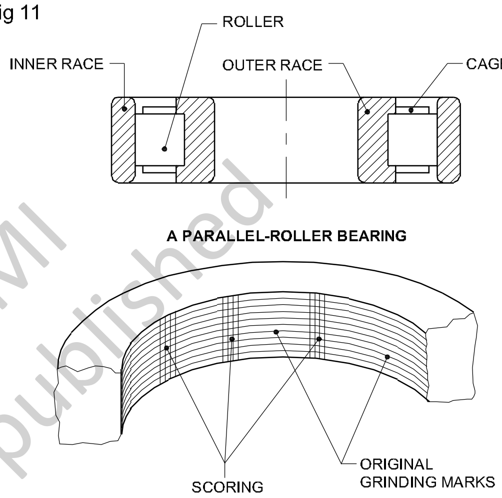


STAINS IN FITTING SURFACES

Check the inner surface of the outer ring. The surface should be smooth and polished with no regular marks of roughness or indentations.

The presence of score marks across the track at intervals corresponding to the pitch of the rollers as shown in Fig 11 indicates faulty initial fitting.

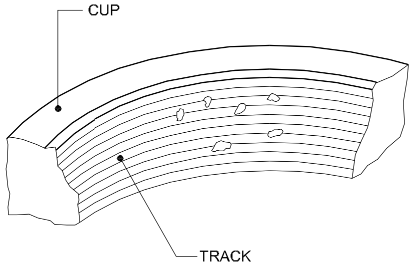
Fig 11



These roller bearings with score mark indicate excessive wear and produce noise.

Rough patches on the track as shown in Fig 12 indicate the wear caused by out-of-balance vibration or fatigue effects. The hard surface flakes off.

Fig 12



Check the general wear of the bearing by using both the hands as described for ball bearings.General wear sometimes causes a loss of brightness of the track, the shine being replaced by a dull surface.

Heavy general wear may produce a distinct groove around the track.

Static electrical discharges may also cause blackened surface pitting of bearing on certain machines. Where this is suspected check the rotor earthing arrangements.

General pitting may be due to rusting caused by inadequate lubrication or damp service conditions.

Examine the cage rings for signs of wear somewhere around the inner circumference. Localized wear of a brass ring may be accompanied by a brassy discolouration of the track, as the minute particles of brass are ground into the surface.

A worn out ring indicates a worn out bearing. Replace it.

Lubrication : Many a time it is detected that the mechanical faults found in the motor is due to imperfect lubrication. A thorough knowledge about lubricatioin is required for the service technician. Most of the motor manufacturers recommend a certain type and grade of lubricant for efficient operation of the motor. It is recommended that the same type and grade should be used to get optimum efficiency of the motor and the specified grade of lubricant should be painted on the motors for guidance.

There are several methods of lubricating motors. Small motors with sleeve bearings have oil holes with spring covers. These motors should be oiled periodically with a good grade of mineral oil as recommended by the manufacturer.

The bearings of larger motors often are provided with an oil ring which fits loosely in a slot in the bearing. The oil ring picks up the oil from a reservoir located directly under the ring. Under normal operating conditions, the oil should be replaced in the motor at least once a year. More frequent oil replacement may be necessary in motors operating under adverse conditions. In all cases, avoid excessive oiling; insufficient oil can ruin a bearing but excessive oil can cause deterioration of the insulation of a winding.

Many motors are lubricated with grease. Periodic replacement of the grease is recommended. In general, the grease should be replaced whenever a general overhaul is indicated, or sooner if the motor is operated under severe operating conditions.

Grease can be removed by using a light mineral oil heated to 165°F or a solvent. Any grease-removing solvent should be used in a well-ventilated work area.

Bearing troubles and the possible remedies are given in Chart 5.The following Do's and Don'ts instruction is pertaining to ball-bearing. Follow it for avoiding bearing problems.

Do 's and Don'ts for ball-bearing assembly, maintenance, inspection and lubrication

Do's	Don'ts
Do work with clean tools, in clean surroundings.	Don't work under the handicap of poor tools, rough bench, or dirty surroundings.
Do remove all outside dirt from housing before exposing the bearing.	Don't use dirty, brittle or chipped tools.
Do treat an used bearing as carefully as a new one.	Don't handle bearings with dirty, moist hands.
Do use clean solvents and flushing oils.	Don't spin uncleaned bearing.
Do lay bearings out on clean paper.	Don't spin any bearings with compressed air.
Do protect disassembled bearings from dirt and rinse of moisture.	Don't use the same container for cleaning the of bearings.
Do use clean, lint-free rags to wipe the bearings.	Don't scratch or nick bearing surfaces.
Do keep the bearing lubricants clean when applying and cover containers when not in use.	Don't remove grease or oil from new bearings.
Do clean outside of housing before replacing bearings.	Don't use incorrect kind or amount of lubricant.
Do keep bearing lubricants clean when applying and cover containers when not in use.	Don't use a bearing as a gauge to check either the housing bore or the shaft fit.
Be sure the shaft size is within specified tolerances recommended for the bearing.	Don't install a bearing on a shaft that shows excessive wear.
Do store the bearing in original unopened cartons	Don't open the carton until bearing is ready to replace. in dry for installation.
Do use a clean, short-bristle brush with firmly embedded bristles to remove dirt, scale or chips.	Don't judge the condition of a bearing until after it has been cleaned.
Be certain that, when installed, the bearing is square with and held firmly against the shaft shoulder.	Don't pound directly on a bearing or ring, when instal-ling,as this may cause damage to the shaft and bearing.

Do's	Don'ts
Do follow lubricating instructions supplied with the machinery. Use only grease where grease is specified. Use only oil where oil is specified. Be sure to use the exact kind of lubricant called for.	Don't overfill when lubricating. Excess greases and oil will ooze out of the over-filled housings past seals and closures, collect dirt and cause trouble. Too much lubricant will also cause over heating, particularly where bearings operate at high speeds.
Do handle grease with clean paddles or grease guns. Store grease in clean containers. Keep the grease containers covered.	Don't permit any machine to stand inoperative for months without running it over periodically. This prevents moisture which may condense in a standing bearing from causing corrosion.

In addition to the bearing faults the motor may develop certain troubles like vibration and noise which may be due to electrical or machancial faults.

Troubleshooting Chart 6 given here illustrates the possible causes, areas of fault and remedies for the faults like vibration and noise.

Chart 6

Vibration and noise in motors

S.No.	Cause	Test	Remedy
1	Loose foundation bolts or nuts.	Inspect nuts and bolts of foundation for loose fittings.	Tighten the foundation nuts.
2	Wrong alignment of coupling.	Check alignment with a spirit level through dial test indicator.	Realign the coupling.
3	Faulty magnetic circuit of stator or rotor.	Measure the current in each phase and they should be equal. Check also per-phase resistance and they should be equal. Check the insulation resistance between the windings and the frame. In a newly wound motor there may be reversed coils in a pole-phase group which can be detected by the compass test.	Repair fault if possible or rewind the motor.
4	Motor running on single phase.	Stop the motor, then try to start. (It will not start on single phase). Check for open in one of the lines or circuits.	Rectify the supply.
5	Noisy ball bearing.	Check the lubrication for correct grade and low noise in the bearing.	If found, replace the lubricant or replace the bearing.
6	Loose punching or loose rotor on shaft.	Check the parts visually.	Tighten all the holding bolts.
7	Rotor rubbing on the stator.	Check for rubbing marks on the stator and rotor.	If found, realign the shaft to centre it or replace the bearings.
8	Improper fitting of end-covers.	Measure the air gap at four different points for uneven position of rotor covers.	Open the screws of the side covers, and then tighten one by one. If trouble still persists, remove the end cover, shift for next position and tighten the screws again.
9	Foreign material in air-gap.	Examine the air-gap.	File or clean out air-gap.
10	Loose fan or bearings.	Check looseness of the fan screw or bearings.	Tighten the fan screws or refit new bearings, if necessary.
11	Slackness in bearing on shaft or in housing.	Remove the bearings and inspect the inner looseness of the race on the shaft and outer race in the housing.	Send the motor to the repair shop for removing the looseness of the shaft and housing, if any.

S.No.	Cause	Test	Remedy
12	Improper fitting of bearings.	Remove the end-covers and examine the assembly of bearings on the shaft or in the housing.	Refit the bearings on the shaft or in the housing.
13	Minor bend in shaft.	Check for alignment on the lathe.	Remove the bend or replace the shaft, if required.

Troubleshooting of motor starters

Objectives : At the end of this lesson you shall be able to
- **state the troubles in the D.O.L. starter, their cause and their remedy**
- **check out the troubles in the mini manual starter, their cause and their remedy.**

Introduction : The D.O.L. starter consists of the fixed contacts, movable contacts, no-volt coil, overload relay and start button which is in green colour and a stop button in red colour with a locking arrangement. Analyse the D.O.L. starter available in the workshop. The main purpose of the contactor is to make and break the motor circuit. These contacts in the contactor suffer maximum wear, due to frequent use and hence these contacts are made of silver alloy material.

A no-volt coil acts as under-voltage release mechanism disconnecting supply to the motor when the supply voltage fails or is lower than the stipulated value. Thus the motor will be disconnected from supply under these conditions. The no-volt coil magnetic system consists of a laminated iron core for minimising the eddy current and hysterisis losses. Shading rings are provided on the pole faces of the magnetic core to reduce the hum level and chattering which is present due to A.C. supply.

A thermal overload relay unit is provided for the protection of the motor. This unit consists of a triple pole, bimetallic relay housed in a sealed bimetallic enclosure. This is provided with a current setting arrangement. After tripping on overload, the relay has to be reset by pressing the stop button. The relay can be reset only after bimetalic strips get cooled sufficiently.

In case the motor does not start even though the start button is pressed, observe whether the stop button is locked with a metallic locking piece provided near the stop button. Release it and press the start button, then observe the functioning of the motor. Even then if the motor does not start check up the 3 phase supply. If the supply is found available at the incoming terminals of the starter, then switch off the supply and rectify the defect in the starter.

Suppose the three phase supply is available and starter NVC is energising but the motor does not start, check for any foreign material in between the contact points. Remove it and test the starter again. Visually observe whether the contacts are closing properly.

If any contact is not closing properly or any burns and pittings are noticed on the contact surface, then remove the contact strips. Dress up properly with zero number sandpaper or with a smooth file or replace it if necessary. Some manufacturers suggest that the contact points made out of silver alloy need to be cleaned with cloth only. It needs no filing or sandpaper rubbing. However, unless the contacts are found to have too much pittings, the filing or dressing with sandpaper is not recommended. Further badly shaped or disfigured contacts need to be replaced with a good ones. See that there is proper spring tension over the contacts. Likewise check all the contact strips of the contactor and clean them with an approved contact cleaner.

When the no-volt coil is activated by the start button, the auxiliary contact of the starter should close to complete the NVC circuit and should remain in the closed position even after the start button is released.

If the overload relay is not functioning properly i.e. not tripping the motor as per setting of the current rating, then replace it with a new one as per with the original specification of the manufacturer.

If a humming and chattering noise is observed in the starter then check for the rated voltage. If the voltage is okay, then check for any gummy material adhered to the pole faces. If found, clean it properly. See whether the shading ring over the pole faces of the NVC is loose. Tighten it properly and also check the spring tension of NVC housing.

Suppose the starter trips often then, check up the load on the motor. (Might be due to overload or over tension of the belt) Reduce the load or tension of the belt. Further check up the motor current in each phase. If the motor takes higher current than specified even though the load is normal, then the fault is with the motor and not with the starter. After attending to the faults and rectifying them, reassemble the starter,connect it to the motor for proper functioning.

Starter check - chart given below could be used to locate trouble in a D.O.L. starter.

Maintenance of DOL starters

Trouble	Cause	Remedy
I Starter check chart		
1 Contacts chatter	Low voltage, coil is not picking up properly. Broken pole shading ring. Poor contact between the pole faces of the magnet. Poor contact between fixed and movable contacts.	Correct the voltage condition. In case there is persistent low voltage, check the supply of the transformer tapping. Replace. Clean the pole faces. Clean contacts and adjust, if necessary.
2 Welding or overheating.	Low voltage preventing magnet from sealing. Abnormal in rush current. Short circuit in the motor. Foreign matter preventing contacts from closing. Rapid inching.	Correct the voltage condition. In case of persistent low voltage, which is accepted normal change the NVC to lower voltage coil. Check excessive load current or use larger contactor. Remove the fault and check to ensure that the fuse rating is correct. Clean contacts with suitable solvent. Install larger device or caution the operator not to operate the inch button too quickly.
3 Short life of contact points	Weak contact pressure.	Adjust or replace contact springs.
4 Noisy magnets	Broken shading coil. Magnet faces not mating. Dirt or rust on magnet faces.	Replace magnet. Align or replace magnet assembly. Clean with suitable solvents.
5 Failure to pick up and seal the contacts.	Low voltage. Coil open or short-circuited. Mechanical obstruction for the moving parts.	Check system voltage. In case persistent low voltage, change to a lower voltage coil. Replace the coil. Clean and check for free movement of contact assembly.
6 Failure of moving mechanism to drop out.	Voltage not removed. Worn or rusted parts causing binding.Residual magnetism due to lack of air gap in magnet path. Gummy substance on pole faces causing binding.	Check wiring in the NVC coil circuit. Replace parts. Replace worn out magnet parts or demagnetise the parts. Clean with suitable solvent.
7 Overheating of coil	Over-voltage. Short circuited turns in coils caused by mechanical damage or corrosion. High ambient temperature. Dirt or rust on pole faces increasing the air gap.	Check and correct terminal voltage. Replace coil. Relocate starter in a more suitable area or use a fan. Clean pole faces.
II Overload relays/ release		
1 Starter is tripping often. Sustained overload.	Incorrect setting of over load relay.	Reset properly. Check for faults/excessive motor currents.
2 Failure to trip (causing motor burn out).	Wrong setting of O.L relay. Mechanical binding due to dirt, corrosion etc.	Check O.L relay ratings and set a proper relay. Clean or replace. Incorrect control wiring. Check the circuit and correct it.

Trouble	Cause	Remedy
III Fuses		
1 Constant blowing of fuses	Short circuit or poor insulation in winding/wiring.	Check the motor and the circuit for insulation resistance.
2 Fuse not blowing under short circuit condition.	Fuse rating too high.	Replace with suitable fuse.
3 Fuse blowing off frequently.	Fuse rating too low. Overloading of feeder.	Replace with suitable fuse. Check for over-current, leakage and short circuit.

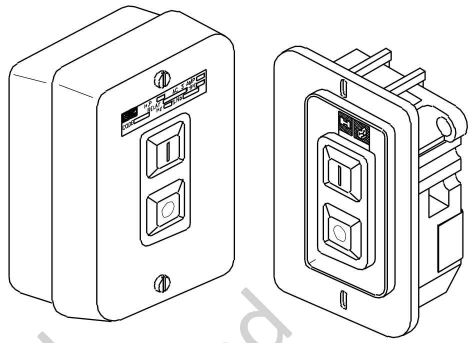
Mini Manual Starter (Refer Fig 1)**:** This starter unit comprises of a double brake 3-pole on load switch operated by means of a toggle mechanism. Adjustable bimetal thermal overload strips are included in it which can be set for the correct load current of the motor.

The stop push-button and overload trips act on the toggle switch mechanism to trip the starter.

The fixed contacts are formed of silver tips on heavy terminal blocks with clamp type terminals. The moving contacts are of copper with silver coating.

In general the manual starters are possessing the toggle switch anchor mechanism. Due to frequent use, the spring tension becomes weak and it will not hold the contacts in the closed position. In such case the lever mechanism should be replaced? If the starter trips often check up the overload thermal strips. If they are defective replace them.

Fig 1



MINI MANUAL STARTER

ELN3314121

Single phase motors - split phase induction motor - induction-start, induction-run motor

Objectives: At the end of this lesson you shall be able to
- **explain briefly the types of AC single phase motors**
- **explain the necessity and methods of split-phasing the single phase to obtain a rotating magnetic field**
- **explain the principle, construction, operation characteristic and application of single phase resistance / induction-start / induction-run motors.**

Single phase motors perform a great variety of useful services at home, office, farm, factory, and in business establishments. These motors are generally referred to as fractional horsepower motors with a rating of less than 1 H.P. Most single phase motors fall into this category. Single phase motors are also manufactured in 1.5,2,3 and up to 10 H.P. as a special requirement.

Single phase motors may be broadly classified as split-phase induction motors and commutator motors according to their construction and method of starting.

Split-phase induction motors can be further classified as:

- resistance-start, induction-run motors
- induction-start, induction-run motors
- permanent capacitor motors
- capacitor-start, induction-run motors
- capacitor-start, capacitor-run motors
- shaded pole motors.
- stepper motor

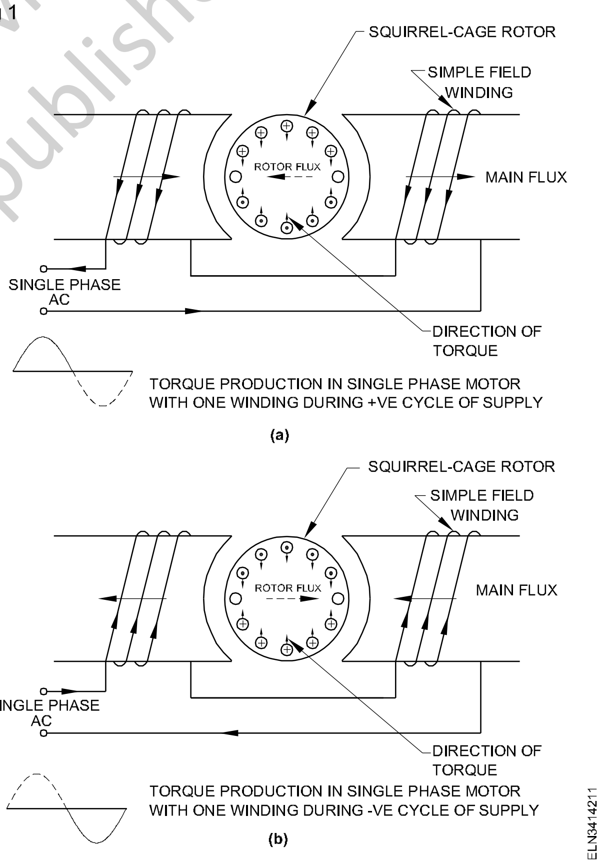
Commutator motors can be classified as:

- repulsion motors
- series motors.

The basic principle of operation of a split-phase induction motor is similar to that of a polyphase induction motor. The main difference is that the single phase motor does not produce a rotating magnetic field but produces only a pulsating field. Hence to produce the rotating magnetic field, phase-spliting is to be done to make the motor to work as a two-phase motor for starting.

First, let us examine the behaviour of the magnetic field as set up by an AC current in a sinlge-phase field winding. With reference to Fig 1, at a particular instant, the current flowing in the field winding produces the magnetic field as shown in Fig 1a. Since the produced magnetic field is varying, it will induce currents in the rotor bars which in turn will create a rotor flux. This stator-induced flux, according to Lenz's law, opposes that of the main field. By applying this principle, the current direction in the rotor bars can be determined as shown in Fig 1a, as well as the torque created between the field and rotor currents. It is apparent that the downward torque produced by the upper rotor conductors is counteracted by the upward torque produced by the lower rotor conductors; hence no rotation results. In the next instant, as shown in Fig 1b, the voltage in the input supply changes its polarity, creating a main field with a change in direction. This main field produces a torque, downward in upper conductors, and upwards in bottom conductors resulting in the cancellation of torque with no movement of the rotor, in this case also. Since the field is pulsating, the torque is pulsating although no net torque is produced over a full cycle.

Fig 1



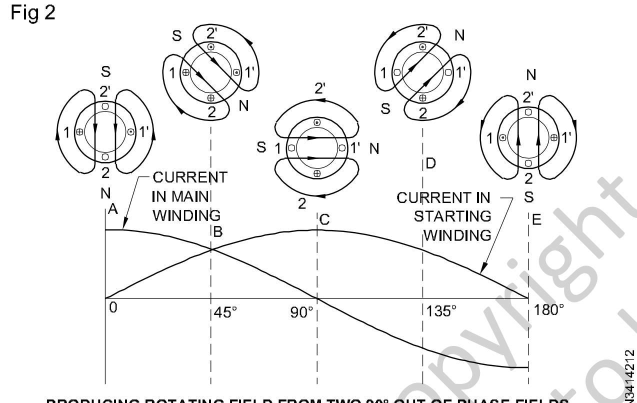
If the rotor is given a small jerk in any direction in the above mentioned cases, it will go on revolving, and will develop a torque in that particular direction due to interaction between the rotor and stator fluxes. Because of this effect, the split-phase motor, once started, needs only one winding to be connected to the supply for running. It is clear that a single phase induction motor, when having only one winding, is not self-starting. If the main field is made revolving instead of pulsating, a rotational torque could be produced in the rotor.

Producing a rotating field from two 90° out-of-phase fields: One of the methods of producing a rotating magnetic field is by split-phasing. This could be done by providing a second set of winding in the stator called the starting winding. This winding should be kept physically at 90 electrical degrees from the main winding, and should carry a current out of phase from the main winding. This, out of phase current, could be achieved by making the reactance of the starting winding being different from that of the main winding. In case both the windings have similar reactance and impedance, the resulting field, created by the main and starting windings, will alternate but will not revolve and the motor will not start.

By split-phasing, the two (main and starting) fields would combine to produce a rotating magnetic field as stated below.

Fig 2 shows that the main (1,1') and starting (2,2') windings are kept in the stator at 90° to each other. For consideration, only, one half cycle is shown with the effects at 45^0 increments.

Fig 2



PRODUCING ROTATING FIELD FROM TWO 90° OUT-OF-PHASE FIELDS

At position `A', only the main winding is producing flux, and the net flux will be in a vertical direction, as shown in the stator diagram. At instant `B', 45° later, both windings are producing flux, and the net flux direction will also have rotated 45°. At position `C', the maximum flux is now in a horizontal direction because only the starting winding is producing flux. At instant `D', the current from the main winding is building up again, but in a new direction, while that from starting winding is now decreasing. Therefore, the net flux at this instant will be as shown in position D. At position `E', the maximum flux is just the opposite of what it was at instant `A'. It should now be evident that the two out-of-phase fields are combining to produce a net rotating field effect.

Working of split-phase motor: At the time of starting, both the main and starting windings should be connected across the supply to produce the rotating magnetic field. The rotor is of a squirrel cage type, and the revolving magnetic field sweeps past the stationary rotor, inducing an emf in the rotor. As the rotor bars are short-circuited, a current flows through them producing a magnetic field. This magnetic field opposes the revolving magnetic field and will combine with the main field to produce a revolving field. By this action, the rotor starts revolving in the same direction of the rotating magnetic field as in the case of a squirrel cage induction motor, which was explained earlier.

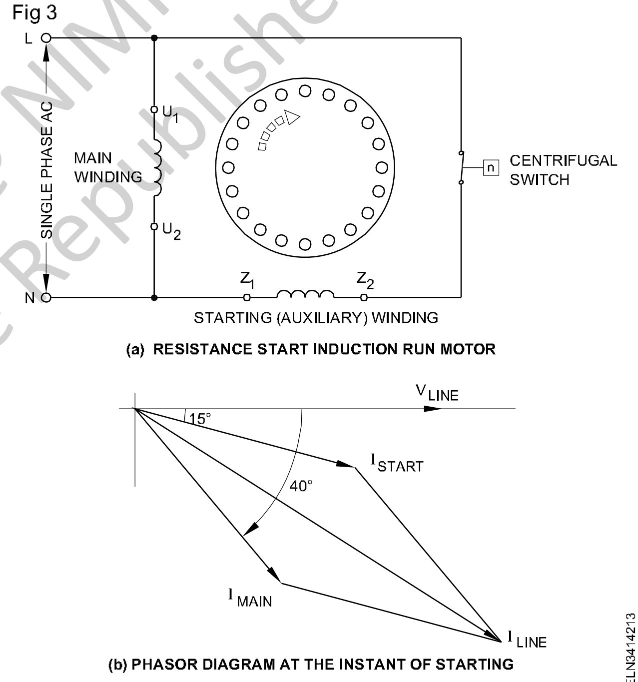
Hence, once the rotor starts rotating, the starting winding can be disconnected from the supply by some mechanical means as the rotor and stator fields form a revolving magnetic field.

Resistance-start, induction-run motor: As the starting torque of this type of motor is relatively small and its starting current is high, these motors are most commonly used for rating up to 0.5 HP where the load could be started easily.

The essential parts are as shown in Fig 3a.

- Main winding or running winding
- Auxiliary winding or starting winding
- Squirrel cage type rotor
- Centrifugal switch

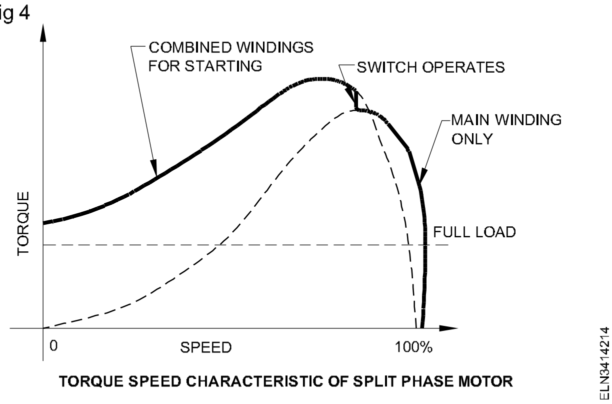
Fig 3



The starting winding is designed to have a higher resistance and lower reactance than the main winding. This is achieved by using smaller conductors in the auxiliary winding than in the main winding. The main winding will have higher inductance when surrounded by more iron, which could be made possible by placing it deeper into the stator slots. It is obvious that the current would split as shown in Fig 3b. The starting current `I start' will lag the main supply voltage `V' line' by 15° and the main winding current. `I main' lags the main voltage by about 40°. Therefore, these currents will differ in time phase and their magnetic fields will combine to produce a rotating magnetic field.

When the motor has come up to about 75 to 80% of synchronous speed, the starting winding is opened by a centrifugal switch, and the motor will continue to operate as a single phase motor. At the point where the starting winding is disconnected, the motor develops nearly as much torque with the main winding alone as with both windings connected. This can be onserved from the typical torque-speed characteristics of this motor, as shown in Fig 4.

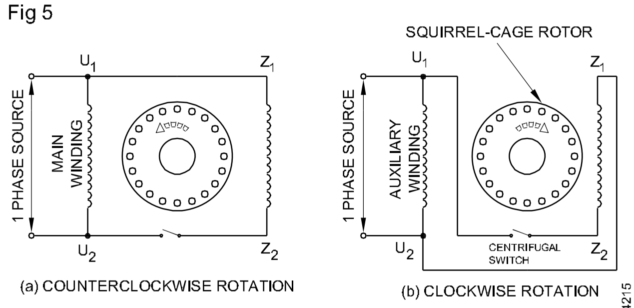
Fig 4



TORQUE SPEED CHARACTERISTIC OF SPLIT PHASE MOTOR

The direction of rotation of a split-phase motor is determined by the way the main and auxiliary windings are connected. Hence, either by changing the main winding terminals or by changing the starting winding terminals, the reversal of direction of rotation could be obtained. Rotation will be, say counter-clockwise, if Z_1 is joined to U_1 and Z_2 is joined to U_2 as per Fig 5a. If Z_1 is joined to U_2 and Z_2 is joined to U_1, then the rotation will be clockwise, as shown in Fig 5b.

Fig 5



METHOD OF CHANGING THE DIRECTION OF ROTATION OF RESISTANCE START INDUCTION RUN MOTOR

Application of resistance-start, induction-run motor: As the starting torque of this type of motors is relatively small and its starting current is high, these are manufactured for a rating up to 0.5 HP where the starting load is light. These motors are used for driving fans, grinders, washing machines and wood working tools.

Induction-start, induction-run motor: Instead of resistance start, inductance can be used to start the motor through a highly inductive starting winding. In such a case, the starting winding will have more number of turns, and will be imbedded in the inner areas of the stator slots so as to have high inductance due to more number of turns, and the area will be surrounded by more iron. As the starting and main windings in most of the cases are made from the same gauge winding wire, resistance measurement has to be done to identify the windings. This motor will have a low starting torque, higher starting current and lower power factor.

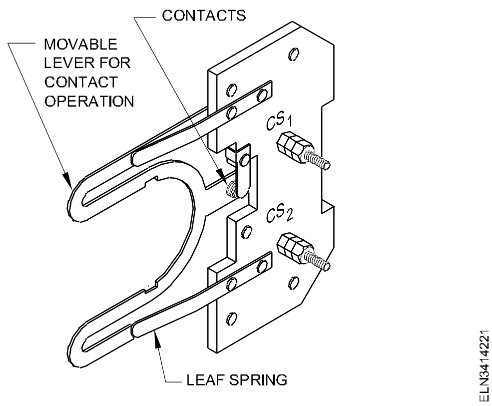
Centrifugal switch

Objectives: At the end of this lesson you shall be able to
- **explain the working, the method of maintenance and testing of a centrifugal switch**
- **explain the necessity of a manual D.O.L. starter and its working**
- **explain the operation of overload relays.**

The centrifugal switch: The centrifugal switch is located inside the motor and is connected in series with the starting winding in the case of capacitor-start, induction-run motors, and for disconnecting the starting capacitor in the case of a two value, capacitor-start, capacitor-run motor. Its function is to disconnect the starting winding after the rotor has reached 75 to 80% of the rated speed. The usual type consists of two main parts. Namely, a stationary part as shown in Fig 1, and a rotating part as shown in Fig 2. The stationary part is usually located on the front-end plate of the motor and has two contacts, so that it is similar in action to a single-pole, single-throw switch. When the rotating part is fitted in the rotor, it rotates along with it. When the rotor is stationary, the insulator ring of the rotating part is in an inward position due to spring tension. This inward movement of the insulator ring allows the stationary switch contacts to be closed which is due to the movable lever pressure against the leaf-spring tension in the switch.

