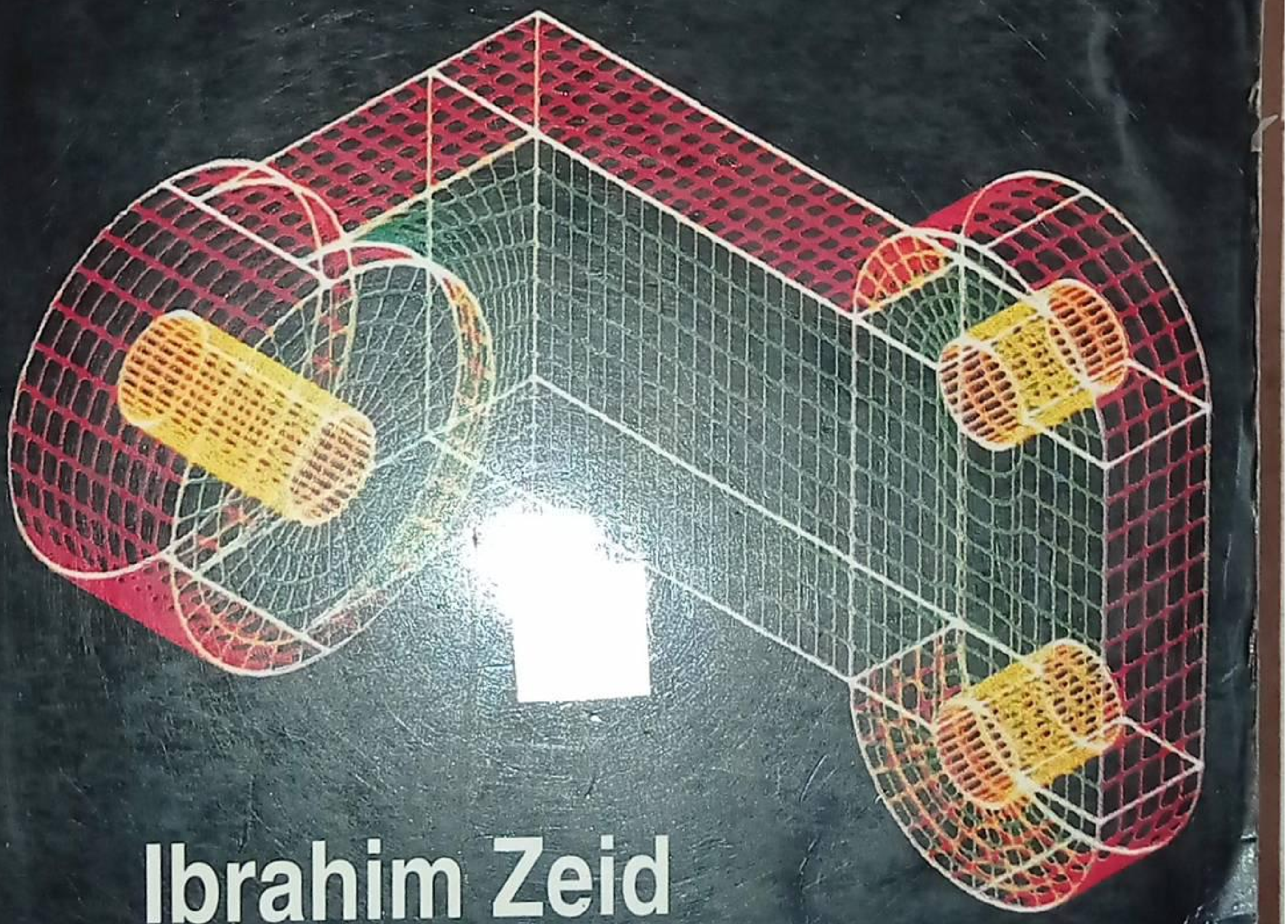
CAD/CAM

Theory and Practice



Ibrahim Zeid

Tata McGraw-Hill
Edition

Scanned by TapScanner

CONTENTS

Preface xxiii

Part I Overview of CAD/CAM Systems

Chapter 1 Introduction 3

1.1 CAD/CAM Contents and Tools 3
1.2 History of CAD/CAM Development 8
1.3 CAD/CAM Market Trends 10
1.4 Definition of CAD/CAM Tools 14
1.5 Industrial Look at CAD/CAM 17
1.6 Book Approach 20
1.7 Book Organization 21
Problems 23
Bibliography 23

Chapter 2 CAD/CAM Hardware 25

2.1 Introduction 25
2.2 Types of Systems 27
2.2.1 Mainframe-Based Systems 28
2.2.2 Minicomputer-Based Systems 30
2.2.3 Microcomputer-Based Systems 31
2.2.4 Workstation-Based Systems 36
2.3 CAD/CAM Systems Evaluation Criteria 36
2.3.1 System Considerations 39
2.3.2 Geometric Modeling Capabilities 40
2.3.3 Design Documentation 41
2.3.4 Applications 41

Scanned by TapScanner

2.4 Input Devices 42
2.4.1 Keyboards 44
2.4.2 Lightpens 47
2.4.3 Digitizing Tablets 48
2.4.4 Mouse Systems