When the rotor attains about 75% of the rated speed, due to centrifugal force, the governor weights fly out, and this makes the insulator ring to come outward. Due to this forward movement of the insulated ring, it presses the movable lever, and the contacts connected through terminals CS_1 and CS_2 open the starting winding.

Fig 1



In older types of centrifugal switches, the stationary part consists of two copper, semicircular segments. These are insulated from each other and mounted inside the front-end plate. The centrifugal switch connections are given to these segments. The rotating part is composed of three copper fingers that ride around the stationary segments, while the motor is at rest or running at lower than 75% of the rated speed. These parts are illustrated in Fig 3.

Fig 2

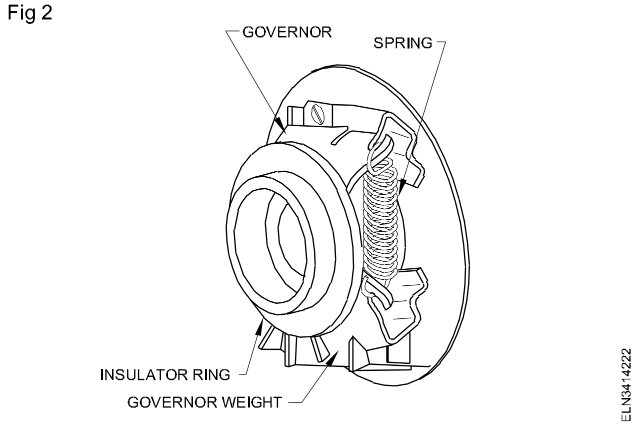
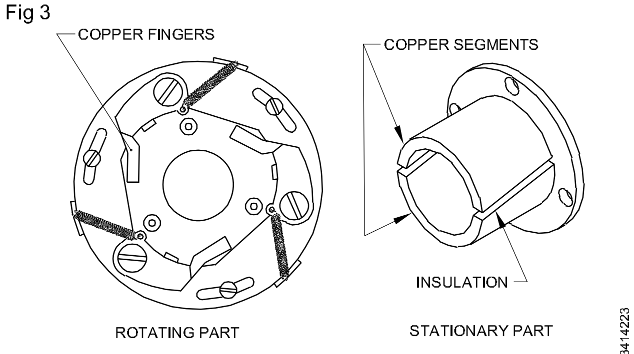


Fig 3



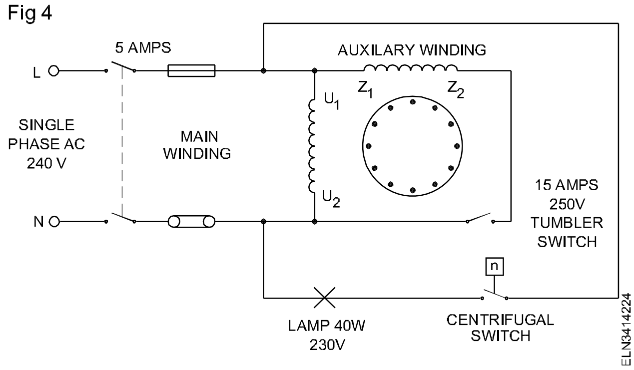
CENTRIFUGAL SWITCH

At the time of starting, the segments are shorted by the copper fingers, thus causing the starting winding to be included in the motor circuit. At approximately 75 percent of the full speed, the centrifugal force causes the fingers to be lifted from the segments, thereby disconnecting the starting winding from the circuit.

Maintenance of centrifugal switch: Access to the centrifugal switch could be had by removing the inspection plate, located in the end covers of the motor. In very many cases, the switch is accessible only when the end plate is removed. These switches need to be checked atleast once in six months to ensure their proper operation. Look for broken or weak springs, for improper movement, for dirt or corrosion or pittings in the contact points. Make sure all parts work freely without binding. Replace the switch, if found defective.

Testing the operation of a centrifugal switch: Though the centrifugal switch could be tested in a static condition, it will be very difficult to assess its operation at dynamic condition. As most of these switches cannot be checked without opening the end plate, the procedure becomes lengthy and cumbersome. To check the dynamic operation of the switch the following method is suggested. Disconnect the interconnecting terminals of the centrifugal switch from the supply and the starting winding. Connect the starting (auxiliary) winding through a 15 amps, single-pole, tumbler switch to the rated supply as shown in Fig 4, and keep the tumbler switch in the `ON' position.

Fig 4



Connect the terminals of the centrifugal switch, through a lamp as shown in Fig 4. Switch `ON' the motor. When the centrifugal switch is in the closed position, the lamp will light. As the motor picks up speed, say in about 20 seconds, open the tumbler switch to disconnect the starting winding. When the speed of the motor attains about 75% of the rated value, the centrifugal switch, if it operates correctly, will open its contacts which could be observed from the lamp going `off'. Soon after switching `on' the main supply, if the lamp is not lighted, or if it lights up but does not go out after 30-40 seconds (75 % of the rated speed) then the centrifugal switch is deemed to be not working, and should be repaired or replaced.

Manual D.O.L. starter: A starter is necessary for starting and stopping the motor, and for providing overload protection.

A manual starter, as it appears, is shown in Fig 5, an open view of the starter is shown in Fig 6, and the internal parts are shown in Fig 7, as a schematic diagram. A manual starter is a motor controller with a contact mechanism operated by hand. A push-button operates the mechanism through a mechanical linkage. As shown in Figs 6 & 7, the starter may have both a thermal overload relay and a magnetic overload relay for overload protection and short circuit protection respectively. Both the relays are made to operate independently, in case of overload or short circuit, to release the start-button for disconnecting the motor from supply. Most of the present day, manual starters have either of the two relays only. Basically, a manual starter is an ON-OFF switch with overload relay only.

Fig 5

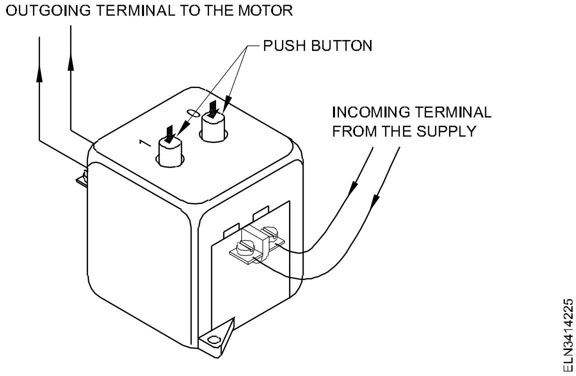
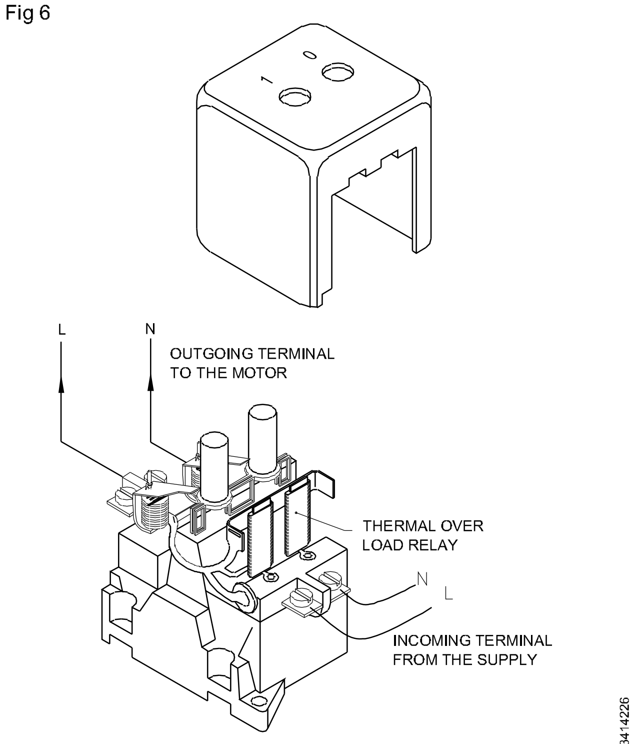
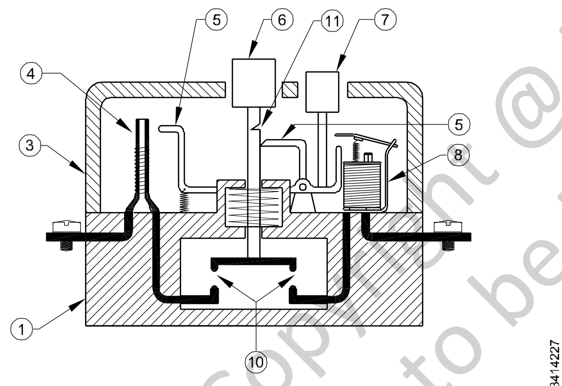


Fig 6



OPEN VIEW OF MANUAL D.O.L STARTER

Fig 7



SCHEMATIC DIAGRAM OF A MANUAL D.O.L STARTER

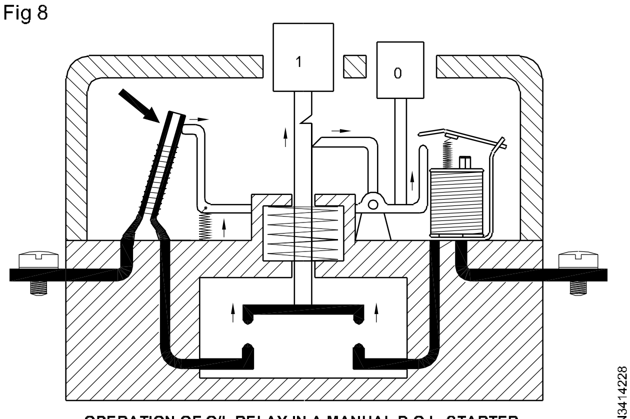
Manual starters are simple and they provide quiet operation.

Operation: Pushing the `ON' button closes the contacts. The contacts remain closed until the STOP button is pushed or the overload relay or the short circuit relay trips the starter.

As shown in Fig 7, when the `ON' push-button (6) is pressed, the switching contact (10) gets closed, and remains in a closed position, as the mechanical lever system (5) holds the stem of the `ON' button by the cavity (11) against the spring tension. By operating the stop button (7), the mechanical lever system (5) gets disengaged from the stem cavity, making the stem of the `ON' button to spring back, thereby opening the switching contacts (10).

Operation of overload relay: In the case of sustained overloads, the heavy currents passing through the heating element of the thermal overload relay heats up the bimetallic strip, making it to bend as shown by the arrow in Fig 8, thereby activating the mechanical lever system to open the switching contacts.

Fig 8



OPERATION OF O/L RELAY IN A MANUAL D.O.L. STARTER

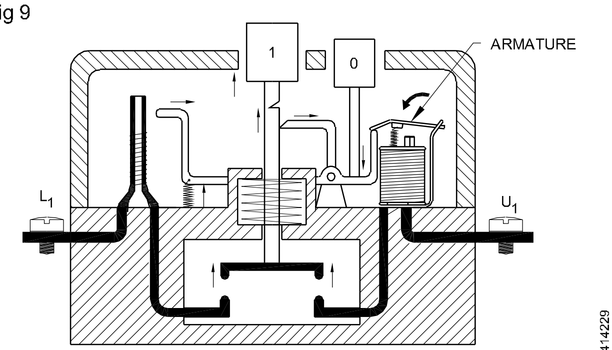
The current setting of the thermal overload relay can be changed by adjusting the setting screw, provided for this purpose (not shown in the figure.)

Operation of short-circuit relay:In the case of a short circuit in the motor circuit, the short circuit current will be very high in value. Though the thermal overload relay is also in series with such a short circuit current, it is sluggish in operation and takes considerable time to operate. On the other hand, the short circuit current within such time of delayed operation, will sufficiently damage the motor winding, power cables or the connected supply line.

The magnetic relay will operate faster than the thermal overload relay in such cases.

During normal load current the magnetic field produced by the coil will not have sufficient pull to attract the armature. But in case of short circuit, the current will be very high and the coil produces sufficient magnetism to attract the armature. Downward movement of the armature activates the mechacnical lever mechanism as shown by the arrow in Fig 9 and the switching contact opens. These contacts cannot be reclosed until the starter mechanism has been reset by pressing the Stop button.

Fig 9

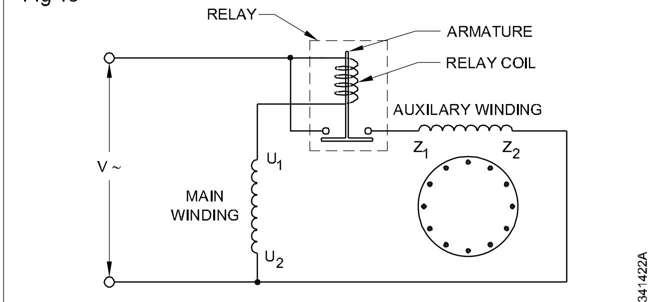


OPERATING OF MAGNETIC RELAY DURING SHORT CIRCUIT

Manual starters are used for fractional horsepower motors. They usually provide across-the-line starting. Manual starters cannot provide low-voltage protection or no-volt release. If power fails, the contacts remain closed, and the motor will restart when the power returns. This may be an advantage for pumps, fans, compressors, and oil burners. But in the case of machinery it can be dangerous to people operating the equipment, and hence, such manual starters are not recommended to be used in these places.

Electromagnetic relay: Single phase induction motors, like poly phase induction motors takes heavy current from the time during starting when started direct on line Advantage of this high starting current is taken to operate electromagnetic type relay which performs the same function as the centrifugal device. Connection diagram for such a relay is shown in Fig 10.

Fig 10



WIRING DIAGRAM FOR AN ELECTROMAGNETIC RELAY

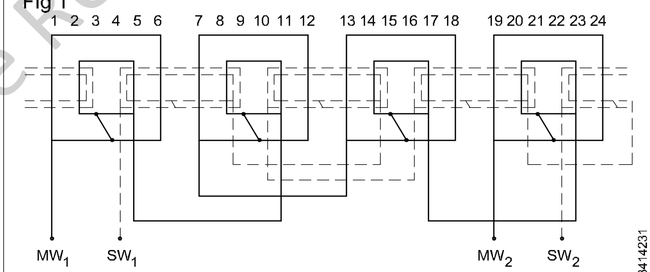
The relay has a coil which is connected in series with the main winding. The auxiliary winding is connected across the supply through a normally open contact of the relay. Since split-phase motors are usually started direct on line, the initial current inrush may be as high a five to six times the rated current. During the starting period, when the main winding current is high, the armature of the relay will be drawn upwards, thereby closing the relay contacts. The auxiliary winding will, therefore, get connected across the supply, thus helping the motor to start rotating. As the rotor starts rotating, the line current gradually goes on decreasing. After the motor reaches proper speed, the main winding current drops to a low value and causes the armature of the relay to fall downwards and open the contacts, thereby cutting out the auxiliary winding from the supply. Such relays are located outside the motor so that they can be easily serviced or replaced. As centrifugal switches are mounted internally, their servicing or replacement is not as simple as an externally mounted over-current relay.

Single phase, split phase type motor winding (concentric coil winding)

Objectives: At the end of this lesson you shall be able to
- **state the important points to be followed while winding split phase motors**
- **explain about coil distribution in concentric winding**
- **prepare the winding table, draw the connection and developed diagrams for concentric coil winding in single phase, split phase type motors.**

Split phase type : In general, single phase motors use a capacitor to split the phase. Some motors are, as found in fans, have the capacitor permanently connected to the supply. In some motors, the capacitor is used only for the starting period, then while running it is disconnected from the supply by the use of a centrifugal switch mechanism. In some other types of motors there are two capacitors, one for starting and the other for running. However, depending upon the power, function and the design of the motor, the capacitor value will be different in each case. Observe this point everytime you come across the split phase motor.

Fig 1



SINGLE PHASE CONCENTRIC WINDING 24SLOTS 4POLES

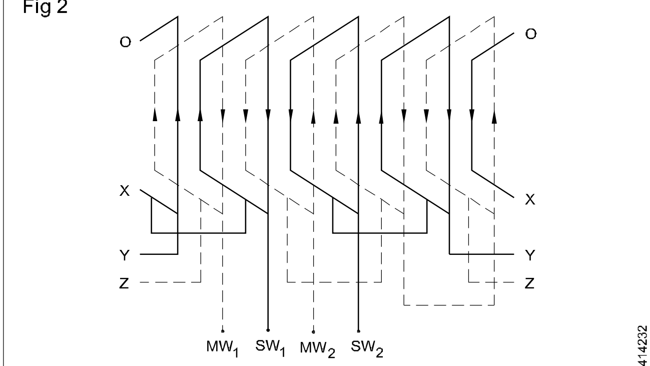
There are certain points to be followed while winding a split phase motor.

1 The single phase winding may have different shapes of coils as explained below.

a Concentric coil winding (Fig 1): This winding requires coils of different shapes in a phase/pole group, and different sizes between the phases in order to accommodate in the slots and for placing both main and starting windings. In addition to this, the coils in the same group may have different number of turns.

b True mesh shaped coils (Fig 2): These coils are of the same size and shape and the end windings form a very tight roll.

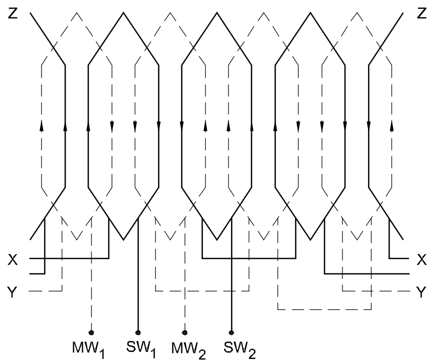
Fig 2



MESH SHAPED COILS

c Diamond mesh shaped coils (Fig 3): These coils are of the same size and shape and the end winding is longer and flatter than the true mesh type coils. The end of the coils has a loop, knuckle or nose.

Fig 3



DIAMOND MESH SHAPED COILS

2 The main and starting winding should be placed 90 electrical degrees apart from each other.

3 All the coil groups may or may not have the same number of coils.

4 The main winding is kept first in the stator slots and the starting winding is kept over the main windings.

5 Normally, the main winding consists of thick winding wire, and the starting winding of thin winding wire. In certain motors both the windings may have same size of winding wire.

6 The number of turns in the main and starting windings may or may not have the same number of turns.

7 In concentric coil winding, the coils in the same group may or may not have the same number of turns.

8 Each slot may contain one or two coil sides.

9 The overhang of the coils should be of exact in size. If it is less, the insertion of the coils will be difficult and if the size is more, the coils may not allow the end covers to be fitted.

10 While inserting concentric coils, start with the smaller pitched coil set.

11 There may be empty slots in the stator. Note their position.

Concentric winding: Concentric type of winding is probably the most common type of winding used in fractional horsepower single phase motors. The winding may be hand wound or may be form wound.

As the starting winding is designed to split the phase and is used to start the motor, it may have less slots (coils) allotted when compared to the main winding. For example there may be 8 coils for main winding and 4 coils only for the starting winding.

Further it is a standard practice to wind only about 70% of the slots of a single phase motor, as owing to the effect of the distribution or spread factor, no advantage is gained by making a single phase winding any wider. Even if the whole of the slots were to be wound, the extra winding would be useless for producing the useful torque.

Similarly it has been found that in single phase motors, no extra loss takes place if all the slots of each pole face are not wound. Thus the running winding looses nothing in efficiency, because some of the slots of each pole are taken for the starting winding.

Winding calculation and diagrams for concentric type winding : Let us discuss the following examples.

Example 1

Prepare the winding table, draw the connection and developed diagrams for a single phase, 4 pole, whole coil connected capacitor motor having 24 slots, 12 coils (8 coils for main and 4 coils for starting winding) with pitches 5, 3 for the main and 5 for the starting winding.

Number of coils per pole in main winding =

$$\frac{\text{Total number of main winding coils}}{\text{Number of poles}} = \frac{8}{4} = 2 \text{ coils/pole}$$

In other words, there will be 8 coils in the main winding forming 4 pole groups. Each group will have two coils under each pole. Pitches assigned will be 5 and 3 for each coil group.

Number of coils per pole in starting winding = 4/4 =1 coil /pole.

There will be 4 groups in starting winding having one coil per group. Pitch assigned will be 5 for the coil.

Summarising the results we have the coil group as given below in Table 1.

Table 1

Winding	Groups	Coil per pole	Pitches	Coil throw	Connection
Main	4	2	5, 3	1-6, 2-5	Whole coil-end to end and start to start
Starting	4	1	5	1-6	Whole coil-end to end and start to start.

Calculation of electrical degrees required for phase splitting

Total electrical degrees = 180 x Total number of poles

= 180x4= 720 electrical degrees

Degrees/slot = 720/24 = 30 electrical degrees

No. of slots required for 90 electrical degrees dis-placement between main and starting winding = 90/30 = 3 slots.

Hence if the main winding starts in, say, slot number one, then the starting winding should be started in 1+3 = 4th slot.

Computing the above information in a winding table we have Table 2.

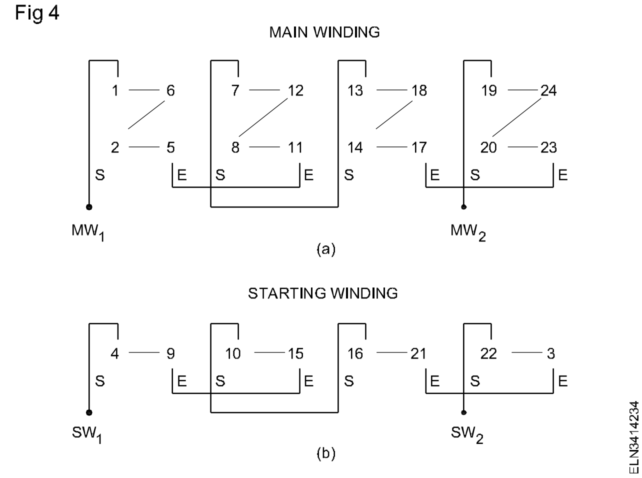
Table 2

Winding table

Winding	Slot position for poles			
	I pole	**II pole**	**III pole**	**IV pole**
Main	1 - 6	7 - 12	13 - 18	19 - 24
	2 - 5	8 - 11	14 - 17	20 - 23
Starting	4 - 9	10 - 15	16 - 21	22 - 3

Remembering whole coil connection the connection diagram is to be drawn as shown in Fig 4.

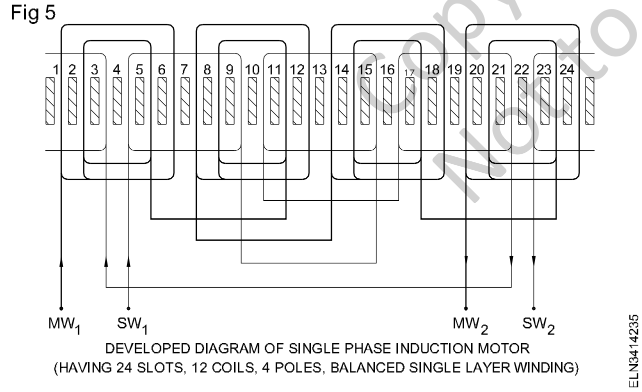
Fig 4



Remember 'S' is for starting and 'E' for end connection.

Based on the winding table the developed diagram is drawn as shown in Fig 5.

Fig 5



Example 2

Prepare the winding table, draw the connection and developed diagrams for a single phase, 4-pole, whole coil connected capacitor motor having 36 slots 28 coils (16 coils for main and 12 coils for the starting winding).

Coil per group in main winding 16/4=4 coils/group/poles

Coil per group in starting winding 12/4 = 3 coils/group/poles

$$\text{Pole pitch} = \frac{\text{Number of slots}}{\text{Number of poles}} - 1 = \frac{36}{4} - 1 = 9 - 1 = 8$$

The coil throw for main winding will be 1-9 and the winding table will be as shown in Table 3.

Table 3

Main winding - winding table

For the same group	1st pole	2nd pole	3rd pole	4th pole
1st coil	1 - 9	10 - 18	19 - 27	28 - 36
2nd coil	2 - 8	11 - 17	20 - 26	29 - 35
3rd coil	3 - 7	12 - 16	21 - 25	30 - 34
4th coil	4 - 6	13 - 15	22 - 24	31 - 33

Calculate the degrees/slot.

Total electrical degrees = 180 x 4 = 720 electrical degrees.

Degrees/slot = 720/36 = 20 electrical degrees

For phase displacement of 90 electrical degrees we require 90/20 = 4.5 slots. As it is impossible to start at 4.5 slots, let us start the starting winding in slot No.5.

Hence the coil throw for starting winding will also be 1 - 9, but it starts in the 5th slot. As such the winding table will be as shown in Table 4

Table 4

Starting winding - winding table

For the same group	1st pole	2nd pole	3rd pole	4th pole
1st coil	5 - 13	14 - 22	23 - 31	32 - 4
2nd coil	6 - 12	15 - 21	24 - 30	33 - 3
3rd coil	7 - 11	16 - 20	25 - 29	34 - 2

There will be several slots having 2 coil sides and some slots may have single coil side only.

Remembering the whole coil connection, the connection diagram will be as shown in Fig 6.

Based on the above, the developed diagram is shown in Fig 7.

Fig 6

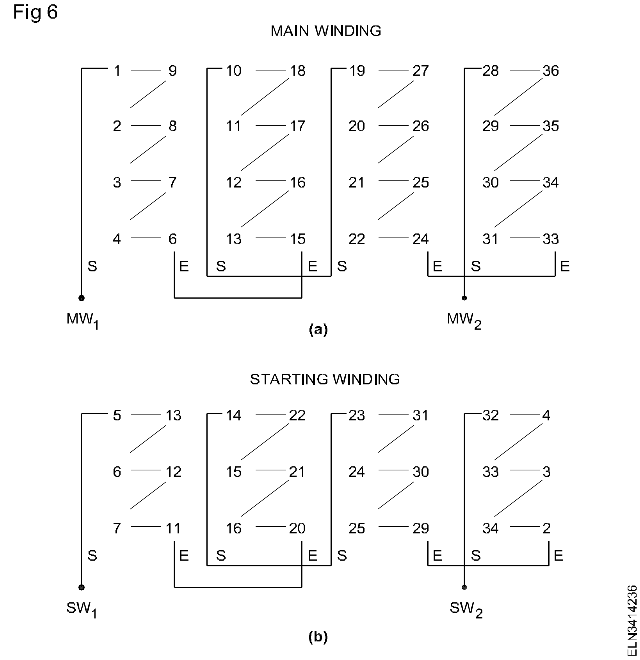
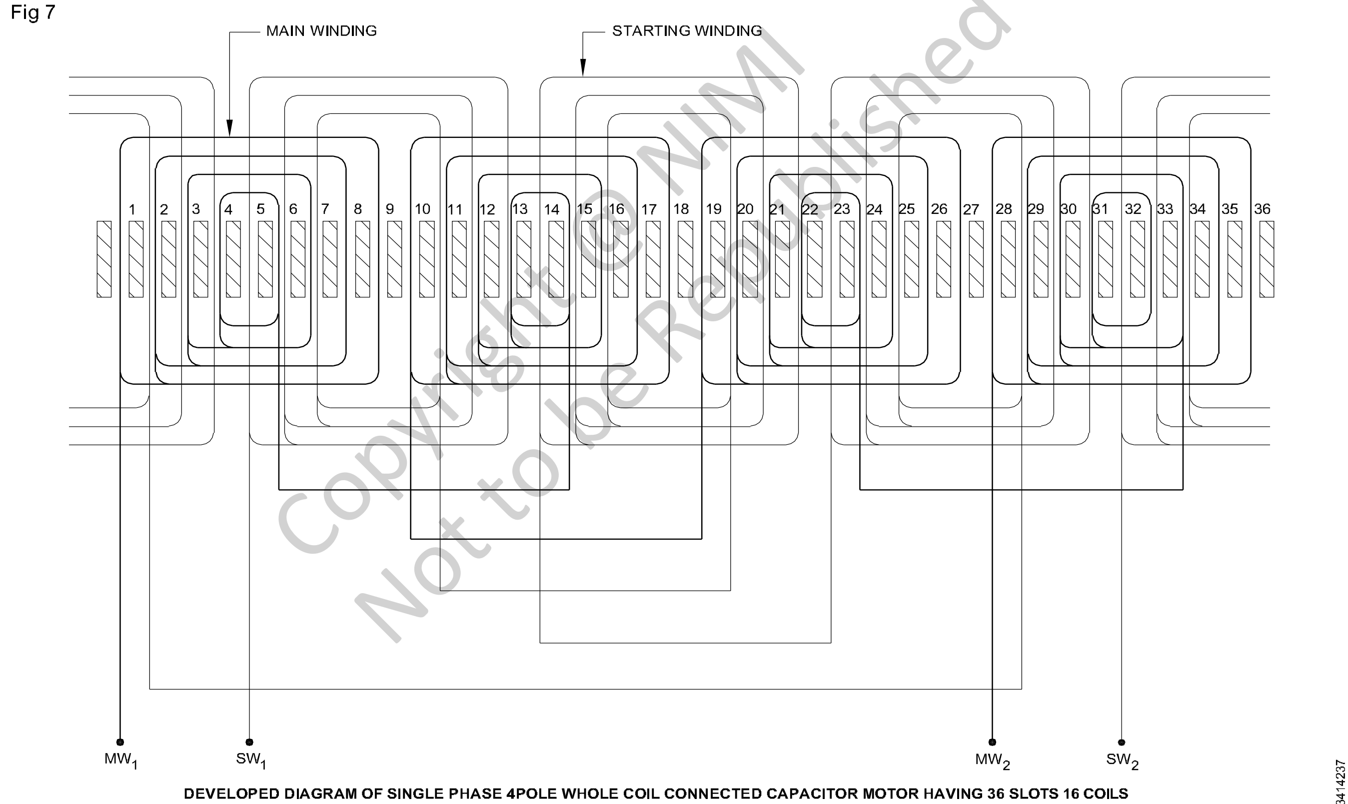


Fig 7



DEVELOPED DIAGRAM OF SINGLE PHASE 4POLE WHOLE COIL CONNECTED CAPACITOR MOTOR HAVING 36 SLOTS 16 COILS FOR MAIN WINDING 12 COILS FOR STARTING WINDING

Capacitor - start, induction - run motor

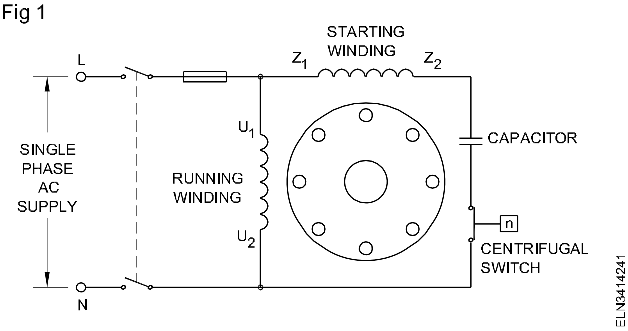
Objectives: At the end of this lesson you shall be able to
- **explain the construction and working of an AC single phase, capacitor-start, induction-run motor**
- **explain the characteristic and application of a capacitor- start, induction-run motor.**

A drive which requires a higher starting torque may be fitted with a capacitor-start, induction-run motor as it has excellent starting torque as compared to the resistance-start, induction-run motor.

Construction and working: Fig 1 shows the schematic diagram of a capacitor-start, induction-run motor. As shown, the main winding is connected across the main supply, whereas the starting winding is connected across the main supply through a capacitor and a centrifugal switch. Both these windings are placed in a stator slot at

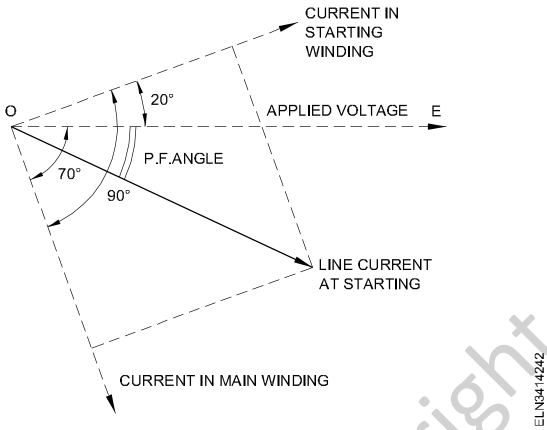
90° electrical degrees apart, and a squirrel cage type rotor is used.

Fig 1



As shown in Fig 2, at the time of starting, the current in the main winding lags the supply voltages by about 70° degrees, depending upon its inductance and resistance. On the other hand, the current in the starting winding due to its capacitor will lead the applied voltage, by say 20° degrees.

Fig 2



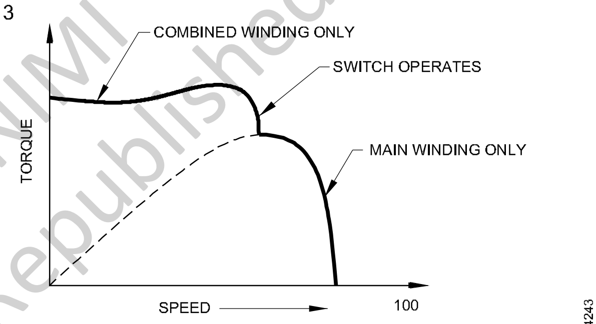
Hence, the phase difference between the main and starting winding becomes near to 90 degrees. This in turn makes the line current to be more or less in phase with its applied voltage, making the power factor to be high, thereby creating an excellent starting torque.

However, after attaining 75% of the rated speed, the centrifugal switch operates opening the starting winding, and the motor then operates as an induction motor, with only the main winding connected to the supply.

Reversing the direction of rotation: In order to reverse the direction of rotation of the capacitor start, induction-run motor, either the starting or the main winding terminals should be changed. This is due to the fact that the direction of rotation depends upon the instantaneous polarities of the main field flux and the flux produced by the starting winding. Therefore, reversing the polarity of any one of the fields will reverse the torque.

Characteristic: As shown in Fig 2, the displacement of current in the main and starting winding is about 80/90 degrees, and the power factor angle between the applied voltage and line current is very small. This results in producing a higher power factor and an excellent starting torque, several times higher than the normal running torque, as shown in Fig 3. The running torque adjusts itself with load by varying inversely with respect to speed as shown in the characteristic curve in Fig 3.

Fig 3



TORQUE-SPEED CHARACTERISTIC OF CAPACITOR START INDUCTION RUN MOTOR

Application: Due to the excellent starting torque and easy direction-reversal characteristic, these machines are used in belted fans, blowers, dryers, washing machines, pumps and compressors.

Capacitors used in single phase capacitor motors

Objectives: At the end of this lesson you shall be able to
- **state the precautions to be followed while using a capacitor in a single phase capacitor motor**
- **explain the methods of testing capacitors.**

A capacitor is a device which can store electrical energy in the form of electrostatic charge. However the main purpose of the capacitor in the single phase motors is to split the phase for producing the rotating magnetic field. In addition, they also draw the leading current, thereby improving the power factor.

Precautions to be followed while using a capacitor in a single phase capacitor motor: Paper or electrolytic capacitors of non-polarized types are used for starting AC capacitor type motors. These capacitors have special marking for use in AC circuits, and will not have polarity marking. Paper or electrolytic capacitors for use in DC circuits have polarity markings. They must not be used in AC circuits as the reversal of AC voltage will heat up the capacitor, producing enormous gas inside the can, thereby blowing it into pieces.

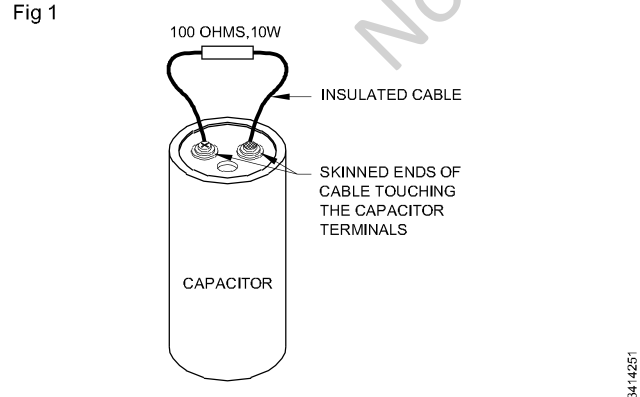
The AC voltage rating inscribed on the capacitor will have two ratings. One for working voltage and another for the maximum value of voltage. Working voltage refers to the normal R.M.S. rating of the supply mains while the maximum rating will be AC peak voltage which will be $\sqrt{2}$ times the rated R.M.S. voltage. Hence, while replacing a capacitor, a careful scrutiny of voltage rating is essential, as otherwise the capacitor may fail and may also explode.

The duty cycle is another important point to be checked. In most of the capacitors, the marking will indicate whether it is for intermittant (short duty) or continuous (long duty) rating. Though continuous rated capacitors can be used for intermittant rating, never an intermittant (short duty) rating capacitor should be used for continuous rating. This has some relation with the centrifugal switch operation, frequency of starting and stopping and load. When the load is heavy or the centrifugal switch is not proper, there will be a chance for the starting winding, along with the capacitor, to be in the main circuit for a long time. In such cases the capacitor, which is intermittant rated, will fail due to overheating. This should be checked when the capacitor fails often in a specified capacitor-start motor.

The capacity of the capacitor, which is given in microfarads, should be the same as is specifed by the manufacturer of the motor. A lower value will result in poorer starting torque and high starting currents, whereas a higher rating may not allow the speed to reach the rated value resulting in the starting winding to be in main line for a long time there by ending in poor operation and efficiency. In capacitor-start, capacitor-run motors, there will be two capacitors. As the starting capacitor will be 5 to 15 times of the rating of the running capacitor, and will also be of intermittant-rated electrolytic type, when compared to the running capacitor, which will be of continuous-rated, oil-filled type. Due care should be taken while connecting these capacitors in the motor, avoiding wrong selection and connection.

While handling a capacitor, due care should be taken to avoid shocks. A good capacitor can hold its charge for several days, and when touched, may give a severe shock. Hence, before touching any terminal of the capacitor, which is in use, the electrical charge should be discharged through a test lamp or through a 100 ohms 10 watts resistor as shown in Fig 1. Direct shorting of the capacitor terminals for discharging should be avoided as far as possible as this results in creating an enormous strain to the inner parts of the capacitor and it may fail.

Fig 1

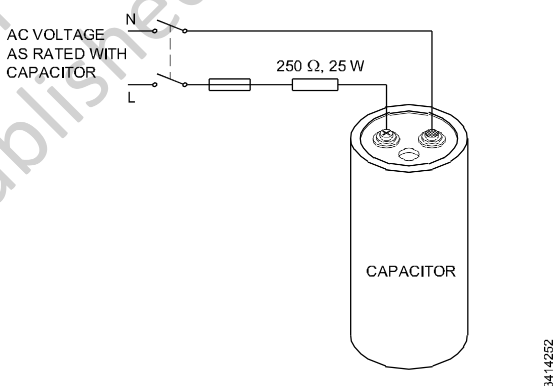


METHOD OD DISCHARGING A CAPACITOR

Method of testing capacitors: Before removing a capacitor from the motor connection for testing, it should be discharged to avoid fatal shocks. The following methods are recommended for testing the large value paper, electrolytic or oil-filled capacitors.

Charge-discharge test: Check the working voltage indicated on the capacitor. If the value is equal or more than that of the usual, single phase voltge, say 240V AC 50 Hz, we can connect it to the supply through a 100 ohms, 25 watts resistor as shown in Fig 2. Preferably, keep the capacitor, while testing on line voltage, inside a covered cardboard box or in a wooden box. Sometimes, if the capacitor is defective, it may explode and cause injury to you. Switch on the circuit for about 3-4 seconds. Then switch `OFF' the supply, and remove the supply terminals carefully with the help of an insulated pliers, without touching the capacitor terminals. Then, short the capacitor terminals with the help of a screwdriver. A bright spark is an indication that the capacitor is working. A dull spark or no spark indicates the capacitor is weak or open. On the other hand, no sparks while touching with the supply terminals indicate that the capacitor is opened. In the case of low capacity capacitors, the spark will be very feeble even if the capacitor is in good condition. Further, this check or the ohmmeter test described in the next para, does not indicate the de-rated value of the capacitor. Hence a capacity check is necessary as will be explained later.

Fig 2

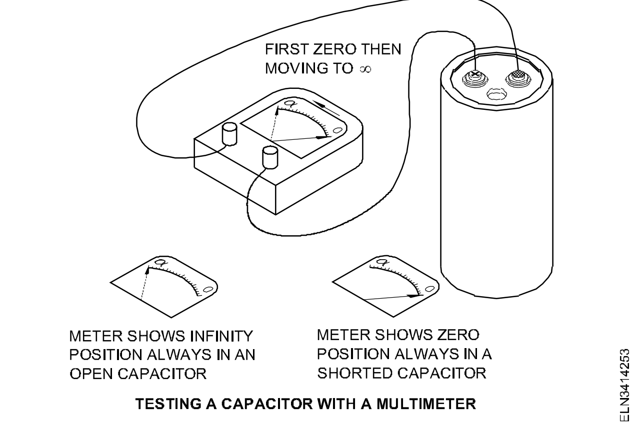


CHARGE TEST ON CAPACITOR

Ohmmeter test: Before using the ohmmeter, the capacitor should be thoroughly discharged to avoid damage to the ohmmeter. Set the range of the ohmmeter to resistance and adjust to zero ohms. Touch the terminals of the capacitor and watch the deflection of the meter. If the needle deflects towards zero and then moves towards infinity, the capacitor is working. Reverse the test leads and test it again, the needle will do the same thing again in a good capacitor. If the capacitor is open, the needle will not go to zero position but will remain in infinity side. On the other hand, in a shorted capacitor, the needle will be in zero position but will not go to infinity side at all. These results are illustrated in Fig 3.

Capacity test: Connection should be as shown in Fig 4. Keep the resistance value maximum at the time of switching `on' to protect the ammeter. Keep the capacitor inside a cardboard or wooden box to avoid injury in case of explosion. The ammeter (I) and voltmeter (V) readings are to be taken when the resistor is completely cut out from the circuit. From the meter readings, the capacity rating of the capacitor in microfarads can be calculated.

Fig 3



TESTING A CAPACITOR WITH A MULTIMETER

Capacity of capacitor in C_F Farad = $\frac{I}{2\pi FV}$

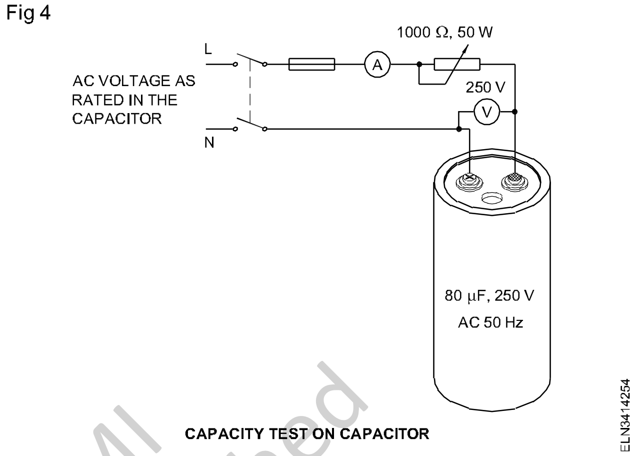
Capacity in microfarad C_{mf} = $\frac{I \times 10^6}{2\pi FV}$

= $\frac{3182 \times I}{V}$ microfarads.

If the capacity is 20 percent more or less than the notified value, replace it.

Insulation test on capacitors: According to BIS 1709-1984 recommendations, the insulation test conducted between the shorted capacitor terminals and the metal can, when measured by a 500V megger/insulation tester, should not be less than 100 megohms. If the can is of insulating material, the measurement could be made between the capacitor terminals and the metal strap holding the can.

Fig 4



CAPACITY TEST ON CAPACITOR

Permanent capacitor motor - capacitor-start, capacitor-run motor and shaded pole motor

Objectives: At the end of this lesson you shall be able to

- **distinguish between the single and two-value, capacitor-start, capacitor-run motors**
- **explain the working of a permanent capacitor motor, state its characteristic and use**
- **explain the working of a capacitor-start, capacitor-run motor, state its characteristic and use.**

Capacitor-start, capacitor-run motors are of two types as stated below.

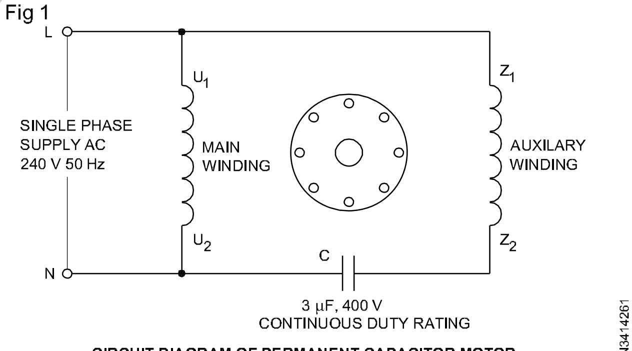
- Permanent capacitor motor (Single value capacitor motor)
- Capacitor-start, capacitor-run motor (Two-value capacitor motor)

Permanent capacitor motor: This type of motor is shown in Fig 1 which is most commonly used in fans. This motor is preferred in drives where the starting torque is not required to be high, while at the same time elimination of the centrifugal switch in the motor is necessary for easy maintenance. The capacitor is connected in series with the auxiliary winding, and remains so throughout the operation. These capacitors should be of oil-type construction and have continuous duty rating.

To avoid low efficiency, the capacity of the condensers is kept low, which, in turn, brings down the starting torque to about 50 to 80% of the full-load torque.

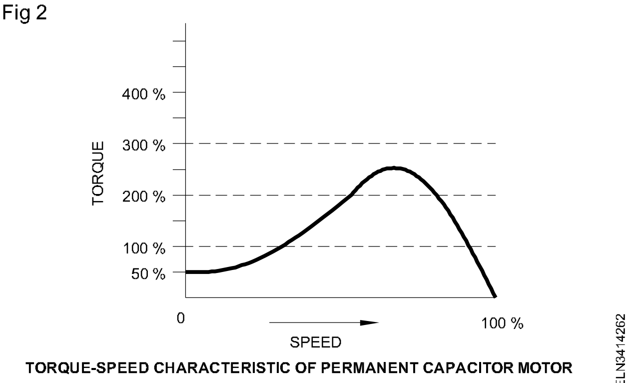
The torque-speed characteristic of the motor is shown in Fig 2. This motor works on the same principle as the capacitor-start, induction-run motor with low starting torque but with higher power factor, during starting as well as in running.

Fig 1



CIRCUIT DIAGRAM OF PERMANENT CAPACITOR MOTOR

Fig 2



TORQUE-SPEED CHARACTERISTIC OF PERMANENT CAPACITOR MOTOR

This motor is most suitable for drives, which require a lower torque during start, easy changes in the direction of rotation, stable load operation and higher power factor during operation. *Examples* - fans, variable rheostats, induction regulators, furnace control and arc welding controls. This motor is cheaper than the capacitor-start, induction-run motor of the same rating.

Capacitor-start, capacitor-run motors: As discussed earlier capacitor-start, induction-run motors have excellent starting torque, say about 300% of the full load torque, and their power factor during starting is high. However, their running torque is not good, and their power factor, while running, is low. They also have lesser efficiency and cannot take overloads.

These problems are eliminated by the use of a two-value capacitor motor in which one larger capacitor of electrolytic (short duty) type is used for starting, whereas a smaller capacitor of oil-filled (continuous duty) type is used for running, by connecting them with the starting winding as shown in Fig 3. A general view of such a two-value capacitor motor is shown in Fig 4. This motor also works in the same way as a capacitor-start induction-run motor, with the exception, that the capacitor C1 is always in the circuit, altering the running performance to a great extent.

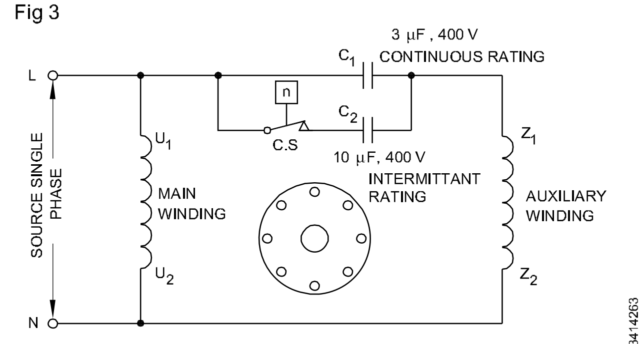
The starting capacitor which is of short-duty rating will be disconnected from the starting winding with the help of a centrifugal switch, when the starting speed attains about 75% of the rated speed.

Characteristic

The torque-speed characteristic of this motor is shown in Fig 5. This motor has the following advantages.

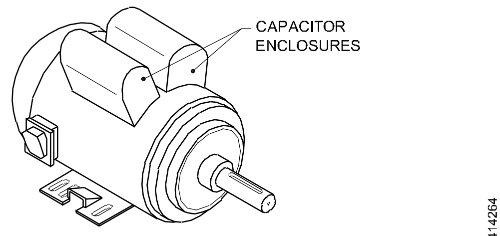
- The starting torque is 300% of the full load torque.
- The starting current is low, say 2 to 3 times of the running current.
- Starting and running P.F. are good.
- Highly efficient running.
- Extremely noiseless operation.
- Can be loaded up to 125% of the full-load capacity.

Fig 3



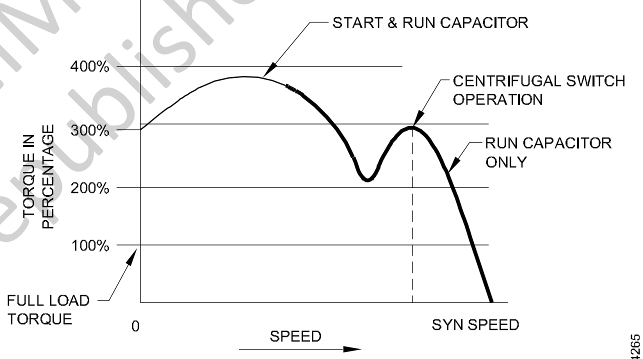
SCHEMATIC DIAGRAM OF A CAPACITOR-START CAPACITOR-RUN MOTOR

Fig 4



CAPACITOR-START CAPACITOR-RUN MOTOR

Fig 5



TORQUE-SPEED CHARACTERSTIC OF CAPACITOR-START CAPACITOR-RUN MOTOR

Application

These motors are used for compressors, refrigerators, air-conditioners etc. where the duty demands a higher starting torque, higher efficiency, higher power factor and overloading. These motors are costlier than the capacitor-start, induction- run motors of the same capacity.

The shaded pole motor

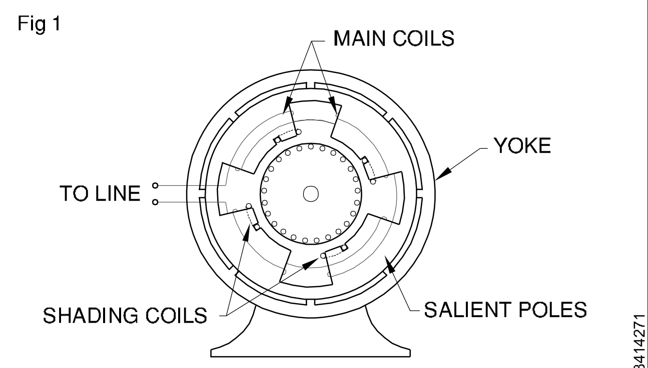
Objectives: At the end of this lesson you shall be able to
- **explain the construction of a shaded pole motor and their functions**
- **explain the principle of working of the shaded pole motor**
- **explain the characteristic of the shaded pole motor and its application.**

Shaded pole motor (construction)

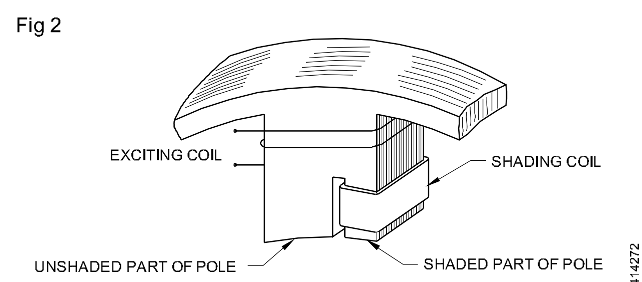
The motor consists of a yoke with salient poles as shown in Fig 1 and it has a squirrel cage type rotor.

Construction of a shaded pole

A shaded pole made up of laminated sheets has a slot cut across the lamination at about one third the distance from the edge of the pole. Around the smaller portion of the pole, a short circuited copper ring is placed which is called the shading coil and this part of the pole is known as the shaded part of the pole. The remaining part of the pole is called the unshaded part which is clearly shown in Fig 2.



A SINGLE-PHASE MOTOR WITH SHADING COILS FOR STARTING



A TYPICAL SHADED-POLE CONSTRUCTION

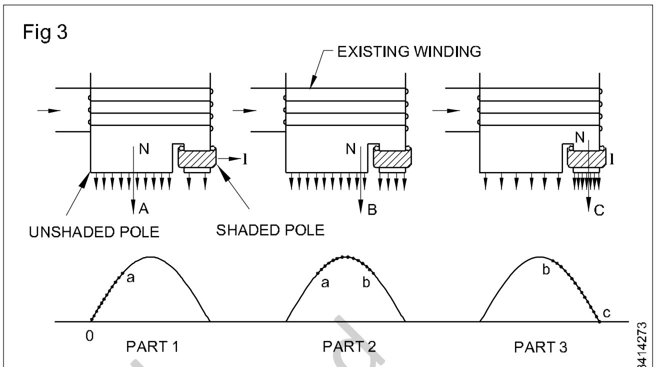
Around the poles, exciting coils are placed to which an AC supply is connected. When AC supply is given to the exciting coil the magnetic axis shifts from the unshaded part of the pole to the shaded part as explained in the next paragraph. This shifting of axis is equivalent to the physical movement of the pole. This magnetic axis which is moving, cuts the rotor conductors, and hence, a rotational torque is developed in the rotor. Due to this torque, the rotor starts rotating in the direction of the shifting of the magnetic axis that is from the unshaded part to the shaded part.

Shifting of the magnetic flux from the unshaded part to the shaded part could be explained as stated below.

As the shaded coil is of thick copper, it will have very low resistance but as it is embedded in the iron core it will have high inductance.

When the exciting winding is connected to an AC supply a sine wave current passes through it. Let us consider the positive half cycle of the AC current as shown in Fig 3. When the current raises from 'zero' to point 'a', the change in current is very rapid (fast), hence induces an emf in the shading coil by the principle of Faraday's laws of electromagnetic induction. The induced emf in the shading coil produces a current which in turn produces a flux which is in opposite direction to the main flux in accordance with Lenz's law. This induced flux opposes the main flux in the shaded portion and reduces the main flux in that area to a minimum value as shown in Fig 3 in the same form of flux arrows. This makes the magnetic axis to be in the centre of the unshaded portion as shown by the arrow (longer one) in part 1 of Fig 3. On the other hand as shown in Part 2 of Fig 3 when current rises from point 'a' to 'b' the change in current is slow, the induced emf and resulting current in the shading coil is minimum and the main flux is able to pass through the shaded portion. This makes the magnetic axis to be shifted to the centre of the whole pole as shown by the arrow in part 2 of Fig 3.

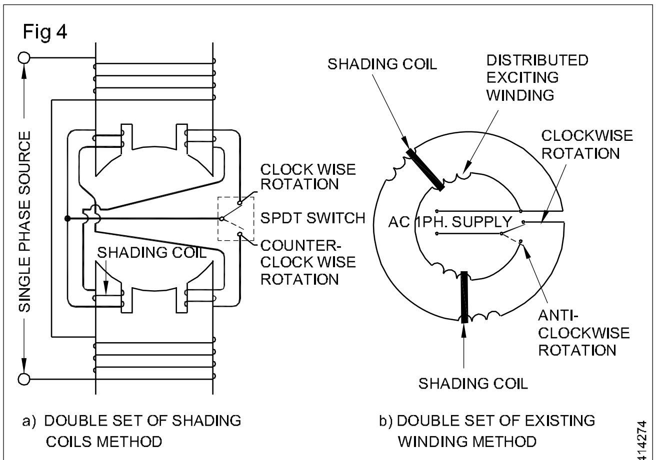
In the next instant, as shown in part 3 of Fig 3, when the current falls from 'b' to 'c', the change in current is fast and its value of change is from maximum to minimum. Hence a large current is induced in the shading ring which opposes the diminishing main flux, thereby increasing the flux density in the area of the shaded part. This makes the magnetic axis to shift to the centre of the shaded part as shown by the arrow in part 3 of Fig 3.



CHANGE OF MAGNETIC AXIS SHOWN FROM POSITION A TO C

From the above explanation it is clear that the magnetic axis shifts from the unshaded part to the shaded part which is more or less physical rotary movement of the poles.

Simple motors of this type cannot be reversed. Specially designed shaded pole motors have been constructed for reversing the direction. Two such types are shown in Fig 4. In a) the double set of shading coils method is shown and in b) the double set of exciting winding method is shown.



METHODS FOR REVERSING SHADED-POLE MOTORS-TWO-POLE CONSTRUCTION

Shaded pole motors are built commercially in very small sizes, varying approximately from 1/250 HP to 1/6 HP. Although such motors are simple in construction and cheap, there are certain disadvantages with these motors as stated below:

- low starting torque
- very little overload capacity

- low efficiency.

The efficiency varies from 5% to 35% only in these motors.

Because of its low starting torque, the shaded pole motor is generally used for small table fans, toys, instruments, hair dryers, advertising display systems and electric clocks etc.

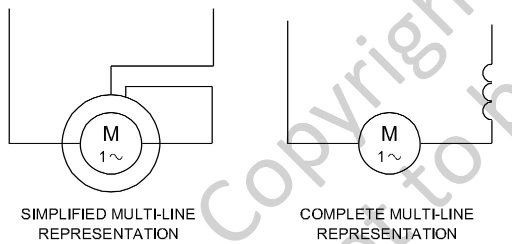
Universal motor

Objectives: At the end of this lesson you shall be able to
- **compare a universal motor with the DC series motor with respect to its construction**
- **explain the operation, characteristic and application of a universal motor**
- **explain the method of changing the direction of rotation**
- **describe the methods of controlling the speed of a universal motor.**

Comparison between a universal motor and a DC series motor: A universal motor is one which operates both on AC and DC supplies. It develops more horsepower per Kg. weight than any other AC motor, mainly due to its high speed. The principle of operation is the same as that of a DC motor. Though a universal motor resembles a DC series motor, it requires suitable modification in the construction, winding and brush grade to achieve sparkless commutation and reduced heating when operated on AC supply, due to increased inductance and armature reaction.

A universal motor could, therefore, be defined as a series or a compensated series motor designed to operate at approximately the same speed and output on either direct current or single phase alternating current of a frequency not greater than 50 Hz, and of approximately the same RMS voltage. Universal motor is also named as AC single phase series motor, and Fig 1 shows the multi-line representation according to B.I.S. 2032, Part IV.

Fig 1

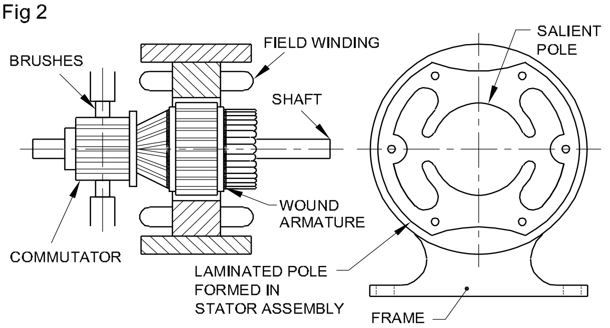


MULTILINE REPRESENTATION OF AC SINGLE PHASE SERIES MOTOR (BIS 2032-PART IV.)

ELN3414281

The main parts of a universal motor are an armature, field winding, stator stampings, frame, end plates and brushes as shown in Fig 2.

Fig 2



PARTS OF A UNIVERSAL MOTOR

ELN3414282

The increased sparking at the brush position in AC operation is reduced by the following means.

- Providing compensating winding to neutralize the armature M.M.F. These compensating windings are either short-circuited windings or windings connected in series with the armature.
- Providing commutating inter-poles in the stator and connecting the inter-pole winding in series with the armature winding.
- Providing high contact resistance brushes to reduce sparking at brush positions.

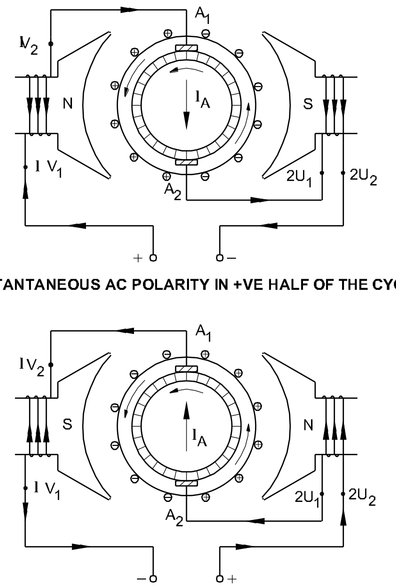
The table given below indicates the differences between a universal motor and a DC series motor.

Universal motor	DC series motor
Can run on AC and DC supplies.	Can run smoothlly on DC supply. However when connected to AC supply, it produces heavy sparks at brush positions and beomes hot due to armature reaction and rough commutation.
Compensating winding is a must for large machines.	Does not require compensating winding.
Inter-poles provided in larger machines.	Does not require inter-poles normally.
High resistance grade brushes are necessary.	Normal grade brushes will suffice.
Air gap is kept to the minimum.	Normal air gap is maintained.

Operation: A universal motor works on the same principle as a DC motor, i.e. force is created on the armature conductors due to the interaction between the main field flux and the flux created by the current-carrying armature conductors. A universal motor develops unidirectional torque regardless of whether it operates on AC or DC supply. Fig 3 shows the operation of a universal motor on AC supply. In AC operation, both field and armature currents change their, polarities, at the same time resulting in unidirectional torque.

Characteristic and application: The speed of a universal motor is inversely proportional to the load, i.e. speed is low at full load and high on no load. The speed reaches a dangerously high value due to low field flux at no loads. In fact the no-load speed is limited only by its own friction and windage losses. As such these motors are connected with permanent loads or gear trains to avoid running at no-load, thereby avoiding high speeds.

Fig 3



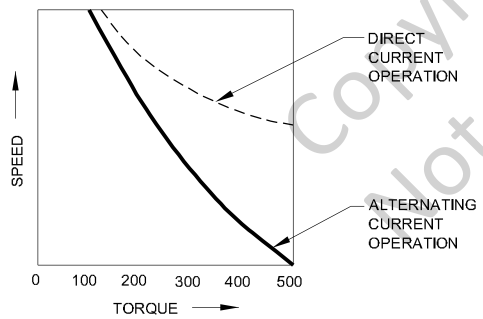
a) INSTANTANEOUS AC POLARITY IN +VE HALF OF THE CYCLE

b) INSTANTANEOUS AC POLARITY IN -VE HALF OF THE CYCLE

ELN3414283

Fig 4 shows the typical torque speed relation of a universal motor, both for AC and DC operations. This motor develops about 450 percent of full load torque at starting, as such, higher than any other type of single phase motor. Universal motors are used in vacuum cleaners, food mixers, portable drills and domestic sewing machines.

Fig 4



TORQUE-SPEED CHARACTERISTIC OF A UNIVERSAL MOTOR

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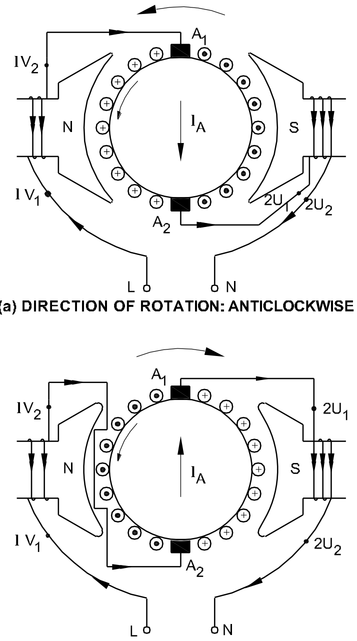
Change of rotation: Direction of rotation of a universal motor can be reversed by reversing the flow of current through either the armature or the field windings. It is easy to interchange the leads at the brush holders as shown in Fig 5.

However, when the armature terminals are interchanged in a universal motor having compensating winding, care should be taken to interchange the compensating winding also to avoid heavy sparking while running.

Speed control of universal motor: The following methods are adopted to control the speed of a universal motor.

Fig 5



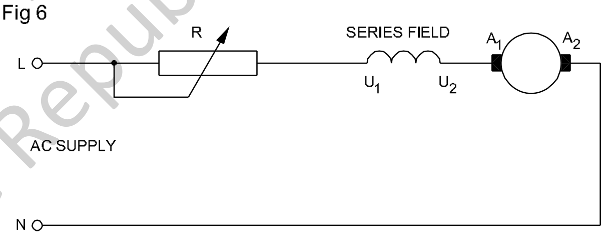
(a) DIRECTION OF ROTATION: ANTICLOCKWISE

b) DIRECTION OF ROTATION:CLOCKWISE BY CHANGING ARMATURE TERMINALS

ELN3414285

Series resistance or applied voltage control method: The motor speed is controlled by connecting a variable resistance in series with the motor. Foot-pedal operated sewing machines incorporate such a control. Fig 6 shows the connections.

Fig 6

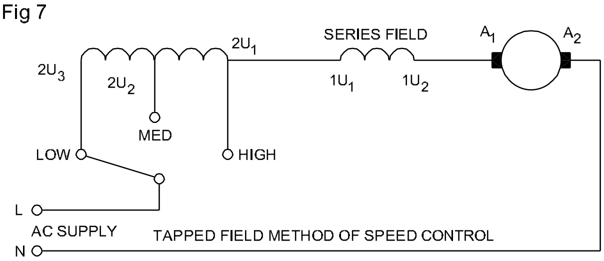


SPEED CONTROLS BY APPLIED VOLTAGE CONTROL

ELN3414286

Tapped field method: In this method,the field winding is tapped at 2 or 3 points and the speed is controlled by the varying field MMF. Fig 7 shows such a connection. Most of the domestic food mixers employ this method of speed control.

Fig 7

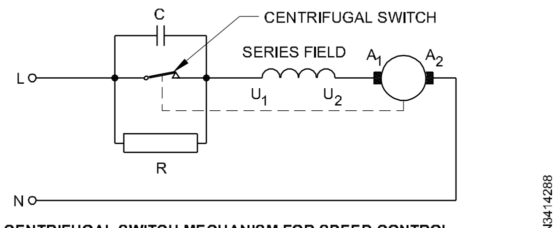


TAPPED FIELD METHOD OF SPEED CONTROL

ELN3414287

Centrifugal switch method: A centrifugal mechanism adjusted by an external lever is connected in series with the motor as shown by Fig 8. If the speed reaches beyond a certain limit, according to the lever setting, the centrifugal device opens the contacts and inserts the resistance R in the circuit, which causes the motor speed to decrease. When the motor speed falls and reaches a predetermined value, the centrifugal switch contact closes, the motor gets reconnected to the supply and the speed rises. Some advanced type of food mixers employ this sort of speed control. A capacitor is used across the centrifugal switch to reduce the switching spark and to suppress the radio interference. Apart from the above methods of speed control, a thyristor is used in certain food mixers to control the speed electronically.

Fig 8



CENTRIFUGAL SWITCH MECHANISM FOR SPEED CONTROL

Troubleshooting of universal motor

Objectives: At the end of this lesson you shall be able to
- **state the advantages and disadvantages of universal motor**
- **explain the method of troubleshooting in universal motor.**

As the name suggest universal motors can operate on either AC or DC supply. By a compromise of design fractional horse power motors may be built to operate satisfactorily on either 240 V 50 Hz AC or direct current at 240 volts. Such motors are known as universal motors.

Advantages of universal motors

- These motors develop high starting torque and have the ability to adjust the torque and speed proportionally when loaded.
- Universal motors can operate on direct current or AC supply.
- Tapped fields provide an easy method of controlling speed.

Disadvantages of universal motors

- Since these motors operate at very high speed upto 40,000 rpm considerable air noise is present.
- Because of the large increase in the power input under stalled onditions and the loss of motor cooling, they can burn out within a short time when overloaded too much.
- Useful for intermittent duty application only.
- They produce radio and television interference.

Troubleshooting chart for universal motor: Table 1 gives possible faults, which occur in universal motor, their causes, mode of testing and suggested rectification. As a universal motor is similar in design to the DC machine, trainees are advised to refer trouble shooting chart pertaining to DC machines also.

Table 1

Troubleshooting chart for universal motor

Trouble	Causes	Mode of testing	Rectification
Motor fails to start	a) No voltage due to blown fuse	a) Test by test lamp or voltmeter	a) Replace the blown fuse.
	b) Open overload relay of starter.	b) Test by test lamp or voltmeter	b) Reset or rectify the overload relay contact
	c) Low voltage due to improper supply voltage.	c) Test by voltmeter.	c) Rectify the loose connections at the switch & fuse.
	d) Open circuited field or armature.	d) Test by ohmmeter or Megger.	d) If possible join properly or replace the winding.
	e) Improper contact of carbon brushes with commutator.	e) Visual inspection and test by test lamp	e) Adjust for proper contact of carbon brush with commutator.
	f) Dirty commutator.	f) Visual inspection and test by test lamp.	f) Clean by buffing the commutator using smooth sandpaper.
Shock to the operator	a) Grounded field or armature circuit due to weak insulation.	a) Test by Megger or test lamp.	a) Rectify the defect and apply shellac varnish to armature and field winding

Trouble	Causes	Mode of testing	Rectification
	b) Insufficent earth.	b) Test by Megger or test lamp.	b) Provide proper earth to the motor.
Over heating of motor	a) Shorted coil of field or armature.	a) Visual inspection and resistance measurement	a) Rewind field or armature coil which is shorted
	b) Tight bearing due to worn out or locked bearing.	b) Test the shaft for free rotation. Check the shield for over heating.	b) Clean the bearings and check for damage. Replace bearing if necessary.
	c) Heavy sparking at commutator due to pitted commutator.	c) By visual inspection.	c) Clean the commutator and true the surface of the commutator.
	d) Shorted commutator.	d) Test the armature by growler.	d) Replace or repair the commutator
	e) Grounded field or armature.	e) Test by Megger.	e) Repair or rewind the field or armature.
Humming sound. Lack of torque due to overheat	a) Short circuited field.	a) Test by ohmmeter.	a) Rewind the field winding.
	b) Shorted armature coil.	b) Test by Growler.	b) Rewind shorted armature winding.

Repulsion motor

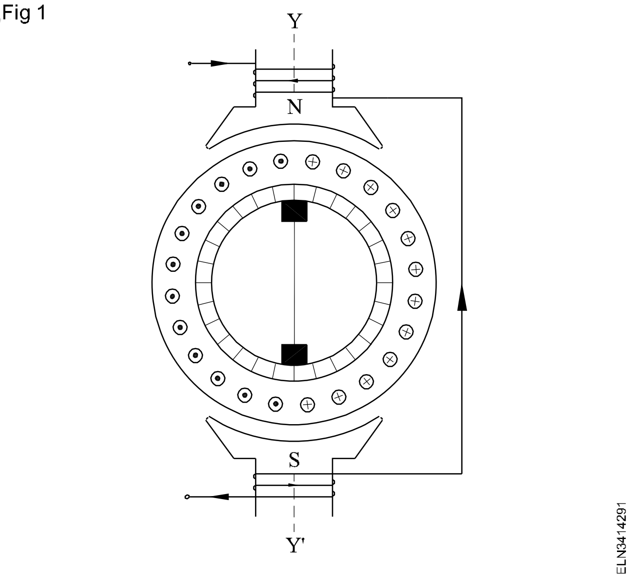
Objectives: At the end of this lesson you shall be able to
- **explain the principle, working, types and construction of the repulsion motor**
- **explain the characteristic and application of the repulsion motor.**

Repulsion motors, though complicated in construction and higher in cost, are still used in certain industries due to their excellent starting torque, low starting current, abilitiy to withstand long spell of starting currents to drive heavy loads and their easy method of reversal of direction.

The repulsion principle : The principle of torque production in a repulsion motor could be explained as follows. Fig 1 shows a two-pole motor with its magnetic axis vertical. An armature, having a commutator which is short-circuited through the brushes, is placed in the magnetic field. When the stator winding is connected to an AC supply, it produces an alternating magnetic field. Assume that at an instant, a north pole at the top and a south pole at the bottom are produced by this alternating magnetic field. Because of this a voltage will be induced in all the rotor conductors by the transformer action. The direction of current in the conductors will be in accordance with Lenz's law such that they create a north pole at the top just below the stator north pole, and a south pole at the bottom just at the top of the stator south pole to oppose the induction action. Hence the stator poles and the rotor poles will oppose each other in the same line. There will, therefore, be no torque developed due to the abscence of the tangential component of the torque.

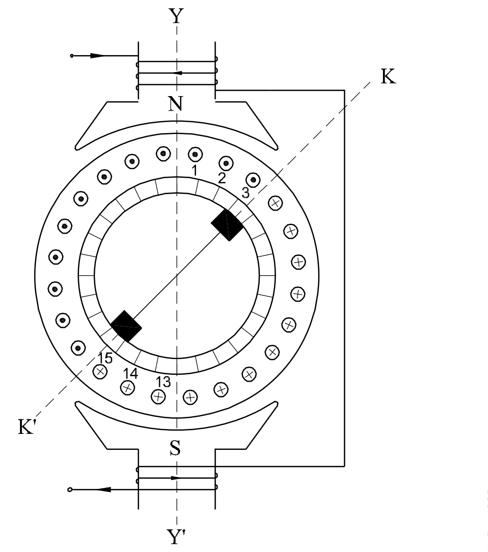
Let us assume that the short-circuited brush-axis is moved to a position as in Fig 2. Due to the present brush position, the magnetic axis of the armature is no longer co-linear with respect to the vertical axis of the main poles.

Fig 1



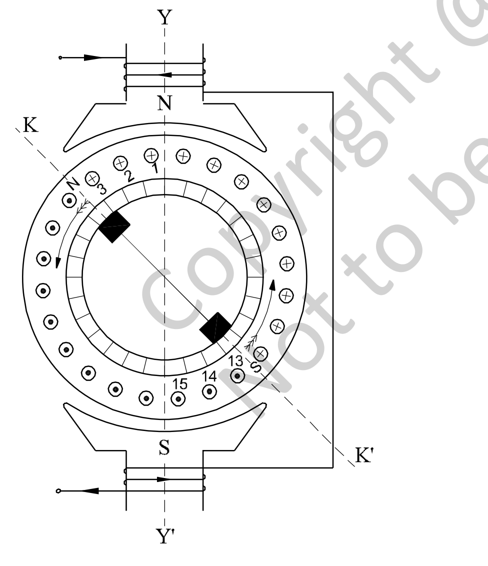
It will now be along the axis `KK' with north and south poles shifted around by an angle `A°' depending upon the shifting of the brushes. In this position, the direction of current in the conductors 1,2,3 and 13,14,15 is reversed, and hence, the armature becomes an electromagnet having the north (N) and south (S) poles in the `KK' axis just at an angle of `A°' from the main magnetic axis. Now there is a condition that the rotor north pole will be repelled by the main north pole, and the rotor south pole is repelled by the main south pole, so that a torque could be developed in the rotor. Now due to the repulsion action between the stator and the rotor poles, the rotor will start rotating in a clockwise direction. As the motor torque is due to repulsion action, this motor is named as repulsion motor.

Fig 2



Direction of rotation : To change the D.O.R. of this motor, the brush-axis needs, to be shifted from the right side as shown in Fig 2 to the left side of the main axis in a counter-clockwise direction as shown in Fig 3.

Fig 3



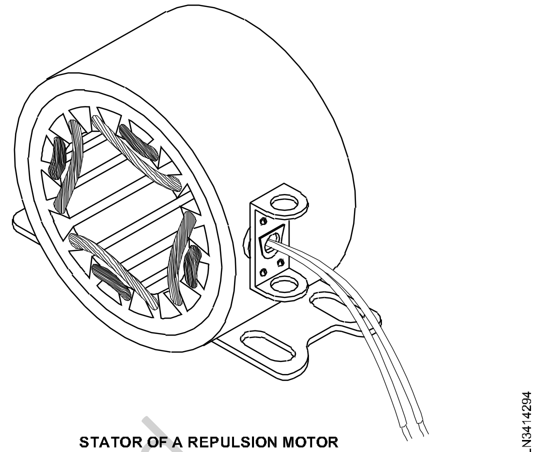
This working principle applies equally well for all types of repulsion motors having distributed windings in the stator.

Types of repulsion motors : There are four types of induction motors as stated below.

- Repulsion motor
- Compensated-repulsion motor
- Repulsion-start, induction-run motor
- Repulsion-induction motor

Construction: The construction of stators is the same in all the types, except for certain variation in the compensated-repulsion motor. In general, for all types of repulsion motors the stator winding is of the distributed, non-salient pole type, housed in the slots of the stator, and only two terminals as shown in Fig 4 are brought out. It is wound for four, six or eight poles. The rotor for each type of motor is different, and will be explained under each type.

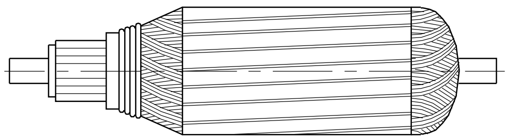
Fig 4



STATOR OF A REPULSION MOTOR

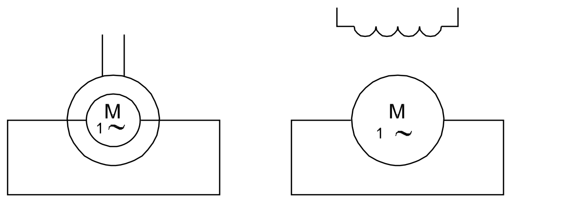
Repulsion motor: The general construction of the repulsion motor is similar to the one explained under the `Repulsive principle'. However the rotor of the repulsion motor is like a DC armature that is as shown in Fig 5, having a distributed lap or wave-winding. The commutator may be similar to the DC armature, that is axial type, having commutator bars in parallel to the shaft or radial or vertical bars on which brushes ride horizontally. The shorted brush position can be changed by a lever attached to the rocker-arm. The B.I.S. symbol for the repulsion motor is shown in Fig 6.

Fig 5



ROTOR OF A REPULSION MOTOR

Fig 6



REPULSION MOTOR

As explained earlier, the torque developed in a repulsion motor will depend upon the amount of brush-shaft as shown in Fig 7, whereas the direction of shift decides the direction of rotation. Further, the speed also depends upon the amount of brush-shift and the magnitude of the load. The torque speed characteristic of the motor is shown in Fig 9.

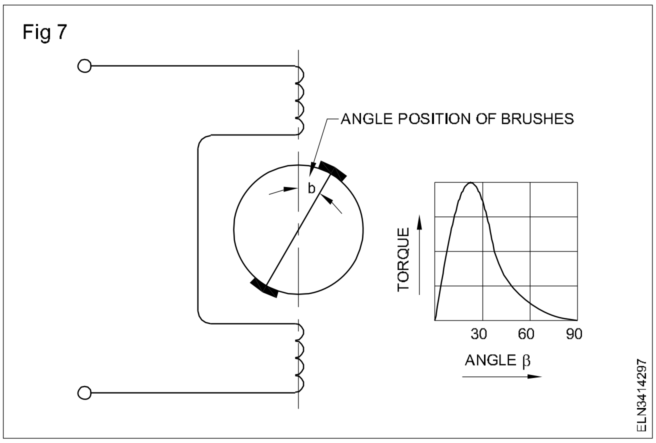


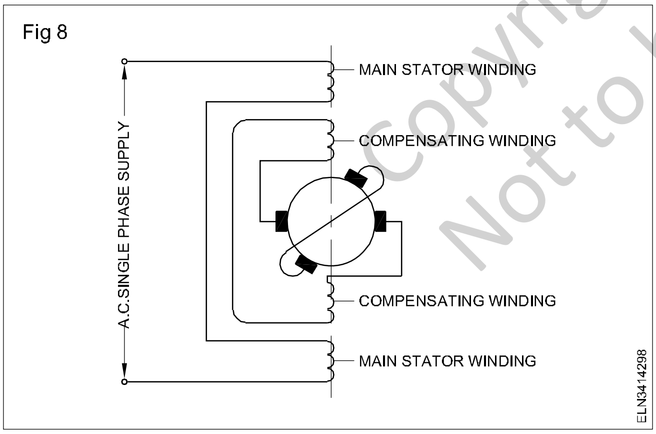
Fig 7

Relationship between the torque and brush-position angle in a repulsion motor

Though the starting torque varies from 250 to 400 percent of the full load torque, the speed will be dangerously high during light loads. This is due to the fact that the speed of the repulsion motor does not depend on frequency or number of poles but depends upon the repulsion principle. Further, there is a tendency of sparking in the brushes at heavy loads, and the P.F. will be poor at low speeds. Hence, the conventional repulsion motor is not much used and the other three improved types are popular.

Compensated repulsion motor : The rotor of the compensated repulsion motor is similar to that of the repulsion motor, except that there is another set of brushes placed in the middle position between the usual short circuited brushes. On the other hand, the stator has an additional winding, called the compensatory winding as shown in Fig 8.

Fig 8

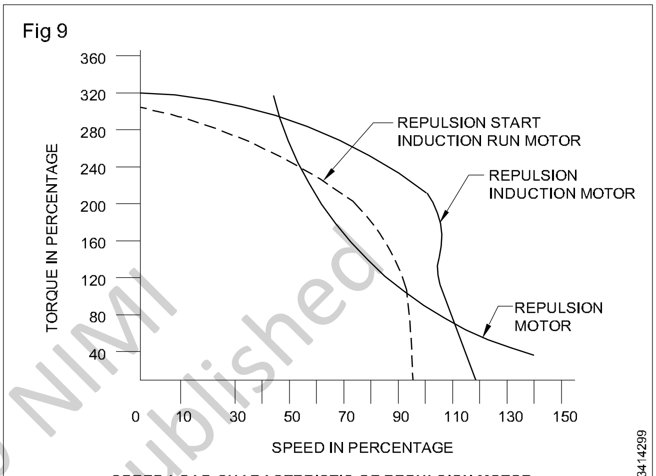


The purpose of the compensating winding is to improve the power factor and to have better speed regulation. This compensating winding is housed in the inner slots of the stator and connected in series with the armature.

Repulsion-start, induction-run motor : The rotor of this motor is similar to that of a repulsion motor but the commutator and the brush mechanism are entirely different. This motor starts like a repulsion motor, and after attaining about 75% of the rated speed, there is a necklace-type shorting mechanism, activated by a centrifugal force which short circuits the entire commutator. From then on, this motor works as an induction motor with a short-circuited rotor (armature). After the commutator is short-circuited, in some machines, there is a special mechanism to lift the brushes to avoid wear and tear of the brushes and the commutator.

The torque speed characteristic of this motor is shown in Fig 9.

Fig 9



SPEED LOAD CHARACTERISTIC OF REPULSION MOTOR

Repulsion-induction motor : The rotor of this motor has a squirrel cage winding deep inside the rotor, in addition to the usual winding. The brushes are short-circuited, and they continuously ride over the commutator. Generally the starting torque is developed in the wound part of the rotor, while the running torque is developed in the squirrel cage winding. The speed torque characteristic is shown in Fig 9. This develops a little less torque, say about 300% of the full load torque, and can start with a load and run smoothly on no load. This motor has its starting characteristic similar to DC compound motor, and running characteristic similar to an induction motor.

APPLICATION: In these motors the average starting torque varies from 300-400 percent of the full load torque, and these motors are preferred in places where the starting period is of comparatively long duration, due to heavy load. These motors are used in refrigerators, air-compressors, coil winders, pertrol pumps, machine tools, mixing machines, lifts and hoists, due to their excellent starting torque, ability to withstand sustained overloads, good speed regulation and easy method of reversal of direction of rotation.

Stepper motor

Objectives: At the end of this exercise you shall be able to
- **state the basic theory and open loop operation of stepper motor**
- **list and explain the each type of stepper motor**
- **state the advantages, disadvantages and application of stepper motor.**

Basic theory

A stepper motor is basically a synchronous motor. There are no brushes. It is an electromechanical device converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of pulses applied.

This device does not rotate continuously, but it rotates in the form of pulses. There are different types of motors available based on the stepper rotation, manufactured with steps per revolution of 12,24,72,144,180 and 200 in stepping angles of 300, 150, 50, 2.50, 20 and 1.80 per steps.

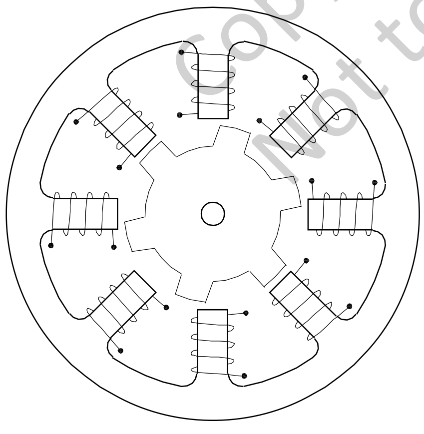
Open loop opearation

One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. The position is known simply by keeping track of the input step pulses.

Stepper motor types: There are three basic stepper motor types. They are

1 Variable-reluctance (Fig 1)

Fig 1



2 Permanent-magnet (Fig 2)

3 Hybrid (Fig 3)

1 Variable-reluctance (VR): This type of stepper motor has been around for a long time. It is probably the easiest to understand from a structural point of view (Fig 1) shows a typical VR stepper motor. This type of motor consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles.

Fig 2

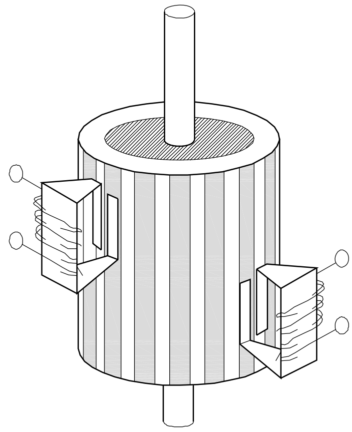
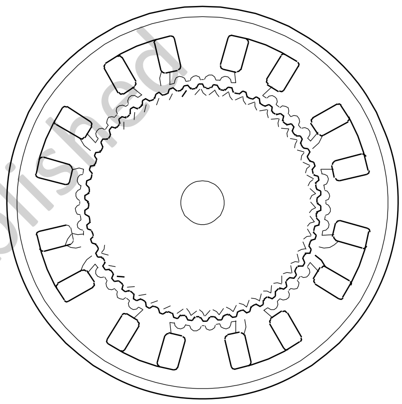


Fig 3



2 Permanent magnet (PM): Often referred to as a "tin can" or "can stock" motor the permanent magnet step motor is a low cost and low resolution type motor with typical step angles of 7.50 to 150 (48 - 24 steps/ revolution) PM motors as the name implies have permanent magnets added to the motor structure (Fig 2). The rotor no longer has teeth as with VR motor. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and because of this the PM motor exhibits improved torque characteristics when compared with the VR type.

3 Hybrid (HB): The hybrid stepper motor is more expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the HB stepper motor range from 3.60 to 0.90 (100 - 400 steps per revolution) The hybrid stepper motor combines the best features of both the PM and VR type stepper motors. The rotor is multi-toothed like the VR motor and contains an axially magnetized concentric magnet around its shaft (Fig 3). The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the airgap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types.

The two most commonly used types of stepper motors are the permanent magnet and the hybrid types.

Advantages and disadvantages

Advantages

1 The rotation angle of the motor is proportional to the input pulse.

2 The motor has full torque at stand still (if the windings are energized)

3 Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3-5% of a step and this error is non cumulative from one step to the next.

4 Excellent response to starting/stopping/reversing.

5 Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing

6 The motor's response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.

7 It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.

8 A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

1 Resonances can occur if not properly controlled

2 Not easy to operate at extremely high speeds.

Application

There are different applications. Some of these include printers, plotters, high-end office equipment, hard disk drives, medical equipment, fax machines, automotive and many more.

Hysteresis motor

Objectives: At the end of this lesson you shall be able to
- **state the construction details of hysteresis motor**
- **explain the working principle of hysteresis motor**
- **state the torque-speed characteristics**
- **list the advantages, disadvantages and application of hysteresis motor.**

A hysteresis motor is a synchronous motor without salient (or projected) poles and without dc excitation which starts by the hysteresis losses induced in its hardened steel secondary member by the revolving filed of the primary and operates normally at synchronous speed and runs on hysteresis torque because of the retentivity of the secondary core.

It is a single-phase motor whose operation depends upon the hysteresis effect i.e., magnetization produced in a ferromagnetic material lags behind the magnetizing force.

Construction:

It consists of: (i) Stator

(ii) Rotor

i) Stator: A stator designed to produce a synchronously-revolving field from a single-phase supply. The stator carries main and auxiliary windings (which is called split phase hysteresis motor) so as top produce rotating magnetic field as shown in Fig 1. The stator can also be shaded pole type (which is called shaded pole hysteresis motor) as shown in Fig 2.

ii) Rotor: The rotor of hysteresis motors are made with magnetic material of high hysteresis losses. i.e. whose hysteresis loop area is very large as shown in Fig 3. The rotor does not carry any winding or teeth. It consists of two or more outer rings and crossbars, all made of specially selected heat-treated hard steel. The type of Steel that has a very large hysteresis loop is chosen. When a rotating filed moves past the rotor, this hysteresis effect causes a torque to be developed and the motor starts to run. As synchronous speed is approached, the crossbars presents a low reluctance path to the flux thereby setting up permanent pole in the rotor and causing the motor to continue to rotate at synchronous speed.

Fig 1

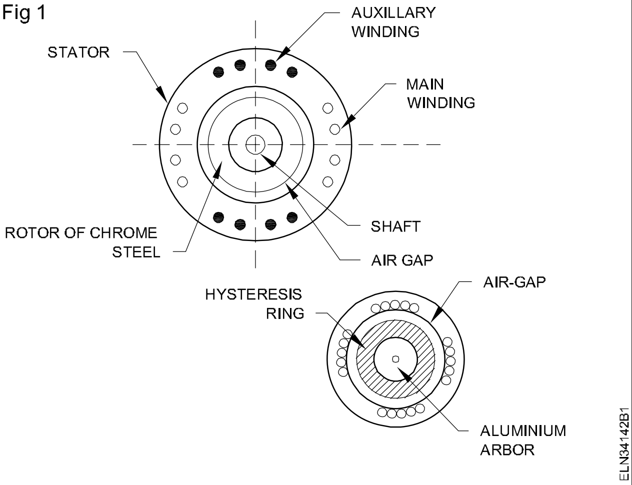


Fig 2

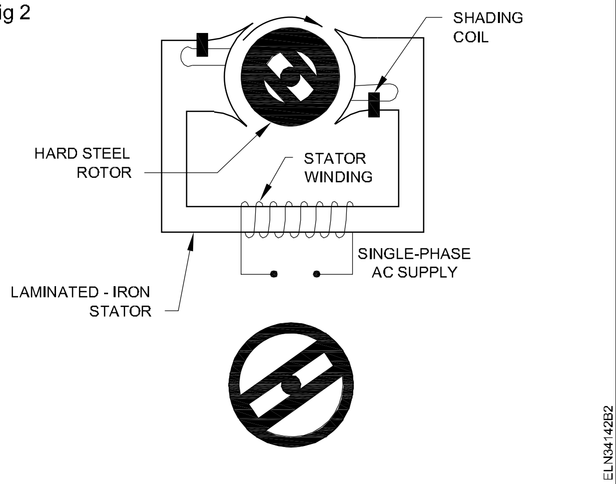
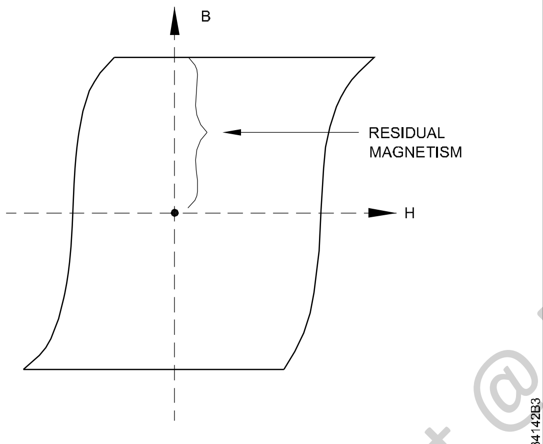


Fig 3



HYSTERESIS LOOP FOR ROTOR MATERIAL

Working principle

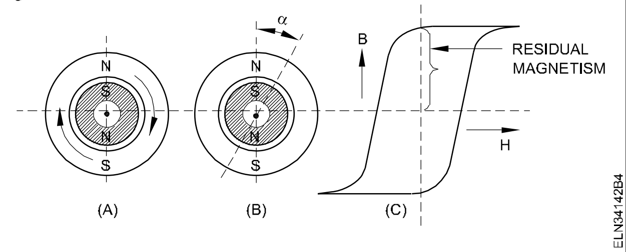
When stator is energized, it produces rotating magnetic field. The main and auxiliary, both the windings must be supplied continuously at start as well as in running conditions so as to maintain the rotating magnetic field. The rotor, initially, starts to rotate due to eddy-current torque and hysteresis torque developed on the rotor. Once the speed is near about the synchronous, the stator pulls rotor into synchronism.

In such case, as relative motion between stator field and rotor field vanishes, so the torque due to eddycurrents vanisehes. When the rotor is rotating in the synchronous speed, the stator revolving field flux produces poles on the rotor as shown in Fig 4.

Due to the hysteresis effect, rotor pole axis lags behind the axis of rotating magnetic field. Due to this, rotor poles get attracted towards the moving stator poles. Thus rotor gets subjected to torque called hysteresis torque. This torque is constant at all speeds.

When the stator field moved forward, due to high residual magnetism (i.e. retentivity) the rotor pole strength remains maintained. The hyteresis torque is independent of the rotor speed. The high retentivity ensures the continuous magnetic locking between stator and rotor. Only hysteresis torque is present which keeps rotor running at synchronous speed.

Fig 4

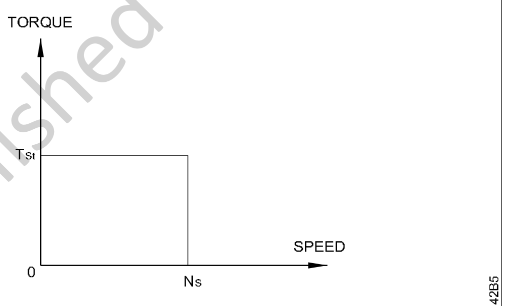


Hysteresis losses are produced in the rotor of a hysteresis motor is proportional to the area of hysteresis loop. These losses are dissipated as heat in the rotor.

Torque-Speed Characteristics

The starting and running torque is almost equal in this type of motor. As stator carries mainly the two-windings its direction can be reversed interchanging the terminals of either main winding or auxiliary winding. The torque-speed characteristics is as shown in Fig 5.

Fig 5



TORQUE - SPEED CHARACTERISTICS OF HYSTERESIS MOTOR

Advantages

The advantages of hysteresis motor are:

1 As rotor has no teeth, no winding, there are no mechanical vibrations.

2 Due to absence of vibrations, the operation is quiet and noiseless.

3 Suitability to accelerate inertia loads. 4. Possibility of multispeed operation by employing gear train.

Disadvantages

The disadvantages of hysteresis motor are:

1 The output is about one-quarter that of an induction motor of the same dimension.

2 Low efficiency

3 Low power factor

4 Low torque

5 Available in very small sizes

Applications

Due to noiseless operation it is used in sound recording instruments, sound producing equipments, high quality record players, electric clocks, teleprinters, timing devices etc.

Reluctance motor

Objectives: At the end of this lesson you shall be able to
- **list out the types of reluctances motor**
- **explain the operation of reluctance motor**
- **list out the application of reluctance motor.**

A reluctance motor is a type of electric motor that induces non-permanent magnetic poles on the ferromagnetic rotor. Torque is generated through the phenomenon of magnetic reluctance.

There are various types of reluctance motor:

- Synchronous reluctance motor
- Variable reluctance motor
- Switched reluctance motor
- Variable reluctance stepping motor.

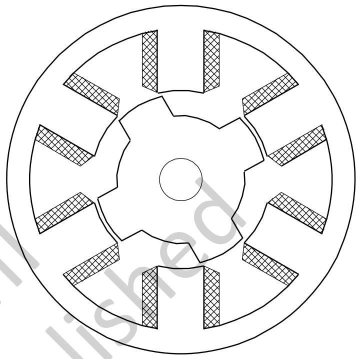
Reluctance motors can deliver very high power density at low cost, making them ideal for many applications. Disadvantages are high torque ripple (the difference between maximum and minimum torque during one revolution) when operated at low speed, and noise[caused by torque ripple

Operation of reluctance motor

The stator consists of multiple projecting (salient) electromagnet poles, similar to a wound field brushed DC motor (Fig 1). The rotor consists of soft magnetic material, such as laminated silicon/steel, which has multiple projections acting as salient magnetic poles through magnetic reluctance. For switched reluctance motors, the number of rotor poles is typically less than the number of stator poles, which minimizes torque ripple and prevents the poles from all aligning simultaneously-a position which cannot generate torque.

When a rotor pole is equidistant from the two adjacent stator poles, the rotor pole is said to be in the "fully unaligned position". This is the position of maximum magnetic reluctance for the rotor pole. In the "aligned position", two (or more) rotor poles are fully aligned with two (or more) stator poles, (which means the rotor poles completely face the stator poles) and is a position of minimum reluctance.

Fig 1



RELUCTANCE MOTOR 6 STATOR & 4 ROTOR

When a stator pole is energized, the rotor torque is in the direction that will reduce reluctance. Thus the nearest rotor pole is pulled from the unaligned position into alignment with the stator field (a position of less reluctance). (This is the same effect used by a solenoid, or when picking up ferromagnetic metal with a magnet.) In order to sustain rotation, the stator field must rotate in advance of the rotor poles, thus constantly "pulling" the rotor along.

Alternator - principle - relation between poles, speed and frequency

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of an alternator**
- **explain the method of production of sine wave voltage by a single loop alternator**
- **describe the relation between frequency, number of poles and synchronous speed.**

Principle of an alternator: An alternator works on the same principle of electromagnetic induction as a DC generator. That is, whenever a conductor moves in a magnetic field so as to cut the lines of force, an emf will be induced in that conductor. Alternatively whenever there is relative motion between the field and the conductor, then, the emf will be induced in the conductor. The amount of induced emf depends upon the rate of change of cutting or linkage of flux.

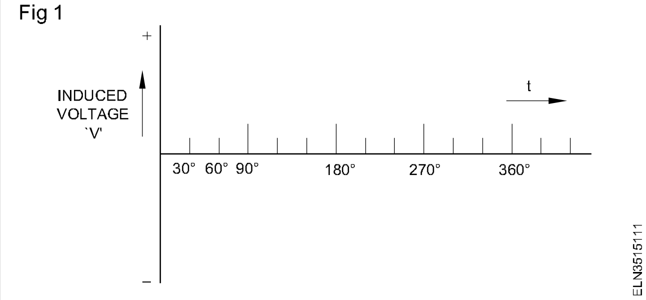
In the case of DC generators, we have seen that the alternating current produced inside the rotating armature coils has to be rectified to DC for the external circuit through the help of a commutator. But in the case of alternators, the alternating current produced in the armatrue coils can be brought out to the external circuit with the help of slip-rings. Alternatively the stationary conductors in the stator can produce alternating current when subjected to the rotating magnetic field in an alternator.

Production of sine wave voltage by single loop alternator: Fig 2a shows a single loop alternator. As it rotates in the magnetic field, the induced voltage in it varies in its direction and magnitude as follows.

To plot the magnitude and direction of the voltage induced in the wire loop of the AC generator in a graph, the electrical degrees of displacement of the loop are kept in the `X' axis as shown in Fig 1 through 30 electrical degrees. As shown in Fig 2c, three divisions on the `X' axis represent a quarter turn of the loop, and six divisions a half turn. The magnitude of the induced voltage is kept in the `Y' axis to a suitable scale.

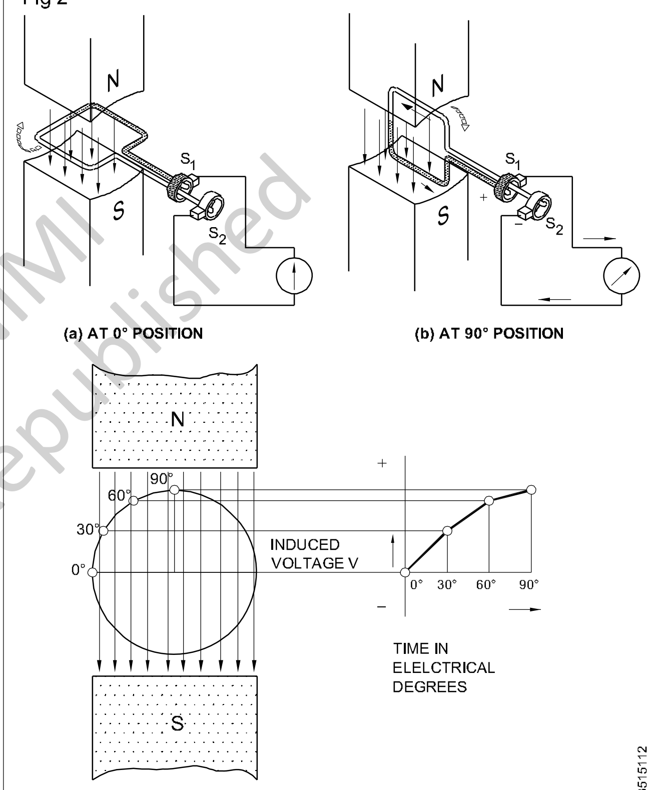
The part above the X-axis represents the positive voltage, and the part below it the negative voltage as shown in Fig 1.

Fig 1



The position of the loop at the time of starting is shown in Fig 2a and indicated in Fig 2c as `O' position. At this position, as the loop moves parallel to the main flux, the loop does not cut any lines of force, and hence, there will be no voltage induced. This zero voltage is represented in the graph as the starting point of the curve as shown in Fig 2c. The magnitude of the induced emf is given by the formula Eo = BLV Sinq

Fig 2



(c) PRODUCTION OF SINE WAVE FORM IN A SINGLE PHASE ALTERNATOR

where

B is the flux density in weber per square metre,

L is the length of the conductors in metres,

V is the velocity of the loop rotation in metres per second and

q is the angle at which the conductor cuts the line of force.

As sin q = 0

E at 0 position is equal to zero. As the loop turns in a clockwise direction at position 30° as shown in Fig 2c, the loop cuts the lines of force and an emf is induced (E_{30}) in the loop whose magnitude will be equal to BLV Sinq where q is equal to 30°.

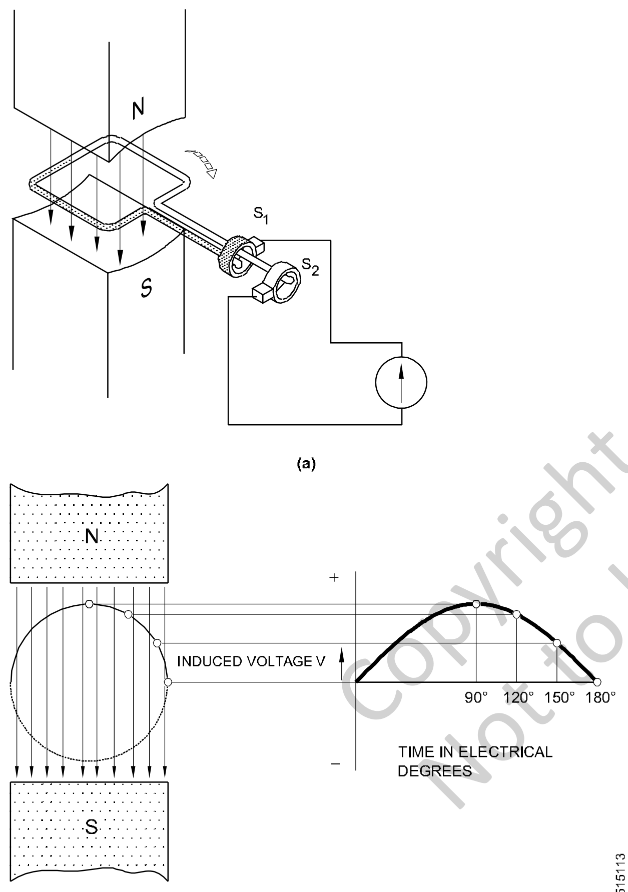
Applying the above formula, we find the emf induced in the loop at 90° position will be maximum as shown in Fig 2c.

As the loop turns further towards 180° it is found the number of lines of force which are cut will be reduced to zero value. If the quantity of emf induced at each position is marked by a point and a curve is drawn along the points, the curve will be having a shape as shown in Fig 3b.

During the turn of the loop, from 0 to 180°, the slip ring S_1 will be positive and S_2 will be negative.

However, at 180° position, the loop moves parallel to the lines of force, and hence there is no cutting of flux by the loop and there is no emf induced in the loop as shown in Fig 3b.

Fig 3



(b) VALUE OF INDUCED E.M.F. AT POSITION 180° FROM START

Further during the turn of the loop from the position 180° to 270°, the voltage increases again but the polarity is reversed as shown in Fig 4b. During the movement of the loop from 180 to 360°, the slip ring S_2 will be positive and S_1 will be negative as shown in Fig 4a. However, at 270° the voltage induced will be the maximum and will decrease to zero at 360°. Fig 5b shows the variation of the induced voltage in both magnitude and direction during one complete revolution of the loop. This is called a cycle.

Fig 4

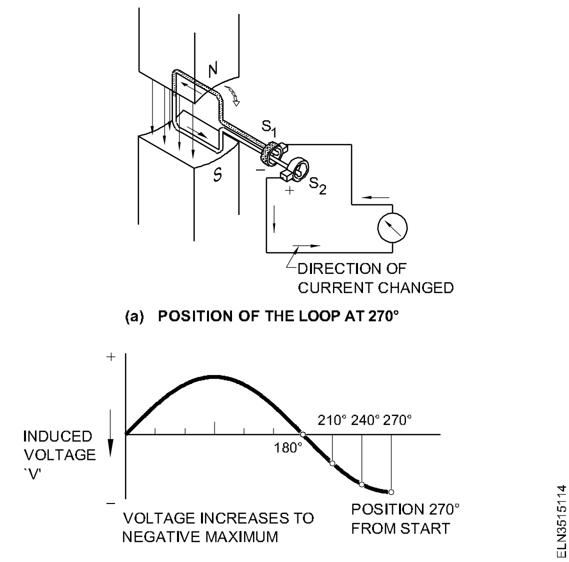
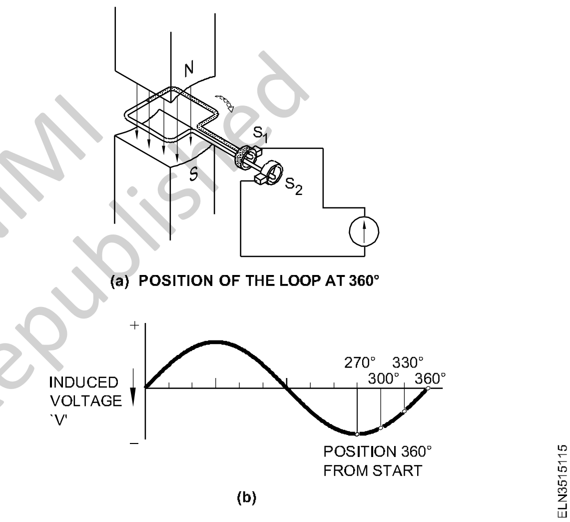


Fig 5

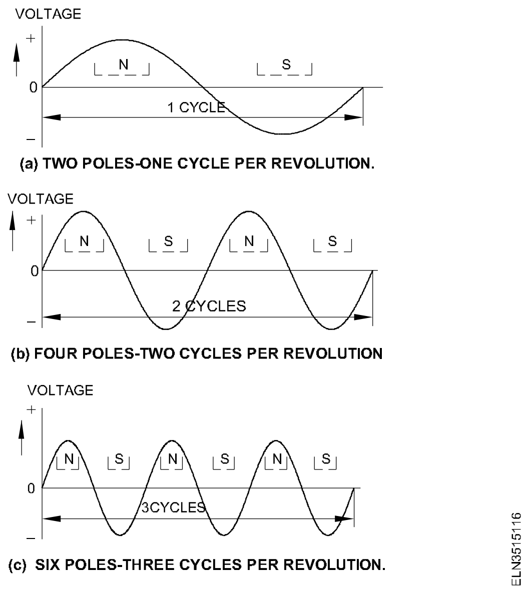


This type of wave-form is called a sine wave as the magnitude and direction of the induced emf, strictly follows the sine law. The number of cycles completed in one second is called a frequency. In our country, we use an AC supply having 50 cycles frequency which is denoted as 50 Hz.

Relation between frequency, speed and number of poles of alternator: If the alternator has got only two poles, the voltage induced in one revolution of the loop undergoes one cycle. If it has four poles, then one complete rotation of the coil produces two cycles because, whenever it crosses a set of north and south poles, it makes one cycle.

Fig 6 shows the number of cycles which are produced in each revolution of the coil, with 2 poles, 4 poles and 6 poles. It is clear from this that the number of cycles per revolution is directly proportional to the number of poles, `P' divided by two. Therefore the number of cycles produced per second depends on P/2, and the speed in revolutions per second.

Fig 6



Therefore frequency $F = \frac{P}{2} \times 'n'$

where `n' is in r.p.s.

`P' is the number of poles.

Generally speed is represented in r.p.m.

Then we have requency $F = \frac{PN}{2 \times 60} = \frac{PN}{120}$

where P is number of poles and N is speed in r.p.m.

Accordingly we can state that the frequency of an alternator is directly porportional to the number of poles and speed.

Types and construction of alternators

Objective: At the end of this lesson you shall be able to
- **explain the construction, and the various types of alternators.**

Types of alternators: DC and AC generators are similar in one important respect, that is, they both generate alternating emf in the armature conductors. The AC generator sends out the electrical energy in the same form of alternating emf to the external load with the help of slip rings.

AC generators, named as alternators, must be driven at a very definite constant speed called synchronous speed, because the frequency of the generated emf is determined by the speed. Due to this reason these machines are called `synchronous alternators or synchronous generators'.

Classification according to the type of rotating part: One way of classifying the alternator is the way in which the rotating part is chosen. In the earlier lessons, we discussed how an alternator can have either stationary or rotating magnetic field poles. Accordingly an alternator having a stationary magnetic field and a moving armature is called a **rotating armature type,** and an alternator with a stationary armature and moving magnetic field is called a **rotating field type.** There are definite advantages in using rotating field type alternators.

Advantages of using rotating field type alternators

Only two slip rings are required for a rotating field type alternator whatsoever the number of phases may be.

As the main winding is placed over the stator, more conductors can be housed in the stator because of more internal peripheral area. More conductors result in higher voltage/current production.

As the winding in which the emf is induced is stationary, there is no possibility of breaking or loosening the winding and its joints, due to rotational forces.

There is no sliding contact between the stationary armature and the external (load) circuit, as the supply could be taken direct. Only two slip rings are provided in the rotor for low power low voltage field excitation. Thus less sparking and less possibility of faults.

The main winding being stationary, the conductors can be easily and effectively insulated, and the insulating cost also will be less for higher output voltage (less dielectric strength insulation will be sufficient).

Stationary main conductors need less maintenance.

As the rotor has a field winding which is lighter for the given capacity than in the rotating armature type, the alternator can be driven at a higher speed.

Classification according to the number of phases: Another way of classifying the alternators is based on production of single or 3-phase by the alternator. Accordingly the types are 1) single-phase alternators 2) three-phase alternators.

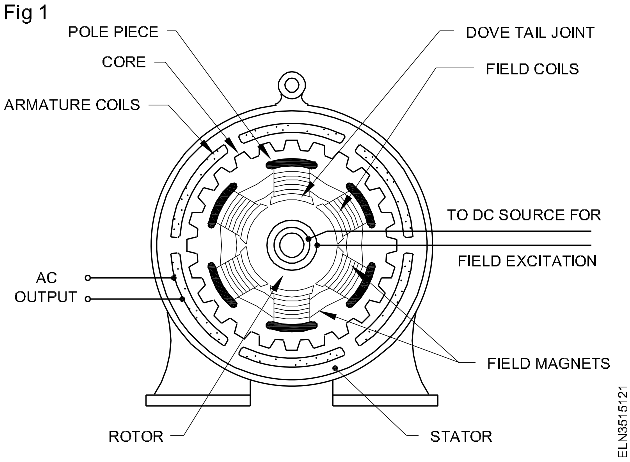
Single-phase alternators: A single-phase alternator is one that provides only one voltage. The armature coils are connected in `series additive'. In other words, the sum of the emf induced in each coil produces the total output voltage. Single phase alternators are usually constructed in small sizes only. They are used as a temporary standby power for construction sites and for permanent installation in remote locations.

Three-phase alternators: This alternator provides two different voltages, namely, phase and line voltages. It has 3 windings placed at 120° to each other, mostly connected in a star having three main terminals U,V,W and neutral `N'.

These alternators are driven by prime movers such as diesel engines, steam turbines, water wheels etc. depending upon the source available.

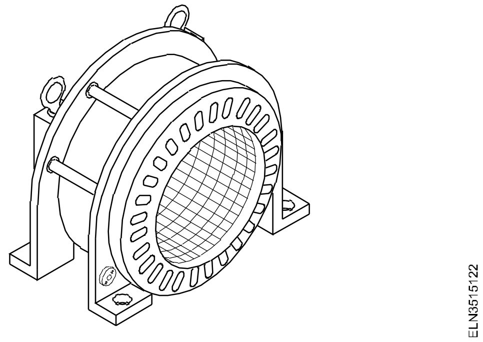
Construction of alternators: The main parts of a revolving field type alternator are shown in Fig 1.

Fig 1



Stator: It consists of mainly the armature core formed of laminations of steel alloy (silicon steel) having slots on its inner periphery to house the armature conductors. The armature core in the form of a ring is fitted to a frame which may be of cast iron or welded steel plate. The armature core is laminated to reduce the eddy current losses which occur in the stator core when subjected to the cutting of the flux produced by the rotating field poles. The laminations are stamped out in complete rings (for smaller machines) or in segments (for larger machines), and insulated from each other with paper or varnish. The stampings also have holes which make axial and radial ventilating ducts to provide efficient cooling. A general view of the stator with the frame is shown in Fig 2.

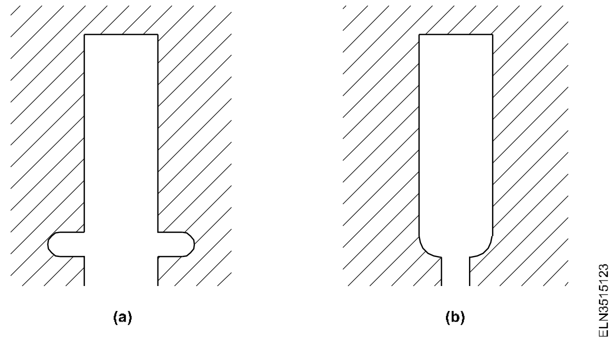
Fig 2



Slots provided on the stator core to house the armature coils are mainly of two types, (i) open and (ii) semi-closed slots, as shown in Fig 3a and b respectively.

The open slots are more commonly used because the coils can be form-wound and pre-insulated before placing in the slots resulting in fast work, less expenditure and good insulation. This type of slots also facilitates easy removal and replacement of defective coils. But this type of slots creates uneven distribution of the flux, thereby producing ripples in the emf wave. The semi-closed type slots are better in this respect but do not permit the use of form-wound coils, thereby complicating the process of winding. Totally closed slots are rarely used, but when used, they need bracing of the winding turns.

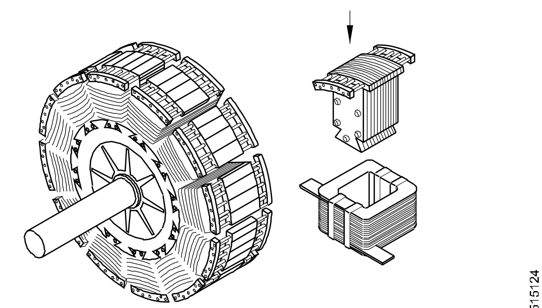
Fig 3



Rotor: This forms the field system, and is similar to DC generators. Normally the field system is excited from a separate source of low voltage DC supply. The excitation source is usually a DC shunt or compound generator, known as an exciter, mounted to the same alternator shaft. The exiting current is supplied to the rotor with the help of two slip- rings and brushes. The field poles created by the excitation are alternately north and south.

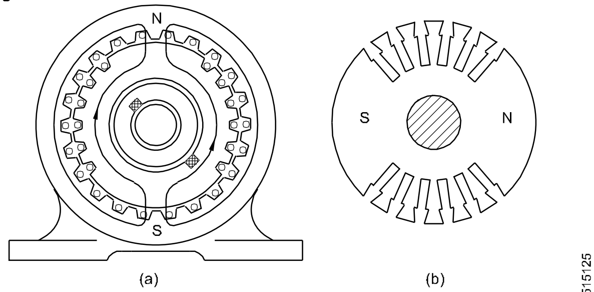
Rotating field rotors are of two types, namely (i) salient pole type as shown in Fig 4 and (ii) smooth cylindrical type or non-salient pole type, as shown in Fig 5.

Fig 4



SALIENT POLE FIELD STRUCTURE

Fig 5



NON-SALIENT POLE TYPE FIELD STRUCTURE

Salient pole type: This type of rotor is used only for slow and medium speed alternators. This type is less expensive, having more space for the field coils and vast heat dissipating area. This type is not suitable for high speed alternators as the salient poles create a lot of noise while running in addition to the difficulty of obtaining sufficient mechanical strength.

Fig 4 shows the salient pole type rotor in which the riveted steel laminations are fitted to the shaft fitting with the help of a dovetailed joint. Pole faces are curved to have uniform distribution of the flux in the air gap leading to production of sinusoidal wave form of the generated emf. These pole faces are also provided with slots to carry the damper winding to prevent hunting. The field coils are connected in series in such a way as to produce alternate north and south poles, and the field winding ends are connected to the slip rings. The DC excitation source is connected to the brushes which are made to contact the slip rings with the required pressure.

Salient pole type alternators could be identified by their larger diameter, short axial length and low or medium speed of operation.

Smooth cylindrical or non-salient pole type rotor: This type is used in very high speed alternators, driven by steam turbines. To have good mechanical strength, the peripheral velocity is lowered by reducing the diameter of the rotor and alternatively with the increased axial length. Such rotors have either two or four poles but run at higher speeds.

To withstand such speeds, the rotor is made of solid steel forging with longitudinal slots cut as shown in Fig 5a which shows a two-pole rotor with six slots. The winding is in the form of insulated copper strips, held securely in the slots by proper wedges, and bound securely by steel bonds.

One part of the periphery of the rotor in which slots are not made is used as poles as shown in Fig 5b.

Smooth cylindrical pole type alternators could be identified by their shorter diameter, longer axial length and high speed of operation.

Rating of alternators

An electrical machines is usually rated at the load, which is can carry without over heating and damage to insulation. i.e the rating of electrical machine is governed by the temperature rise caused by internal losses of the machine. The copper loss in the armature (I2R) depends upon the strength of the armature current and is independent of power factor.

The output in kW is proportional to power factor for the alternator of a given kVA. For example output of 1000 kVA alternator on full load will be 200, 500, 800, 1000 kW at power factor 0.2, 0.5, 0.8 and unity respectively but copper losses in armature will remain the same regard less of power factor.

For the above reasons alternators are usually rated in kVA (kilo Volt Ampere).

Hunting

Hunting is a phenomenon in alternator which is caused by continuous fluctuation in load. When the load on the alternator is frequency changing, then the rotor of the alternator runs unsteadily making a noise of a whistle due to oscillations, or vibrations set up in the rotor. This phenomenon is called as hunting of alternators.

Hunting is prevented by the Damper Windings provided in the field pole core.

Generation of 3-phase voltage and general test on alternator

Objectives: At the end of this lesson you shall be able to

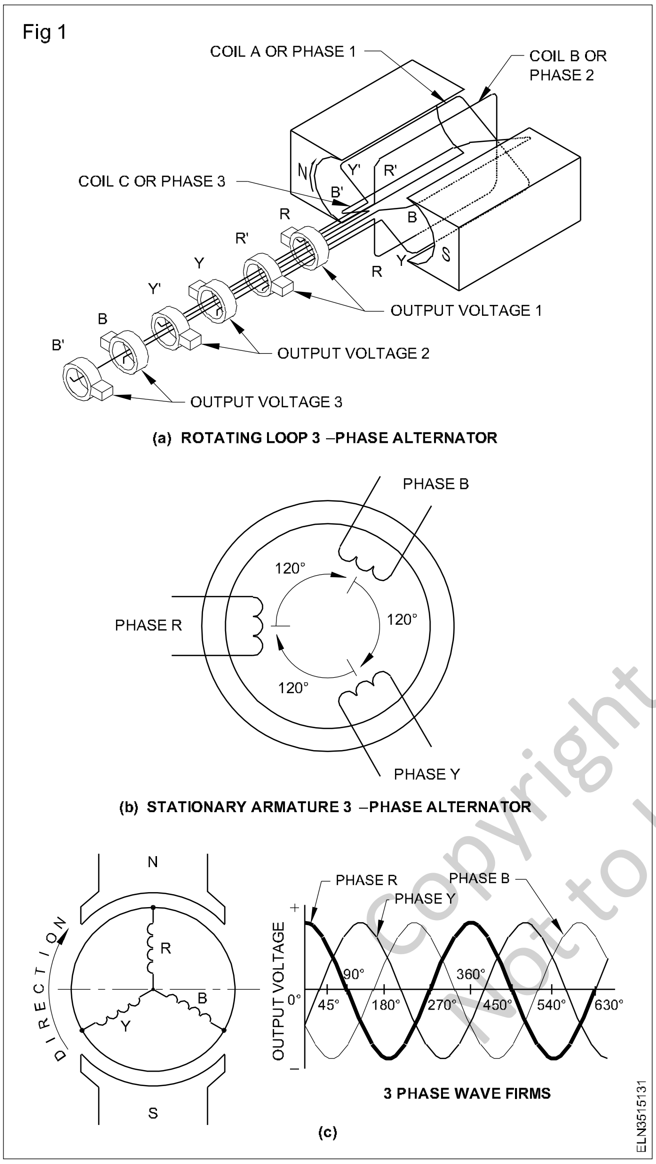
- **explain the method of generating 3-phase voltage wave-forms by a 3-phase alternator**
- **state the phase sequence of 3ϕ supply**
- **state the method of testing an alternator for continuity insulation and earth connection**
- **state e.m.f. equation of the alternator**
- **state the I.E.E. regulations and B.I.S. recommendations pertaining to earthing of the alternator.**

An AC three-phase system is the most common system used in the present world. It is because of its high efficiency, less cost of material required for the generation, transmission and distribution for a given capacity. The three-phase system supplies power to drive three-phase motors in industry as well as supplying power to single phase motors and lighting loads for both industrial and domestic purposes. Present day electricians may be employed in a generating station or may be employed in a standby power station where three-phase alternators are used. Hence a fairly good knowledge about production of 3-phase voltages, their phase sequence and general testing of alternators is essential.

Generation of three-phase voltage: Basically,the principle of a three-phase alternator (generator) is the same as that of a single phase alternator (generator), except that there are three equally spaced coils or windings which produce three output voltages which are out of phase by 120° with each other.

A simple rotating-loop, three-phase generator with its output voltage wave-forms is shown in Fig 1c.

As shown in Fig 1a, three independent loops spaced about 120° apart are made to rotate in a magnetic field with the assumption that the alternator shown is a rotating armature type. As shown in Fig 1a, the three loops are electrically isolated from each other and the ends of the loops are connected to individual slip rings. As the loops are rotating in a uniform magnetic field, they produce sine waves. In a practical alternator, these loops will be replaced by a multi-turn winding element and distributed throughout the rotor slots but spaced apart at 120° electrical degrees from each other. Further, in practice, there will not be six slip rings as shown in Fig 1a but will have either four or three slip rings depending upon whether the three windings are connected in a star or delta respectively.



We also know, as discussed earlier, that the rotating magnetic field type alternators are mostly used. In such cases only two slip rings are required for exciting the field poles with DC supply. Fig 1b shows a stationary, 3-phase armature in which individual loops of each winding are replaced by coils spaced at 120 electrical degrees apart. However, the rotating part having the magnetic poles is not shown.

Fig 1c shows the rotating armature type alternator in which the 3 coils of the three-phases are connected in star which rotates in a two-pole magnetic field. According to Fig 1c, the coil `R' moves under the influence of the `N' pole cutting the flux at right angles, and produces the maximum induced voltage at position `Oº' as shown in the graph as per Faraday's Laws of Electromagnetic induction. When the coil `R' moves in a clockwise direction, the emf induces falls to zero at 90 degrees, and then increases to -ve maximum under the influence of the south pole at 180 degrees. Likewise the emf induced in the `R' phase will become zero at 270 degrees and attain +ve maximum at 360 degrees. In the same manner the emf produced by coils `Y' and `B' could be plotted on the same graph. A study of the sine wave-forms produced by the three coils RYB shows that the voltage of coil `R' leads voltage of coil `Y' by 120°, and the voltage of coil `Y' leads voltage of coil `B' by 120°.

Phase sequence: The phase sequence is the order in which the voltages follow one another, i.e. reach their maximum value. The wave-form in Fig 1c shows that the voltage of coil R or phase R reaches its positive maximum value first, earlier than the voltage of coil Y or phase `Y', and after that the voltage of coil B or phase B reaches its positive maximum value. Hence the phase sequence is said to the RYB.

If the rotation of the alternator shown in Fig 1c is changed from clockwise to anticlockwise direction,the phase sequence will be changed as RBY. It is the most important factor for parallel connection of polyphase generators and in polyphase windings. Further the direction of rotation of a 3-phase induction motor depends upon the phase sequence of the 3-phase supply. If the phase sequence of the alternator is changed, all the 3-phase motors, connected to that alternator, will run in the reverse direction though it may not affect lighting and heating loads.

The only difference in the construction of a single phase alternator and that of a 3-phase alternator lies in the main winding. Otherwise both the types of alternators will have similar construction.

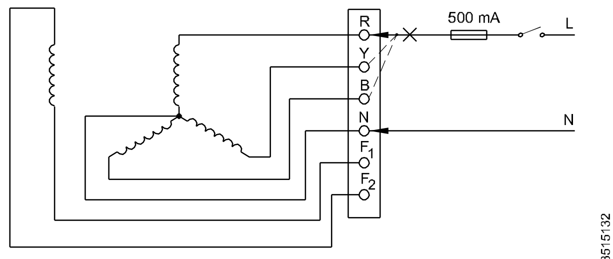
General testing of alternator: Alternators are to be periodically checked for their general condition as they will be in service continuously. This comes under preventive maintenance, and avoids unnecessary breakdowns or damage to the machine. The usual checks that are to be carried out on an altenator are:

- continuity check of the windings
- insulation resistance value between windings
- insulation resistance value of the windings to the body
- checking the earth connection of the machine.

Continuity test: The continuity of the windings is checked by the following method as shown in Fig 2.

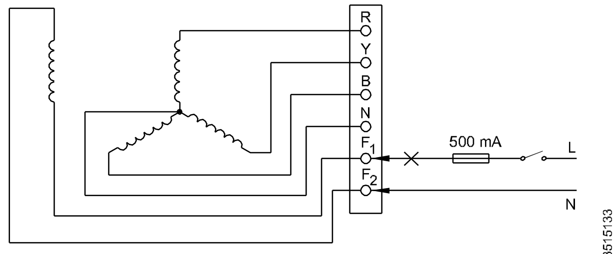
A test lamp is connected in series with one end to the neutral (star point) and the other end to one of the winding terminals (R Y B). If the test lamp glows equally bright on all the terminals RYB then the continuity of the winding is all right. In the same way, as shown in Fig 3, we can test the field leads F_1 and F_2 for field continuity.

Fig 2



CONTINUITY TEST ON MAIN WINDING OF A 3-PHASE ALTERNATOR

Fig 3



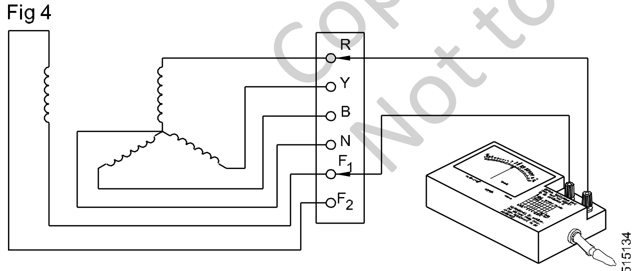
CONTINUITY TEST ON FIELD WINDING OF A 3-PHASE ALTERNATOR

Testing continuity with the test lamp only indicates the continuity in between two terminals but will not indicate any short between the same windings. A more reliable test will be to use an ohmmeter to check the individual resistances of the coils, and compare them to see that similar coils have the same resistance. The readings, when recorded, will be useful for future reference also.

For insulation resistance test

Between windings: As shown in Fig 4, one end of the Megger lead is connected to any one terminal of the RYB and the other is connected to F_1 or F_2 of the field winding. If the Megger reads one megohm or more, then the insulation resistance is accepted as okay.

Fig 4

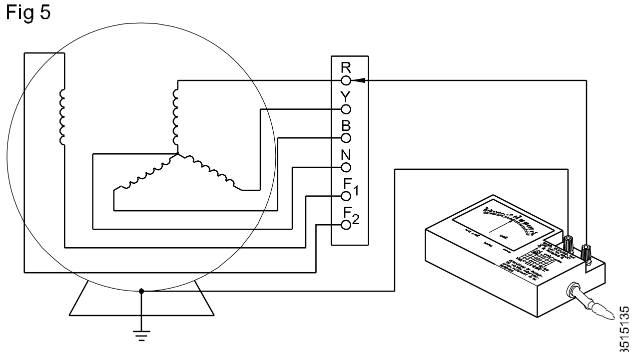


INSULATION TEST BETWEEN WINDINGS

If there is short, between the armature and field windings, the Megger reads zero ohms. If it is weak, it shows less than one megohm.

Testing insulation resistance between body and windings: As shown in Fig 5, one lead of the Megger is connected to one of the leads of the RYB, and the other lead of the Megger is connected to the body. If the insulation between the windings and the frame is all right, the Megger reads more than one megohm.

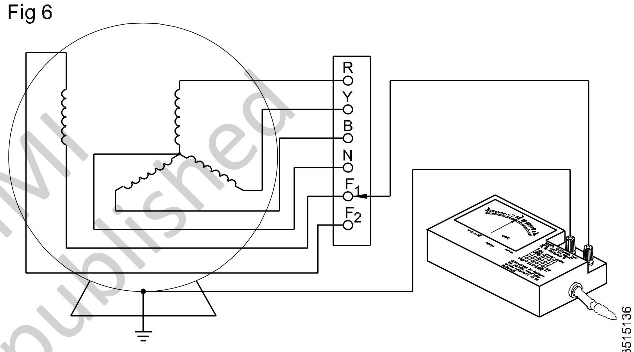
Fig 5



INSULATION TEST BETWEEN MAIN WINDING AND FRAME

The field is tested by connecting one terminal of the Megger to F_1 or F_2 of the field and the other terminal to the body as shown in Fig 6. If the insulation between the field and the frame is all right, the Megger reads more than one megohm. A lower reading than one megohm shows weak insulation and leakage to the ground.

Fig 6



INSULATION TEST BETWEEN FIELD WINDING AND FRAME

Caution

While conducting the insulation resistance test, if the Megger reads zero, then it should be concluded that the insulation of the winding has failed completely and needs thorough checking.

> **The permissible insulation resistance should not be less than 1 megohm.**

Earthing of alternators: This consists of two equally important requirements as stated below.

- Earthing of the neutral of the alternator
- Earthing of the alternator frame.

Earthing of neutral: According to B.I.S. 3043-1966, it is recommended to use one of the following methods for earthing the neutral of the alternator.

- Solid earthing
- Resistance earthing
- Reactance earthing
- Arc-suppression coil earthing

The selection and the type of earthing depends to a large extent on the size of the unit, the system voltage protection scheme used, the manufacturer's recommendation and the approval of the electrical inspectorate authority. Trainees are advised to refer to B.I.S.3043-1966 for further details. As earthing of neutral is essential for the operation of protective relays, to maintain proper voltage in the system and for safety reasons, trainees are advised to identify the method of neutral earthing adopted in the available alternator, maintain the continuity of earth connections and keep the earth electrode resistance within the specified value.

Earthing alternator frame: This earthing is essential for the safety of the workers, and to keep the frame of the alternator at zero earth potential. Operation of the earth fault relays or fuses to open the electrical circuits in case of earth faults is fully dependent upon earthing of the frame.

As per I.E. rules No.61, all the electrical equipment/ machines are to be provided with double earthings for safe operation. The condition of earth must be checked periodically, and the earth electrode and the earth conductor resistance must also be measured and recorded at repeated intervals of time. The earth electrode and the earthing conductors should be maintained such that the resistance value is lower than the stipulated value according to the design of the system.

Emf equation of the alternator

Objective: At the end of this lesson you shall be able to
- **explain the emf equation to calculate the induced emf in an alternator.**

Equation of induced emf: The emf induced in an alternator depends upon the flux per pole, the number of conductors and speed. The magnitude of the induced emf could be derived as stated below

Let Z = No.of conductors or coil sides in series/ phase in an alternator

P = No.of poles

F = frequency of induced emf in Hz

Ø = flux per pole in webers

k_f = form factor = 1.11 - if emf is assumed to be sinusoidal

N = speed of the rotor in r.p.m.

According to Faraday's Law of Electromagnetic Induction we have the average emf induced in a conductor

= rate of change of flux linkage

$$= \frac{d\varnothing}{dt}$$

$$= \frac{\text{change of total flux}}{\text{time duration in which the flux change takes place}}$$

In one revolution of the rotor (ie in 60/N seconds), each stator conductor is cut by a flux equal to PØ webers.

Hence the change of total flux = dØ = PØ and the time duration in which the flux changes takes place

= dt = 60/N seconds.

Hence the average emf induced in a conductor

$$= \frac{d\varnothing}{dt} = \frac{P\varnothing}{\frac{60}{N}} \text{ volts} \quad \text{-------- Eq 1}$$

Substituting the value for $N = \frac{120F}{P}$ in eqn 1

we have the average emf induced in a conductor =

$$= \frac{P\varnothing 120F}{P60} \text{ volts} = 2\varnothing F \text{ volts} \quad \text{------ Eq. 2}$$

If there are Z conductors in series per phase we have the average emf per phase = 2ØFZ volts.

Then r.m.s. value of emf per phase = average value x form factor

$= V_{AV} \times K_F$

$= V_{AV} \times 1.11$

= 2ØFZ x 1.11

= 2.22ØFZ volts.

Alternatively r.m.s. value of emf per phase = 2.22ØF2T volts

= 4.44ØFT volts

where T is the number of coils or turns per phase and Z = 2T.

This would have been the actual value of the induced voltage if all the coils in a phase were (i)full pitched and (ii) concentrated or bunched in one slot. (In actual practice, the coils of each phase are distributed in several slots under all the poles.) This not being so, the actually available voltage is reduced in the ratio of these two factors which are explained below.

Pitch factor (K_p or K_c.): The voltage generated in a fractional pitch winding is less than the full pitch winding. The factor by which the full pitch voltage is multiplied to get voltage generated in fractional pitch is called pitch factor, and it is always less than one; and denoted as K_p or K_c. Normally this value is given in problems directly; occasionally this value needs to be calculated by a formula $K_p = K_c = \cos \alpha/2$

where α is the electrical angle by which the coil span falls short of full pitch.

Example: Calculate the pitch factor for a winding having 36 stator slots, 4 poles with a coil span of 1 to 8.

$$\text{For full pitch} = \frac{\text{Number of stator slots}}{\text{Number of slots}} = \frac{36}{4} = 9.$$

Hence winding should start at 1 and end at 10.

In actual practice the coil span is taken as 1 – 8.

Hence actual pitch = 8 – 1 = 7.

Hence the coil span is short pitched by = 9 – 7 = 2.

$$\text{The angle } \alpha = \frac{\text{difference in pitch}}{\text{full pitch}} \times 180^\circ$$

$$= \frac{2}{9} \times 180^\circ = 40^\circ$$

where 180° is the complete angle for full pitch.

$$\text{Pitch factor } K_c = \cos\frac{\alpha}{2} = \cos\frac{40}{2} = \cos 20 = 0.94.$$

Distribution factor (K_d): It is imperative that the conductors of the same phase need to be distributed in the slots instead of being concentrated at one slot. Because of this, the emf generated in different conductors will not be in phase with each other, and hence, cannot be added together to get the total induced emf per phase but to be added vectorially. This has to be taken into account while determining the induced voltage per phase.

Therefore, the factor by which the generated voltage must be multiplied to obtain the correct value is called a distribution factor, denoted by K_d and the value is always less than one. The formula for finding the value of K_d is given below.

$$K_d = \frac{\sin m\,\beta/2}{m \sin \beta/2}$$

where m is the number of slots per phase per pole

$$\beta = \frac{180^o}{\text{No. of slots per pole}}$$

Example: A six-pole alternator rotating at 1000 r.p.m. has a single-phase winding housed in three slots per pole; the slots in groups of three being 20° apart. Find the distribution factor.

$$K_d = \frac{\sin m\,\beta/2}{m \sin \beta/2}$$

where m = 3 slots per phase per pole

$\beta = 20^0$

$$K_d = \frac{\sin 3 \times 20/2}{3 \sin 20/2} = \frac{\sin 30^\circ}{3 \sin 10^\circ}$$

$$= \frac{0.5}{3 \times 0.1736} = 0.96$$

Example: A 3-phase, 12-pole, star-connected alternator has 180 slots with 10 conductors per slot, and the conductors of each phase are connected in series. The coil span is 144° (electrical). Find the distribution factor and the pitch factor K_p.

$$K_d = \frac{\sin m\,\beta/2}{m \sin \beta/2}$$

$$m = \frac{180}{3 \times 12} = 5 \text{ slots per phase per pole.}$$

$$\beta = \frac{180^\circ}{\frac{180}{12}} = 12^\circ$$

$$K_d = \frac{\sin 5 \times \frac{12}{2}}{5 \sin \frac{12}{2}} = \frac{\sin 30^\circ}{5 \sin 6^\circ} = \frac{0.5}{5 \times 0.1045} = 0.957$$

$$K_p = \cos\frac{\alpha}{2}$$

= Cos (180-144)/2 = Cos 36/2 = Cos 18° = 0.95.

From the foregoing, it is found that the pitch factor and the distribution factor are to be used to multiply the induced emf to get the actual induced voltage. Thus emf induced in an alternator E_o per phase = 4.44 $K_p K_d F \text{Ø} T$ volts.

In the case of a star-connected alternator, the line voltage $= E_L = \sqrt{3}E_P = \sqrt{3}E_0$ and in the case of a delta-connected alternator the line voltage $E_L = E_p = E_o$. However, if the value of either Kd or K_p is not given in the problem it can be assumed to be one.

Example: Calculate the effective voltage in one phase of an alternator, given the following particulars. F=60 Hz, turns/phase T = 240, flux per pole Ø = 0.0208 webber.

Solution: As K_c/K_p and K_d values are not given, we can assume they are equal to one.

Voltage/phase E = 4.44 ØFT volts

= 4.44 x 60 x 0.0208 x 240 volts

= 1329.86 V or 1330 volts.

Example: The following information is given in connection with a 3-phase alternator. Slots = 96, poles = 4, r.p.m. = 1500, turns/coil = 16 in single layer, Ø = 2.58 x 10^6 lines. Calculate the voltage generated/phase.

$$F = \frac{PN}{120} = \frac{4 \times 1500}{120} = 50 \text{ Hz.}$$

$$\text{Coils per phase} = \frac{\text{No. of slots}}{\text{No. of phases}} = \frac{96}{3} = 32.$$

Therefore turns/phase = 32 x 16 = 512

= 2.58 x 10^6 lines = 2.58 x 10^6 x 10^{-8} weber

V = 4.44 FØT

= 4.44 x 50 x 512 x 2.58 x 10^6 x 10^{-8} = 2932 volts.

Example: The stator of a 3-phase, 16-pole alternator has 144 slots, and there are 4 conductors per slot connected in two layers, and the conductors of each phase are connected in series. If the speed of the alternator is 375 r.p.m. calculate the emf induced per phase. The resultant flux in the air gap is 5 x 10^{-2} webers per pole, sinusoidally distributed. Assume the coil span as 150° electrical.

Sinusoidal distribution, hence the wave form is sine wave and the emf induced

E_o = E_p = 4.44 K_cK_dFØT volts

$$K_c = \cos\frac{\alpha}{2} = \cos(180-150)/2 = \cos\frac{30}{2}$$

= Cos 15 = 0.966

$$m = \frac{144}{3 \times 16} = 3$$

$$\beta = \frac{180^\circ}{\frac{144}{16}} = \frac{180}{9} = 20^\circ$$

$$K_d = \frac{\sin 3 \times \frac{20}{2}}{3 \sin \frac{20}{2}} = 0.96.$$

$$\text{Number of slots/phase} = \frac{144}{3} = 48$$

Number of conductors/slots = 4

Number of conductors in series per phase = 48 x 4

$$\text{Number of turns in series per phase} = \frac{48 \times 4}{2} = 96.$$

$$\text{Frequency} = \frac{PN}{120} = \frac{16 \times 375}{120} = 50 \text{ Hz.}$$

E_{ph} = 4.44 K_cK_dFØT

= 4.44 x 0.966 x 0.96 x 50 x 5 x 10^{-2} x 96

= 988 volts.

Characteristic and voltage regulation of the alternator

Objectives: At the end of this lesson you shall be able to
- **explain the load characteristic of an alternator and the effect of the P.F. on terminal voltage**
- **explain the regulation of alternators and solve problems therein.**

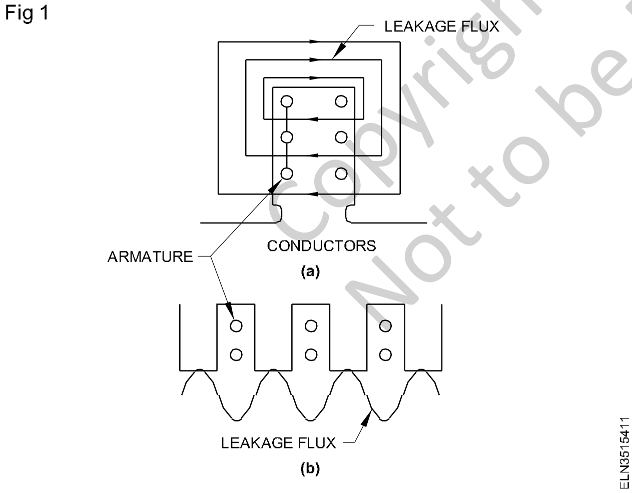
Load characteristic of an alternator: As the load on the alternator is changed, its terminal voltage is also found to change. The reason for this change is due to the voltage drop in the alternator because of

- armature resistance R_a
- armature leakage reactance X_L
- armature reaction which, in turn, depends upon the power factor of the load.

Voltage drop in armature resistance: Resistance of each phase winding of the alternator causes a voltage drop in the alternator, and it is equal to I_pR_a where I_p is the phase current and R_a is the resistance per phase.

Voltage drop in armature leakage reactance: When the flux is set up in the alternator due to the current flow in the armature conductors, some amount of flux strays out rather than crossing the air gap. These fluxes are known as leakage fluxes. Two types of leakage fluxes are shown in Figs 1a and b.

Fig 1



Though the leakage fluxes are independent of saturation, they do depend upon the current and the phase angle between the current and the terminal voltage `V'. These leakage fluxes induce a reactance voltage which is ahead of the current by 90°. Normally the effect of leakage flux is termed as inductive reactance X_L and as a variable quantity. Sometimes the value X_L is named as synchronous reactance to indicate that it refers to working conditions.

Voltage drop due to armature reaction: The armature reaction in an alternator is similar to DC generators. But the load power factor has considerable effect on the armature reaction in the alternators.

The effects of armature reaction have to be considered in three cases, i.e. when load power factor is

- unity
- zero lagging
- zero leading.

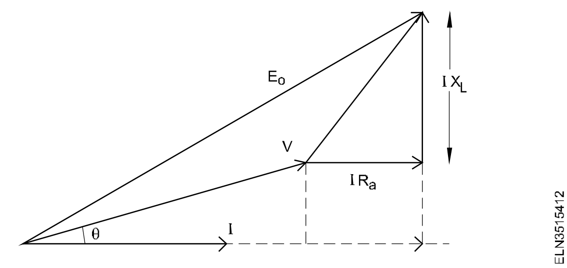
At unity P.F. the effect of armature reaction is only cross-magnetising. Hence there will be some distortion of the magnetic field.

But in the case of zero lagging P.F. the effect of armature reaction will be de-magnetising. To compensate this de-magnetising effect, the field excitation current needs to be increased.

On the other hand, the effect of armature reaction due to zero leading P.F. will be magnetising. To compensate the increased induced emf, and to keep the constant value of the terminal voltage due to this additional magnetising effect, the field excitation current has to be decreased.

Effect of armature resistance and reactance in the alternator: The induced emf per phase in an alternator is reduced by the effect of armature resistance, and reactance drops as shown vectorially in Fig 2 where

Fig 2



V is the terminal voltage per phase

I is the phase current

θ is the power factor angle between phase current and terminal voltage

E_o is the induced emf per phase

R_a is the armature resistance per phase

X_L is the armature reactance per phase.

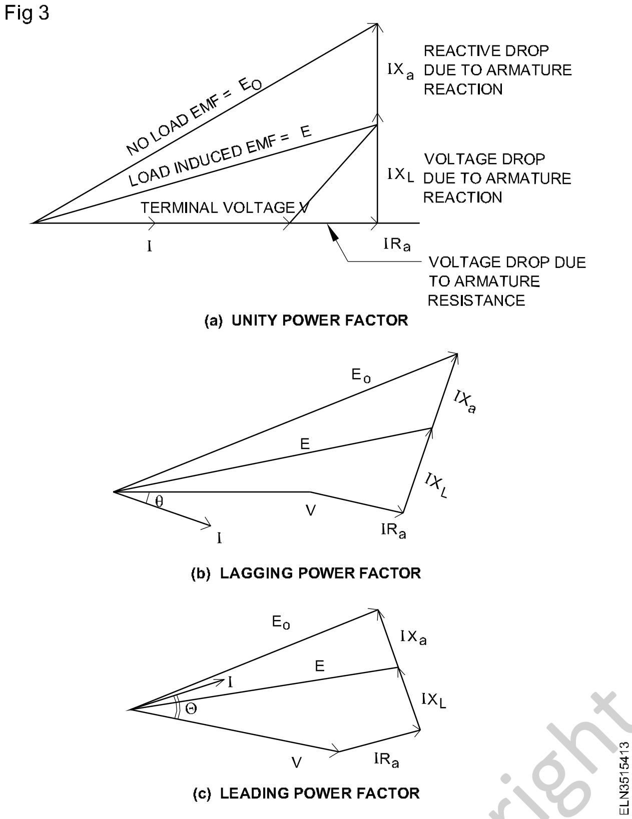
The induced emf can be calculated either vectorially or mathematically.

Mathematically the induced emf

$$E = \sqrt{(V\cos\theta + IR_a)^2 + (V\sin\theta + IX_L)^2}$$

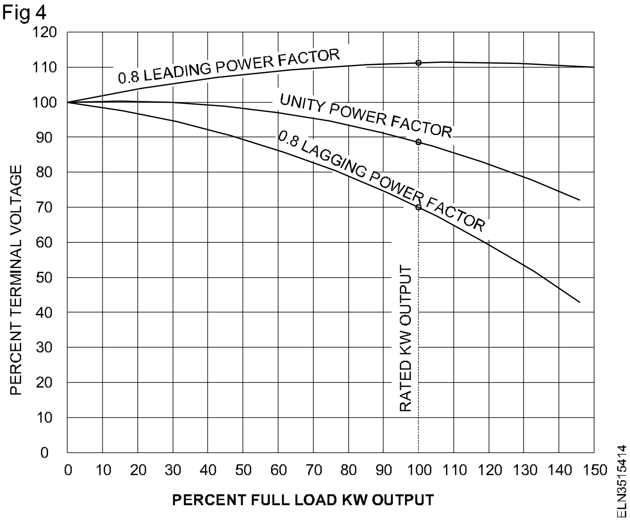
For any value of P.F. either lagging or leading, a combination of the effects of cross-magnetising, de-magnetising or magnetising takes place. In all the effects of armature reaction, it is shown vectorially as a force acting in line with the reactance drop as shown in Fig 3 by a vector IX_a. However this value is not measurable.

Fig 3



On the basis of the above information, it is found that the terminal voltage of an alternator with unity power factor load will fall slightly on load as shown in Fig 4. Also it is found that the terminal voltage falls considerably for an alternator having lagging power factor. On the contrary, with leading P.F. the terminal voltage of the alternator on load increases even beyond the no-load terminal voltage as shown in Fig 4.

Fig 4



Rating of alternators: As the power factor for a given capacity load determines the load current, and the alternator's capacity is decided on load current, the rating of the alternator is given in kVA or MVA rather than kW or MW in which case the power factor also is to be indicated along with the wattage rating.

Example: A 3-phase, star-connected alternator supplies a load of 5 MW at P.F. 0.85 lagging and at a voltage of 11 kV. Its resistance is 0.2 ohm per phase and the synchronous reactance is 0.4 ohm per phase. Calculate the line value of the emf generated.

Full load current = $I_L = \dfrac{P}{\sqrt{3}E_L\cos\theta}$

$$\frac{5 \times 1000 \times 1000}{\sqrt{3} \times 11000 \times .85} = 309 \text{ Amps.}$$

In star $I_L = I_P$

IR_a drop = 309x0.2=61.8 V

Ix_L drop = 309 x 0.4 = 123.6 V

Terminal voltage (line)=11000 V

Terminal voltage(phase) $= \dfrac{11000}{\sqrt{3}} = 6350$V

Power factor = 0.85

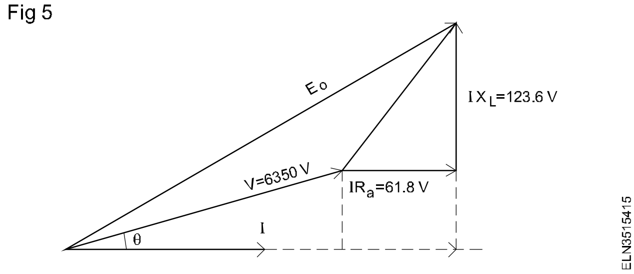
Power factor angle = $\theta = \cos^{-1}(.85)$

= Cos 31.8°

Sin θ = 0.527.

Drawing the vector, as shown in Fig 5, with the above data, we have

Fig 5



$$E_o = \sqrt{(V\cos\theta + IR_a)^2 + (V\sin\theta + IX_L)^2}$$

$$= \sqrt{(6350 \times 0.85 + 61.8)^2 + (6350 \times 0.527 + 123.6)^2}$$

= 6468.787 volts.

Line voltage = $\sqrt{3}E_P = \sqrt{3} \times 6469 = 11204$V

The voltage regulation of an alternator: The voltage regulation of an alternator is defined as the rise in voltage when the load is reduced from the full rated value to zero, with the speed and field current remaining constant. It is normally expressed as a percentage of the full load voltage.

$$\% \text{ of voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

where V_{NL} - no load voltage of the alternator

V_{FL} - full load voltage of the alternator

The percentage regulation varies considerably, depending on the power factor of the load, and as we have seen for leading P.F. the terminal voltage increases with load, and for lagging P.F. the terminal voltage falls with the load.

Example: When the load is removed from an AC generator, its terminal voltage rises from 480V at full load to 660V at no load. Calculate the voltage regulation.

$$\% \text{ regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

$$\frac{660 - 480}{480} \times 100 = 37.5\%$$

Parallel operation and synchronisation of three phase alternators - brushless alternator

Objectives: At the end of this lesson you shall be able to
- **state the necessity and conditions for paralleling of alternators**
- **explain the methods of paralleling two 3 phase alternators**
- **state the effect of changes in field excitation and speed on the division of load between parallel operation.**

Necessity for paralleling of two alternators

Whenever the power demand of the load circuit is greater than the power output of a single alternator, the two alternators to be connected in parallel

Conditions for paralleling (synchronising) of two 3 phase alternators

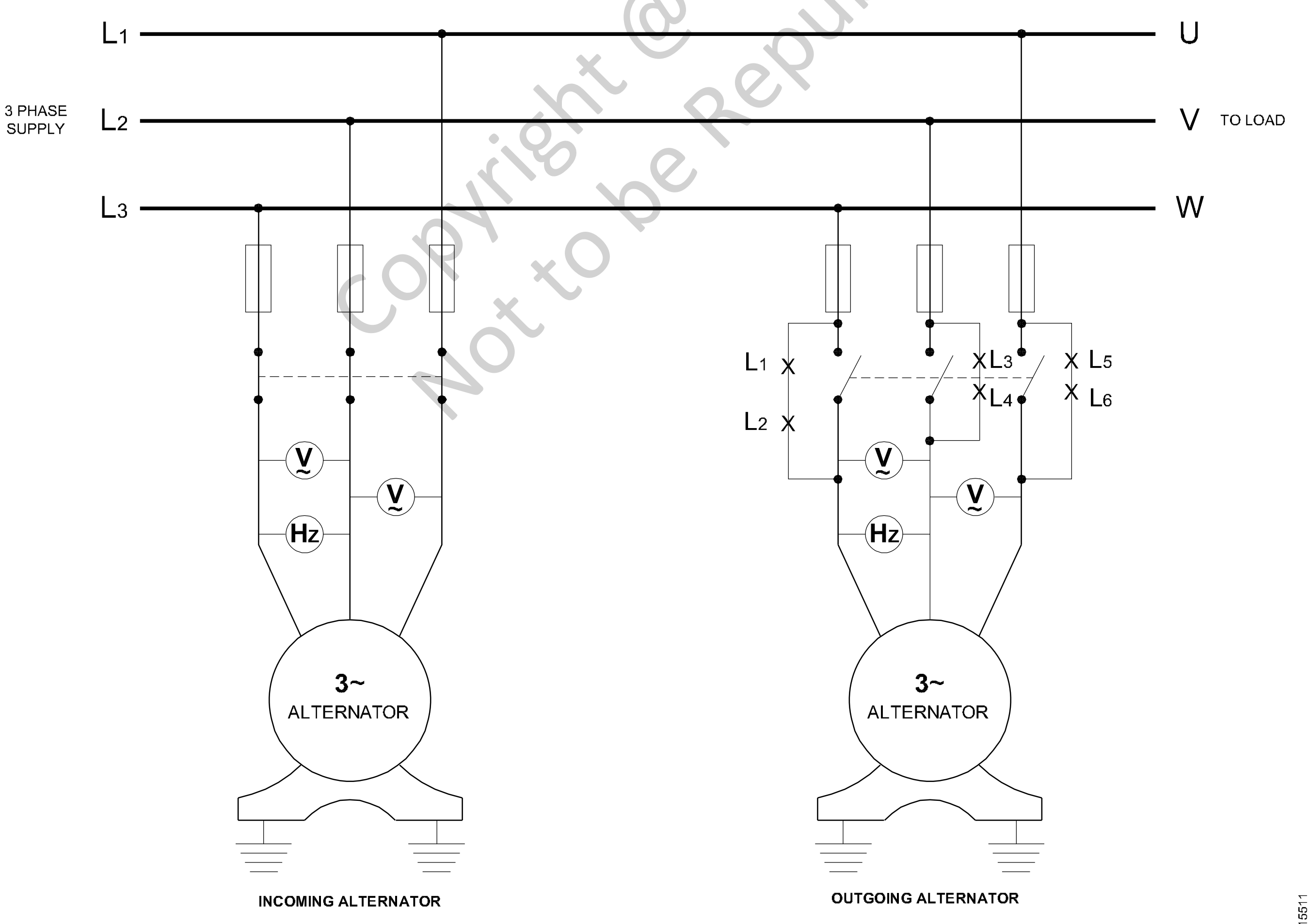
- The phase sequence of both 3 phase alternators must be same. It can be checked byusing phase sequence meters
- The output voltages of the two 3 phase alternators must be same.
- The frequency of both the alternators must be same

Dark lamp method

The following describes the method of synchronizing two alternators using the dark lamp method.

Fig 1 illustrates a circuit used to parallel two three-phase alternators. Alternator 2 is connected to the load circuit. Alternator 1 is to be paralleled with alternator 2 Three lamps rated at double the output voltage to the load are connected between alternator 2 and the load circuit as shown. When both machines are operating, one of two effects will be observed:

Fig 1



PARALLEL OPERATION OF 3 PHASE ALTERNATOR BY DARK LAMP METHOD

1 The three lamps will light and go out in unison at a rate which depends on the difference in frequency between the two alternators.

2 The three lamps will light and go out at a rate which depends on the difference in frequency between the two machines, but not in unison. In this case, the machines are not connected in the proper phase sequence and are said to be out of phase. To correct this, it's necessary to interchange any two leads to alternator 1. The machines are not paralleled until all lamps light and go out in unison. The lamp method is shown for greater simplicity of operation.

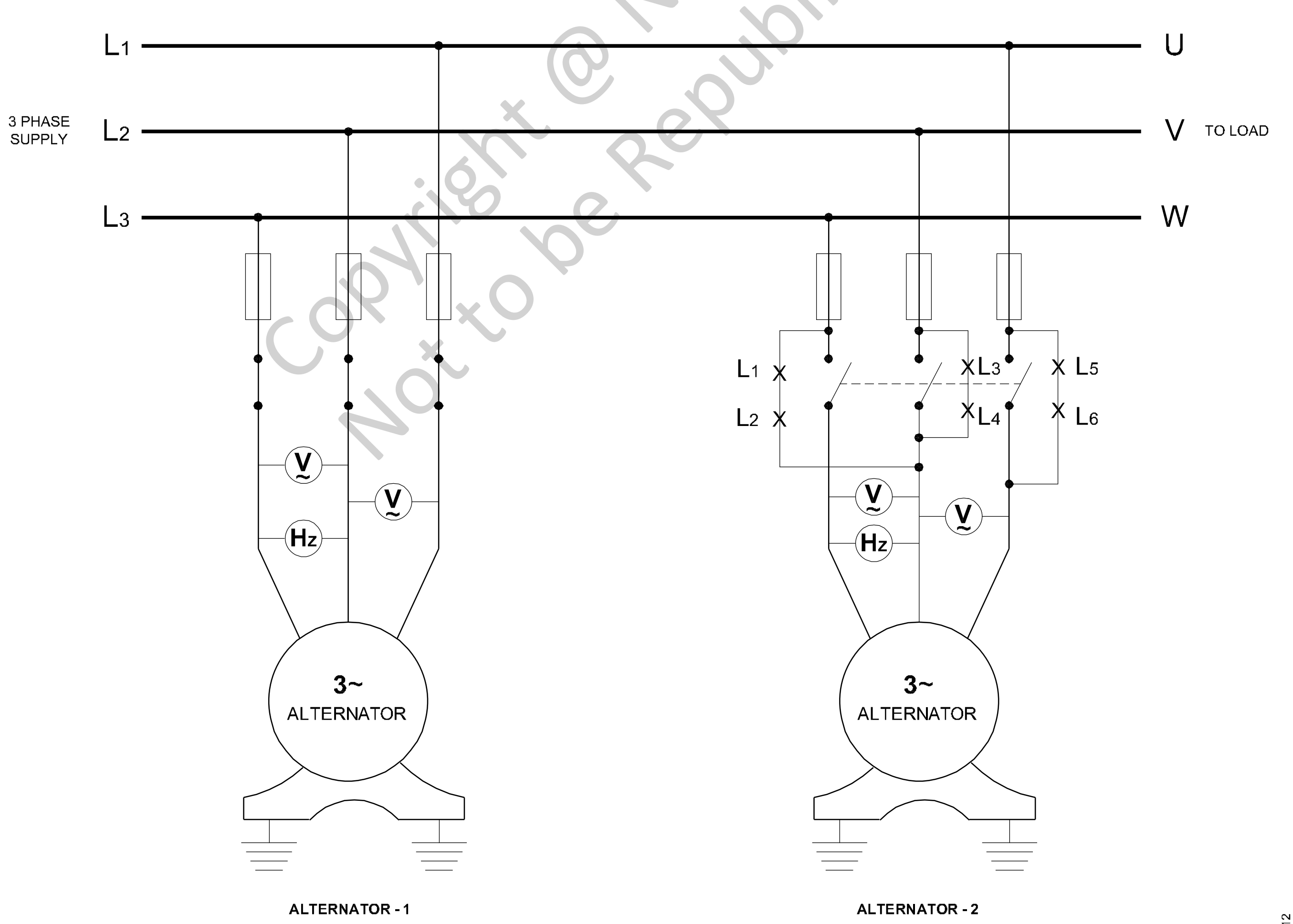
By making slight adjustments in the speed of alternator 1 the frequency of the machines can be equalized so that the synchronizing lamps will light and go out at the lowest possible rate. When the three lamps are out, the instantaneous electrical polarity of the three leads from 1 is the same as that of 2 At this instant, the voltage of 1 is equal to and in phase with that of 2 Now the paralleling switch can be closed at the middle period of the darkness of the lamps so that both alternators supply power to the load. The two alternators are in synchronism, according to the three dark method.

The three dark method has certain disadvantages and is seldom used. A large voltage may be present across an incandescent lamp even though it's dark (burned out). As a result, it's possible to close the paralleling connection while there is still a large voltage and phase difference between the machines. For small capacity machines operating at low speed, the phase difference may not affect the operation of the machines. However, when large capacity units having low armature reactance operate at high speed, a considerable amount of damage may result if there is a large phase difference and an attempt is made to parallel the units.

Two bright, one dark method (Dark and bright lamp method)

Another method of synchronizing alternators is the two bright, one dark method. In this method, any two connections from the synchronizing lamps are crossed after the alternators are connected and tested for the proper conditions for paralleling phase rotation. (The alternators are tested by the three dark method.) Fig 2 shows the connections for establishing the proper phase rotation by the three dark method. Fig 2 shows the lamp connections required to synchronize the alternator by the two bright, one dark method.

Fig 2



DARK & BRIGHT LAMP METHOD

When the alternators are synchronized, lamps 1 and 2 are bright and lamp 3 is dark. Since two of the lamps are becoming brighter as one is dimming, it's easier to determine the moment when the paralleling switch can be closed. Furthermore, by observing the sequence of lamp brightness, it's possible to tell whether the speed of the alternator being synchronized is too slow or too fast and can be connected it.

At the moment when the two lamps are full bright and one lamp is full dark, the synchronizing switch can be closed.

Now the both alternator are synchronized and share the load according to their ratings.

Synchroscope method

Objectives: At the end of this lesson you shall be able to
- **state the types of synchroscope**
- **explain the working principle of synchroscope.**

Synchroscope

A synchroscope is used to determine the correct instant for closing the switch which connects an alternator to the power station busbars. This process of connecting at the correct instant or synchronizing is necessary when an unloaded “incoming” machine is to be connected to the busbars in order to share the load.

The correct instant of synchronizing is when the busbar and the incoming machine voltages

a) are equal in magnitude,

b) are in phase and

c) have the same frequency.

For a 3-phase machine the phase sequence of the two should be the same. This condition is verified by a phase sequence indicator.

The voltages can be checked with the help of a voltmeter. The function of the synchroscope is to indicate the difference in phase and frequency of voltage of the busbar and the incoming machine.

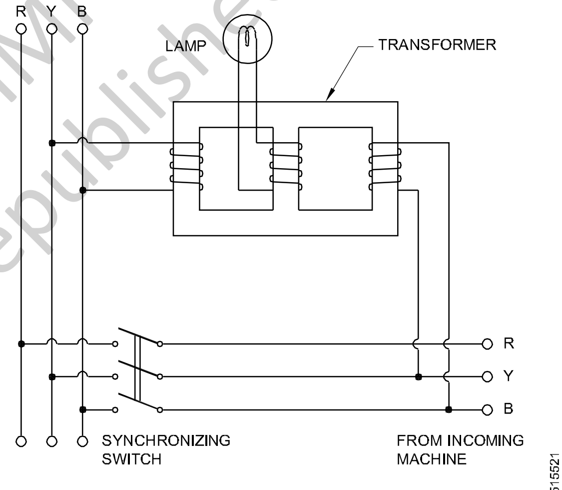
Synchroscopes may either be of **the electro-dynamometer type** or **the moving iron type**. Both types are special forms of respective power factor meters.

Electro dynamometer (Weston) type synchroscope

Fig 1 shows a simple circuit of Weston type synchroscope. it consists of three limbed transformer. The winding one of the outer limbs is excited from busbars and that on the other outer limb by the incoming machine. The winding on the central limb is connected to a lamp.

The windings on the outer limbs produce two fluxes which are forced through the central limb. The resultant flux through the central limb is equal to the phasor sum of these fluxes. This resultant flux induces an emf in the winding of the central limb. The two outer limb windings are so arranged that when the busbar and the incoming machine voltages are in phase, the two fluxes though the central limb are additive and thus emf induced in the central limb winding is maximum. Hence under these conditions the lamp glows with maximum brightness. When the two voltages are 180° out of phase with each other the resultant flux is zero and hence no emf is induced in the central limb winding, with the result the lamp does not glow at all and is dark. If the frequency of the incoming machine is different form that of the busbars, the lamp will be alternately bright and dark or in other words the lamp flickers. The frequency of flickering is equal to the difference in frequencies of the busbar and the incoming machine.

Fig 1



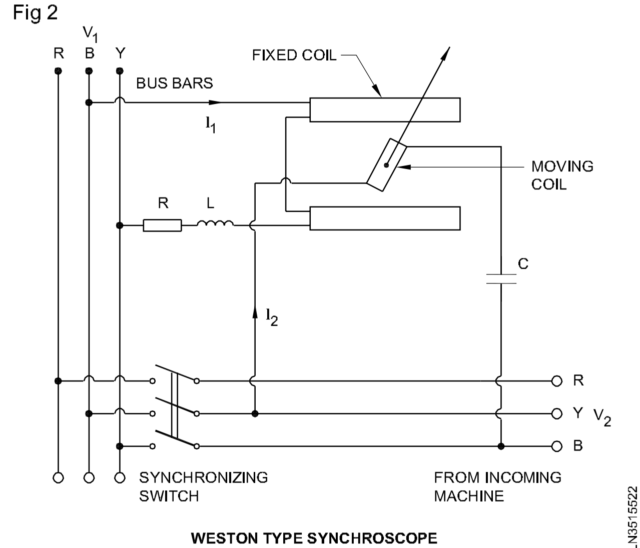
WESTON TYPE SYNCHROSCOPE

The correct instant of synchronizing is when the lamp is flickering at a very slow rate and is at its maximum brightness.

One of the defect of this simple circuit is that it does not indicate whether the incoming machine is too fast or too slow. This defect can be corrected by introducing an electrodynamometer type instrument into the circuit shown in Fig 2.

The electrodynamometer instrument consists of a fixed coil divided into two parts. The fixed coil is designed to carry a small current and is connected in series with a resistance across the busbars. The moving coil is connected in series with a capacitor across the terminals of the incoming machine. The instrument is provided with control springs which act as current leads for the moving coil. The shadow of the pointer is thrown on an opal glass.

Fig 2

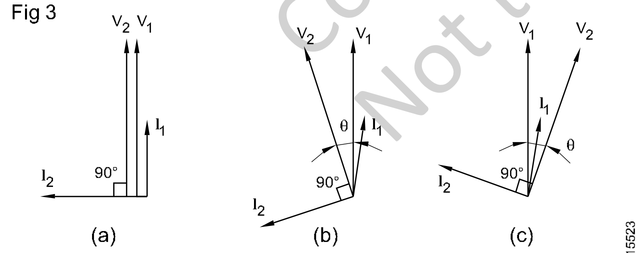


WESTON TYPE SYNCHROSCOPE

When the two voltages are in phase with each other, current I_1 and I_2 in fixed and moving coils respectively will be in quadrature with each other (Fig 3a) and therefore there will be no torque on the instrument. The control springs are so arranged that the pointer is in vertical position under this condition. Also the lamp is at its maximum brightness and the pointer is silhoueted against the opal glass.

If the incoming machine voltage V_2 is leading the busbar voltage V_1 and the incoming machine slightly too slow, the conditions of the circuit will slowly change from those shown in Fig 3b to those shown in Fig 3c. Then the torque will change from $KI_1I^2 \cos (90° + \theta)$ i.e., from a negative value through zero to a positive value. And during this period lamp will be bright and the pointer will be seen to move from left hand side of dial through the vertical position to the right and side of dial. The dial can thus be marked with directions Fast and Slow as shown in Fig 4.

Fig 3



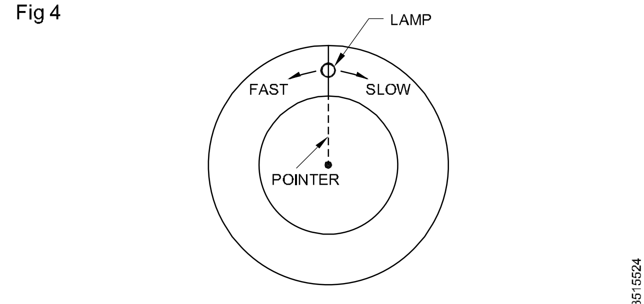
PHASOR DIAGRAMS

During this period when the voltages V_1 and V_2 are 180° out of phase the pointer will move back. But it will not be visible as under these conditions as the lamp is dark.

The visible movement of the pointer is therefore a series of traverses on the dial in one direction. If the incoming machine is too fast the visible traverses will be in the other direction. The correct instant of synchronizing is when the pointer is visible at its central position and is moving very slowly.

It may be observed that in order to have an exact quadrature relationship between currents I_1 and I_2 when voltages V_1 and V_2 are in phase, is obtained only if small inductance L is introduced in the fixed coil circuit.

Fig 4

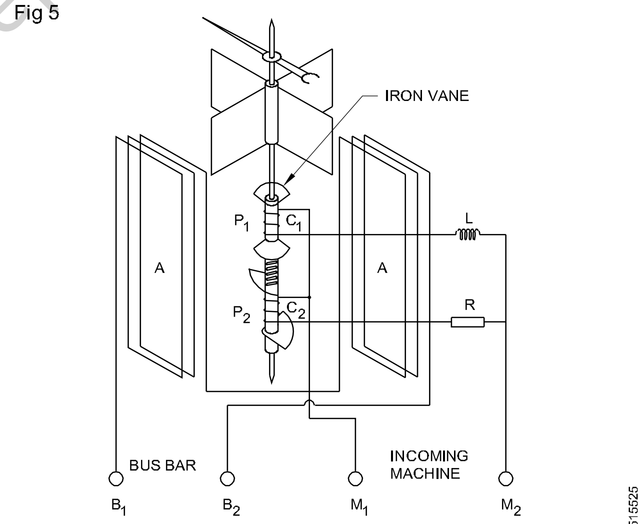


DIAL OF WESTON SYNCHROSCOPE

Moving Iron synchroscope

Fig 5 shows the construction of a moving iron synchroscope which is due to Lipman. It has a fixed coil divided into two parts. This fixed coil A is designed for a small value of current and is connected in series with a resistance across two phases of the busbar. There are two iron cylinders C_1 and C_2 mounted on the spindle. Each iron cylinder is provided with two iron vanes whose axes are 180° out with each other. The iron cylinders are excited by two pressure coils P_1 and P_2 which are connected to two phases of the incoming machine. One of the coils has a series resistance and the other has a series inductance. This is done in order to create an artificial phase difference of 90° between the currents of two pressure coils. There are no control springs. The instrument is provided with a pointer which moves over a dial marked Fast and Slow.

Fig 5



NALDER LIPMAN TYPE SYNCHROSCOPE

When the frequency of incoming machine is the same as that of busbars, the instrument behaves exactly like the corresponding form of the power factor meter. The deflection of the pointer from the plane of reference is equal to phase difference between the two voltages.

However if the frequencies of the two voltages are different, the pointer rotates continuously at a speed corresponding to difference in frequency of the two voltages. The direction of rotation depends whether the incoming machine is too fast or too slow.

Brushless alternator

Objectives: At the end of this lesson you shall be able to
- **state the principle and basic theory of brushless alternator**
- **explain the construction of brushless alternator**
- **describe the working of 3 phase brushless alternator.**

Principle of brushless alternator

In all alternators, voltage may be generated by rotating a coil in the magnetic field or by rotating a magnetic field within a stationary coil wire. To produce voltmeter either the coil is moving or the magnetic field is moving. Either configuration works equally well and both are used separately or in combination depending on mechanical, electrical and other objectives.

In the case of brushless alternator both combination is used together in one machine.

The stationary part of an alternator is called the stator and the roating part is called the rotor. The coils of wire used to produce a magnetic field are called the field winding and the coils that the power are called the armature winding. Here both armature and field winding used as rotor as well as stator.

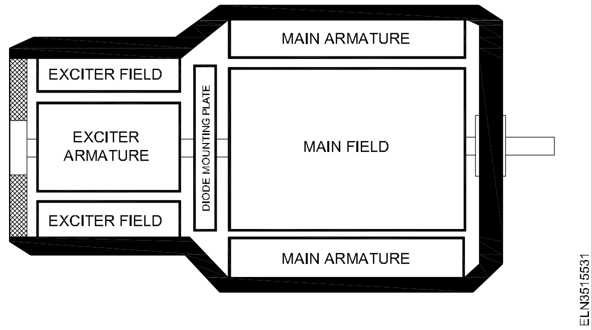
Working of brushless alternator

Brushless alternators having two part one is excitation alternator part and another is main alternator part (Fig 1)

Excitation alternator

The armature is rotor and field winding is stator. When it starts rotating a voltage is generatred in Exciter armature which gives current the main field to produce magnetic field in main alternator.

Fig 1



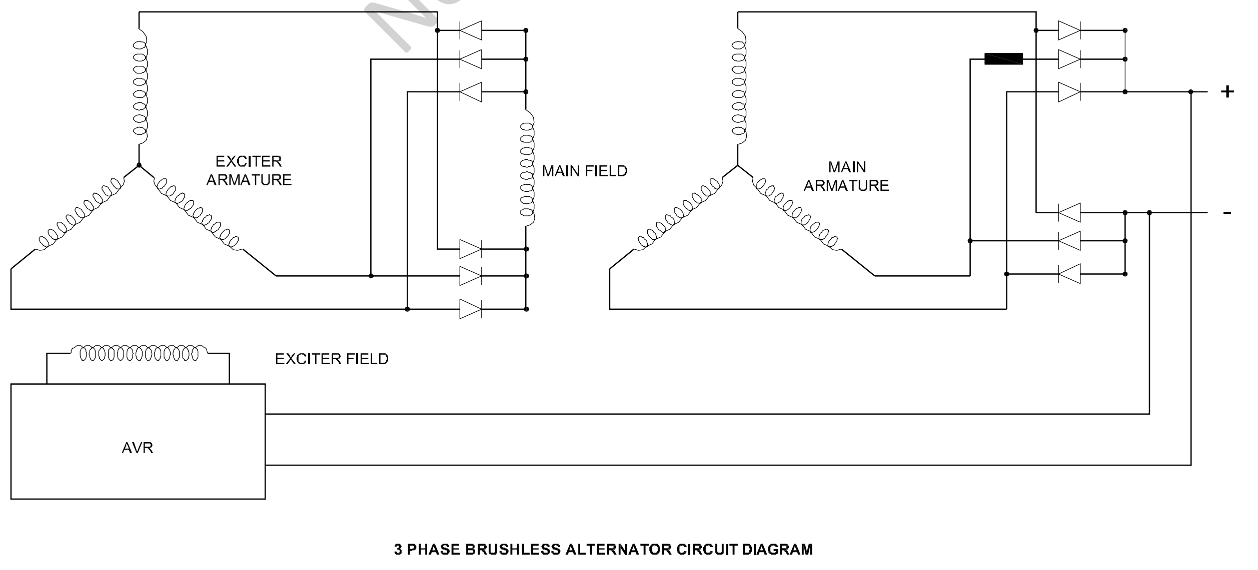
Main alternator

Here main field is rotor and armature is stator so the supply can be taken out directly. No brushes required. Voltage produced in the exciter armature produce a magnetic field on the main alternator rotor. When this magnetic field cuts the main armature, a potential difference produced. Here the voltage produced can be regulated by exciter field current (Fig 2).

Basic theory

When an electric current is passed through a coil of wire, a magnetic field is produced (an electromagnet). Conversely, when a magnetic field is moved through a coil of wire, a voltage is induced in the wire. The induced voltage becomes a current when the electrons have some place to go such as into a battery or other load. Both of these actions take place in alternators, motors and generators or dynamos.

Fig 2



3 PHASE BRUSHLESS ALTERNATOR CIRCUIT DIAGRAM

Construction

A brushless alternator is composed of two alternators built end-to-end on one shaft. Smaller brushless alternators may look like one unit but the two parts are readily identifiable on the large versions. The larger of the two sections is the main alternator and the smaller one is the exciter. The exciter has stationary field coils and a rotating armature (power coils). The main alternator uses the opposite configuration with a rotating field and stationary armature

Exciter

The exciter field coils are on the stator and its armature is on the rotor. The AC output from the exciter armature is fed through a set of diodes that are also mounted on the rotor to produce a DC voltage. This is fed directly to the field coils of the main alternator, which are also located on the rotor. With this arrangement, brushes and slip rings are not required to feed current to the rotating field coils. This can be contrasted with a simple automotive alternator where brushes and slip rings are used to supply current to the rotating field

Main alternator

The main alternator has a rotating field as described above and a stationary armature (power generation windings). This is the part that can be confusing so take note that in this case, the armature is the stator, not the rotor.

With the armature in the stationary portion of the alternator, the high current output does not have to go through brushes and slip rings. Although the electrical design is more complex, it results in a very reliable alternator because the only parts subjects to wear are the bearings.

Three-phase brushless alternator

A three phase alternator has a minimum of 3 sets of windings spaced 120^0 apart around the stationary armature (stator). As a result, there are 3 outputs from the alternator and they are electrically spaced 120^0 out of phase with each other. A multi-pole design will have multiple sets of 3 windings. These sets of windings (poles) are spaced evenly around the circumference of the machine. The more poles there are , the slower the alternator turns for a given voltage and frequency. More poles increase the complexity of the alternator and that in part accounts for the higher price of slower speed versions.

Other than in single-phase power plants, most alternators, including the automotive type, generate 3-phase power. A three-phase AC alternator will not have any diodes in it. If the output is DC, it will probably have 6 diodes to convert the output from the main alternator to DC. This is the configuration used in automotive alternators. A 3-phase brushless alternator may have 4 or 6 diodes on the rotor for the exciter output in addition to the diodes that may be on the stator

There are two ways that 3-phase machines can be wired. One is the delta (triangle) configuration with one wire coming off each "point of triangle". The other is the wye (Y) or star configuration. They have one wire from each branch of the "Y" and in some cases a 4" common wire is added from the centre/centre point of the "Y" (the common connection point between the windings)

Multiple voltage machines will have additional wires to allow them to be configured for the desired system voltage.

Synchronous motor

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of synchronous motor**
- **explain the constructional details of synchronous motor**
- **state the different methods of starting a synchronous motor**
- **compare the features of synchronous motor and induction motor**
- **state the applications of synchronous motors.**

Synchronous motor

An alternator which runs as a motor is called as synchronous motor. 3-phase AC supply is required for the AC winding and suitable DC voltage is required for the field winding excitation. The synchronous motors are not self starting.

Working principle

When the stator winding of a three-phase synchronous motor is connected to a three-phase supply, a rotating field is set up in the machine. If the rotor is then started in the direction of rotation of the rotating field, the north pole of the rotating field draws the south pole of the rotor with it, and the south pole of the rotating field draws the north pole of the rotor. The rotor continues to turn at a speed of rotation which can be calculated from the familiar formula, Ns = 120f/p. It turns synchronously with the rotating field. The machine is now working as a motor.

Construction

In construction, synchronous motors are almost identical with the corresponding alternator, and consist essentially of two elements.

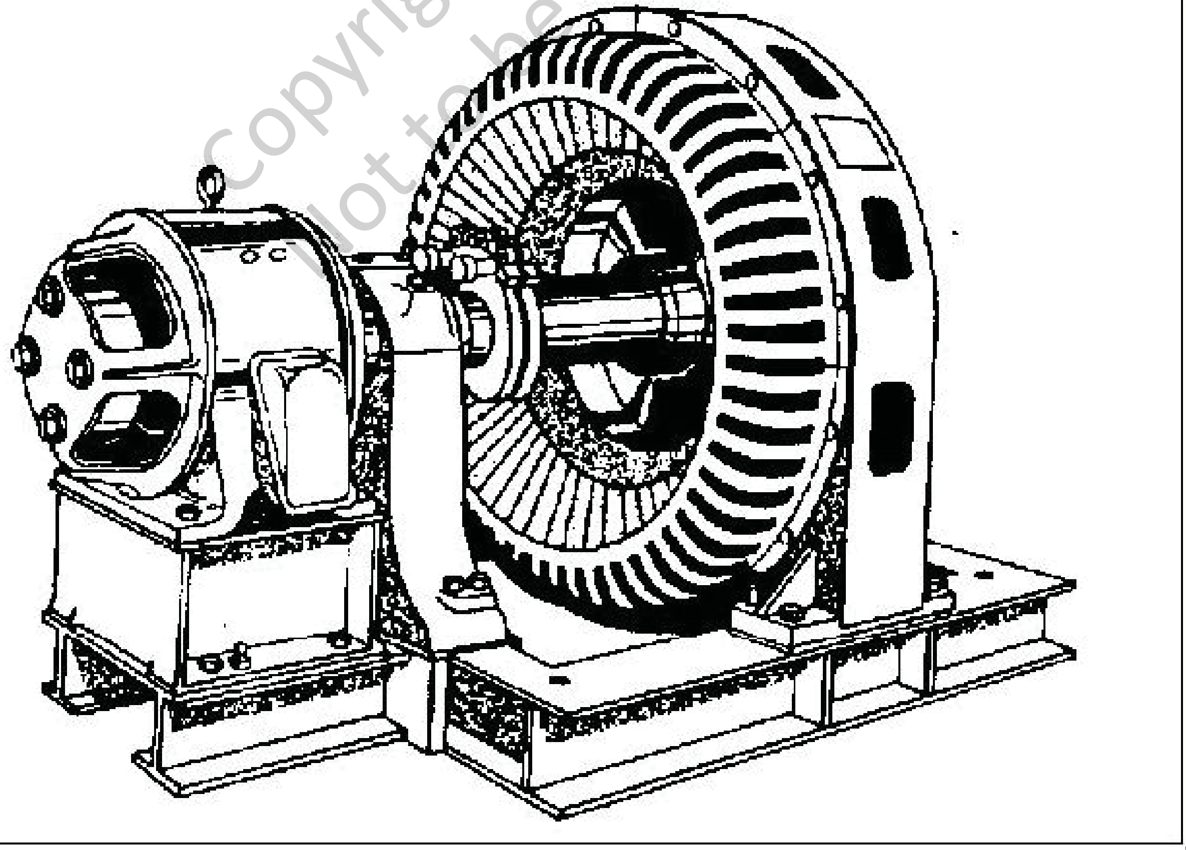
1 Stator (armature)

2 Rotor (field)

A synchronous motor may have either a revolving armature or a revolving field, although most synchronous motors are of the revolving field type. The stationary armature which is wound for the same number of poles as rotor is attached to the stator frame while the field magnets are attached to a frame which revolves with the shaft.

The field coils are excited by direct currents, either from a small DC generator (usually mounted on the same shaft as the motor and called as an exciter), or from other DC source. Figure 1 shows a directly connected exciter.

Fig 1



Methods of starting a synchronous motor

1 By using a pony motor

2 By using damper windings

3 By synchronisation

1 By using a pony motor

A three-phase current is fed to the stator winding of three-phase synchronous machine and its rotor is started by a pony (starting) motor, having same number of poles as that of synchronous motor. The small induction motor coupled to the synchronous machine for starting purpose is called the pony motor. The pony motor brings the motor very close to the synchronous speed, then the DC is supplied to the field and the switch of the pony motor is switched 'off'. Then the motor pulls itself to the synchronous speed.

2 By using damper windings

The damper winding is just like squirrel cage winding consisting of copper embedded in the pole shoe and short circuited at both sides.

Action of damper winding at start

While starting a synchronous motor set up a rotating magnetic field that cuts the cage (damper) winding on the field system (rotor) and induces current in it. A torque is developed and the motor runs to a speed a little less than that of synchronous speed as an induction motor. The DC excitation is then switched on and definite poles on the rotor are set up. Now the two sets of poles suddenly lock each other by which the motor pulls into synchronous speed.

While starting a synchronous motor provided with damper windings, first the main field windings is short circuited and AC supply is switched on to stator terminals through suitable starter. The motor starts up and when a steady speed is reached DC excitation is applied after removing the short on the field winding. If the excitation is sufficient the machine will be pulled into synchronism.

3 By synchronisation

Initially the synchronisation motor is run as an alternator and it is synchronised with the main supply bus by following one of the synchronisation methods. After synchronisation the prime mover is disconnected. Now the alternator, ie the synchronous motor continues to run at synchronous speed by drawing power from supply mains.

Comparision of Synchronous and Induction motor

	Aspects	Synchronous motor	Induction motor
1	Speed	Synchronous speed constant is independent of load condition.	Less than synchronous speed. Decreases with increasing load.
2	Power factor	Operates at all power factors whether lagging or leading.	Operates at only lagging power factor.
3	Efficiency	Very good	Good
4	Cost	Costlier	Cheaper
5	Starting	Not self-starting	Self-starting
6	Speed control	No question	Can be controlled to small units.
7	Application	Used for mechanical load and also to improve power factor as synchronous condenser.	Limited to supply of mechanical load.

Application

Synchronous motors are employed exclusively as power factor correction devices, they are termed as synchronous condenser, because the effect on the power system is the same as that of a static capacitor which also produces a leading current.

1 Induction motors of all types particularly when they are underloaded

2 Power transformers and voltage regulators

3 Arc welders

4 Induction furnaces and heating coils

5 Choke coils and magnetic systems and

6 Fluorescent and discharge lamps, neon signs, etc.

Causes of low power factor

The principle cause of a low power factor is due to the reactive power flowing in the circuit. The reactive power depends on the inductance and capacitance of the apparatus.

The disadvantages of low power factor are as follows

1 Overloading of cables and transformer

2 Decreased line voltage at point of application

3 Inefficient operation of plant and

4 Penal power rates

The advantages of high power factor are as follows

1 Reduction in the current

2 Reduction in power cost

3 Reduced losses in the transformers and cables

4 Lower loading of transformers, switch gears, cables etc.

5 Increased capability of the Power system (additional load can be met without additional equipment)

6 Improvement in voltage conditions and apparatus performance and

7 Reduction in voltage dips caused by welding and similar equipment

Power factor control

If the rotor excitation is varied when the motor is running on load, the load angle and stator current will change, but the speed, load (and hence input power) remain the same.

The power factor of the motor can therefore be adjusted by means of the excitation. Unity power factor operation is possible over a wide range of loads and by using a high rotor excitation the motor can operate at leading power factor. This is particularly valuable with a large synchronous motor, which can be used to compensate for the lagging power factor of other induction motors on the same site.

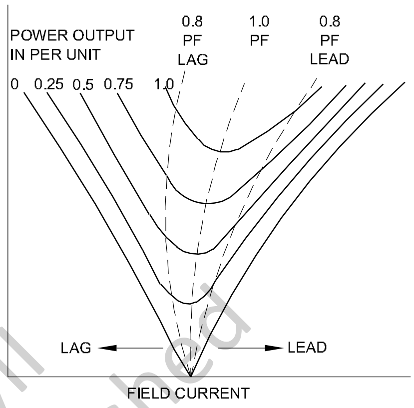
Instant speed application

As the efficiency of a synchronous motor is high, these motors are well suited for loads where constant speed is required.

V Curves of synchronouos machines

V-Curve of a synchronous machine shows the relation between the armature current and excitation current, when the load and input voltage to the machine is constant. At a constant load, if excitation is changed the power factor of the machine changes, i.e. when the field current is small (machine is under-excited) the P.F. is low and as the excitation is increased the P.F. improves so that for a certain field current the P.F. will be unity and machine draws minimum armature current. This is known as normal excitation. If the excitation is further increased the machine will become over-excited and it will draw more line current and P.F. becomes leading and decreases. Therefore, if the field current is changed keeping load and input voltage constant, the armature current changes to make VIcosθ constant. Variation of armature current with excitation are called 'V' curves (Fig 2).

Fig 2



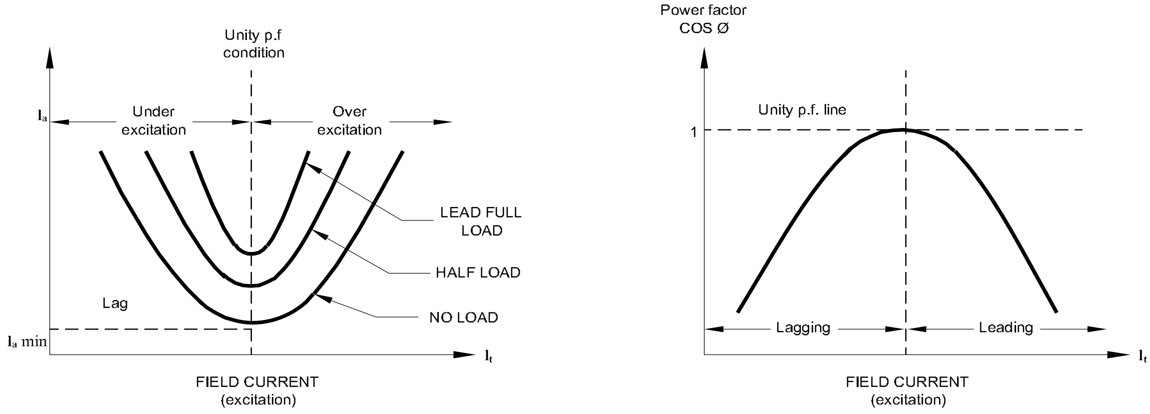
The Fig 3 shows V and inverse V curves of synchronous motor.

Effect of Changing Excitation on Constant load

As shown in Fig. (4a), suppose a synchronous motor is operating with normal excitation (E_b = V) at unity p.f. with a given load. If R_a is negligible as compared to X_S, then I_a lags E_R by 90° and is in phase with V because p.f. is unity. The armature is drawing a power of V.I_a per phase which is enough to meet the mechanical load on the motor. Now, let us discuss the effect of decreasing or increasing the field excitation when the load applied to the motor remains constant

Fig 3

V and inverse V curve of Synchronous Motor



a) Excitiation Decreased

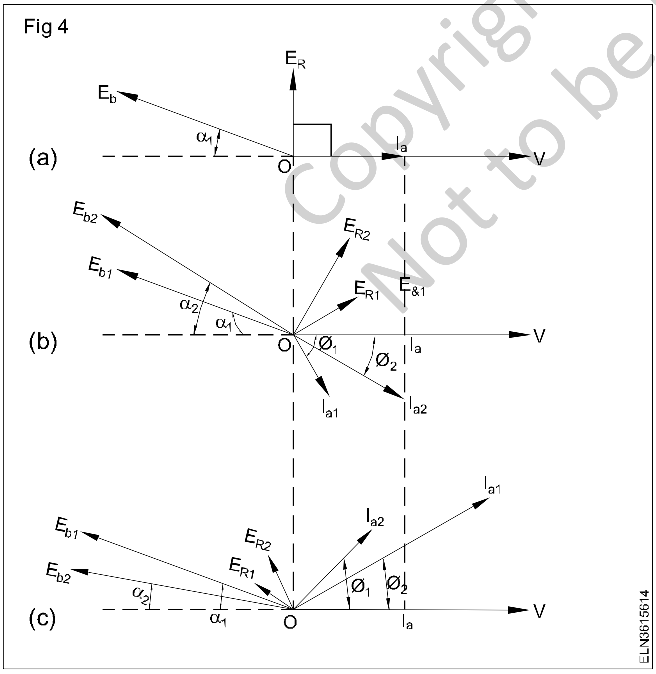
As shown in Fig (4b), suppose due to decrease in excitation, back e.m.f. is reduced to E_{b1} at the same load angle α_1. The resultant voltage E_{R1} causes a lagging armature current I_{a1} to flow. Even though I_{a1} is larger than I_a in magnitude it is capable of producing necessary power $V.I_a$ for carrying the constant load because I_{a1} cos ϕ_1 component is less than I_a so that $V.Ia_1 \cos \phi_1 < V.I_a$.

Hence, it becomes necessary for load angle to increase from α_1 to α_2. It increases back e.m.f. from E_{b1} to E_{b2} which, in turn, increases resultant voltage from E_{R1} to E_{R2}. Consequently, armature current increases to I_{a2} whose in-phase component produces enough power ($VI_{a2} \cos \phi_2$) to meet the constant load on the motor.

b) Excitation Increased

The effect of increasing field excitation is shown in Fig 4c where increased E_{b1} is shown at the original load angle α_1. The resultant voltage E_{R1} cause a leading current I_{a1} whose in-phase component is larger than I_a. Hence, armature develops more power than the load on the motor. Accordingly, load angle decrease from α_1 to α_2 which decreases resultant voltage from E_{R1} to E_{R2}. Consequently, armature current decreases from I_{a1} to I_{a2} whose in-phase component $I_{a2} \cos \phi_2 = I_a$. In that case, armature develops power sufficient to carry the constant load on the motor.

Hence, we find that variations in the excitation of a synchronous motor running with a given load produce variations in its load anlge only.



Different Torques of a Synchronous Motor

Various torques associated with a synchronous motor are as follows:

1 starting torque

2 running torque

3 pull-in torque and

4 pull-out torque

a) Starting Torque

It is the torque (or turning effort) developed by the motor when full voltage is applied to its stator (armature) winding. It is also sometimes called breakaway torque. Its value may be as low as 10% as in case of centrifugal pumps and as high as 200 to 250% of full-load torque as in the case of loaded reciprocating two-cylinder compressors.

b) Running Torque

As its name indicates, it is the torque developed by the motor under running conditions. It is the driven machine. The peak horsepower determine the maximum torque that would be required by the driven machine. The motor must have a break-down or a maximum running torque greater than this value in order to avoid stalling.

c) Pull-in Torque

A synchronous motor is stated as induction motor till it runs 2 to 5% below the synchronous speed. Afterwards, excitation is switched on and the rotor pulls into step with the synchronously - rotating stator field. The amount of torque at which the motor will pull into step is called the pull-in torque.

d) Pull-out- Torque

The maximum torque which the motor can develop without pulling out of step or synchronism is called the pull-out torque.

Normally, when load on the motor is increased, its rotor progressively tends to fall back in phase by some angle (called load angle) behind the synchronously-revolving stator magnetic field though it keeps running synchronously. Motor develops maximum torque when its rotor is retarded by an angle of 90° (or in other words, it has shifted backward by a distance equal to half the distance between adjacent poles). Any further increase in load will cause the motor to pull out of step (or synchronism) and stop.

MG set and rotary converter and inverter

Objectives: At the end of this lesson you shall be able to
- **list the advantages of direct current over alternating current**
- **list the methods of converting AC to DC**
- **state the advantages and disadvantages of MG-set**
- **describe the rotary converter construction and its working.**

The AC system has been adopted universally for the generation, transmission and distribution of electric power. It is more economical than a DC system of generation, transmission and distribution. There are applications where DC is either essential or more advantageous over AC.

DC is essential in the following applications.

- Electrochemical process such as electroplating, electro-refining etc.
- Storage battery charging.
- Arc lamp for search light and cinema projectors.

Direct current is more advantageous in the following applications.

- Traction purposes - DC series motor.
- Operating telephones, relays, time switches.
- Rolling mills, paper mills, elevators where fine speed control, frequent starting against heavy torque and rotation in both directions are required, DC motors are more suitable.

The conversion of AC to DC has become a necessity due to the above reasons.

Methods : The methods of conversion of AC to DC

- Motor-generator set
- Rotary converter
- Mercury arc rectifier
- Metal rectifiers
- Semi-conductor diodes and SCR

Out of the above five the motor generator sets and semi-conductor rectifiers are now mostly in use. The other types have become obsolete for obvious reasons.

Motor generator set : It consists of a 3-phase AC motor directly coupled to a DC generator. In the case of larger units, the AC motor is invariably a synchronous motor and the DC generator is usually compound.

Advantages

1 The DC output voltage is practically constant. The output (DC) voltage is not affected by changes in AC supply voltage.

2 DC output voltage can be easily controlled by the shunt field regulator.

3 The M.G set can also be used for power factor correction, where synchronous motor is used for driving the generator.

Disadvantages

1 It has a comparatively low efficiency.

2 It requires more floor space.

Rotary or synchronous converter

A rotary converter is used when a large DC power is required. It is a single machine with one armature and one field. It combines the function of a synchronous motor and a DC generator. It receives alternating current through a set of slip rings mounted on one side of the armature rotating synchronously (N_s = 120 f/P) and delivers direct current from the opposite end through the commutator and brushes.

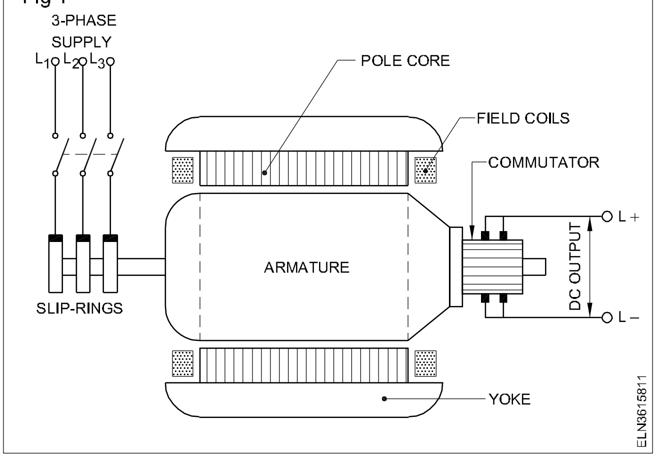
Construction : In general construction and design, a rotary converter is more or less like a DC machine. It has interpoles for better commutation. Its commutator is larger than that of a DC generator of the same size because it has to handle a larger amount of power.

The only added feature are -

- a set of slip-rings mounted at the end opposite to the commutator end
- dampers in the pole faces as in a synchronous motor.

A simple sketch illustrating the main parts of a rotary (synchronous) converter is shown in Fig 1.

Fig 1



The fact that the emf induced in the armature conductors of a DC generator is alternating and that it becomes direct (unidirectional) only due to the rectifying action of the commutator, the slip-rings are to be connected to some suitable points on the armature winding to use this machine as an alternator.

The rotary converter armature is mostly lap wound. The number of parallel paths in the armature is equal to the number of poles. Therefore the number of equi-potential points on the armature is equal to the number of pairs of poles. The number of tappings taken to each slip-ring is, therefore, equal to the number of pairs of poles. For a 3-phase lap wound rotary converter, it is essential that the number of armature conductors per pole should be divisible by 3.

Operation : In its normal role, the machine is connected to a suitable AC supply through the slip-rings and it delivers direct current at the commutator. In this application the machine runs as a synchronous motor receiving AC power from the slip-ring side and as viewed from the commutator end, it runs as a DC generator delivering DC power.

Mercury arc rectifier : In general, a rectifier may be defined as a device which converts a fluctuating current of zero mean value (alternating current) into a fluctuating current of finite mean value (direct current). It is a device for converting AC to DC.

It has many advantages over the rotary converter and M.G.set. With the invention of semiconductor diodes which is more advantageous than mercury arc rectifier, nowadays no one wants to use mercury arc rectifier.

The comparison of the M.G.set, rotary converter and rectifier with regards to certain specific aspects are given in the tabular form below.

Converter Aspects for comparison	Rectifier	M.G.Set	Rotary converter
Machinery	No moving/rotating	Two machines i.e. one AC another one DC generator	Single machine
Cost	Cheap	Very costly	Costly
Noise	Noiseless	Noisy	Noisy
Efficiency	Good, as high as 95%	Very low because of two rotating machines	Low
Maintenance cost	Low	High	High
Overloading capacity	Can be overloaded up to 50%	Cannot be overloaded	Cannot be overloaded
Power factor of AC	Low power factor	Low power factor	Good power factor
Attention during its operation	Constant attention required	Less attention required	No attention required
Space required	High	Very high	Low

Maintenance of MG set

Objective: At the end of this exercise you shall be able to
- **list out the points to be considered for maintenance of MG set.**

The MG set must be maintained by inspecting electrically and mechanically. The following points to be considered while carrying out maintenance.

Electrical inspection list

- General cleaning of all electrical components and control panels
- Check/rectify motor insulation resistance by megger
- Check/rectify earth wiring
- Check/rectify main switch fuses
- Check/rectify stator, brushes etc.
- Check/rectify bearings of motor, rotating parts and use oil grease for proper lubrication
- Check/rectify/check starting panel
- Check/rectify over load relays
- Check/rectify loose connections and tighten them
- Replace damaged flexible conductors and cables
- Check/rectify the control system

- Replace the carburized non operative contactor if necessary.

Carry out the maintenance work in MG set by referring the mechanical inspection list and lubrication instruction given below

Mechanical inspection list

- Clean thoroughly and do visual inspection
- Check/rectify motor couplings and bearings
- Check for tightness of coupling, checking formulation both,
- Checking of pipeline flanger
- Check/rectify machine for functional operation and verify with the operator
- Lubrication, Maintenance prints
- Check/rectify the bearings for the lubrication
- Use oil gun/grease to lubricate the same.

A separate register is to be maintained by the maintenance authority to keep the records for each maintenance on all working days.

Attend the breakdown maintenance of mechanical and electrical nature, during the operation of the MG set.

Project work

Objectives: The Trainees/Participants shall be able to
- **prepare project report of the project selected**
- **draw circuit diagram/layout diagram**
- **list the specification of the material/component to be procured**
- **list the plan of action to be executed**
- **develop the project, complete and submit it.**

Selection of project and its execution

- Discuss in details of the project - necessity, marketing facility, cost involvement, availability of material and hope of future development and expansion.
- Collect all materials and tools required to start the work.
- The project has to be agreed by all the members involved and get the approval of the concerned authority.
- Prepare an action oriented plan to execute the work within a stipulated time table which is to be accepted by all the members and also the approval of instructor concerned.
- Complete the project as per the plan.
- Test, calibrate and finish the project as per the plan and execution.
- Keep the project with optimum finish and good workmanship.

Preparation of project report

- Report should start with an introductory information connected with a known subject and highlight its importance in present conditions.
- A survey to be conducted regarding the marketing and its commercial applications.
- A brief working principle and its operation has to be illustarted in the report.
- Highlight the maintenance, repair and periodic servicing etc in the report.
- Costing should be competitive and affordable to the concerned without any reservations.
- Project should have the flexibility for further expansion to an advanced version without major changes.
- Report should be listed with reference books and website details.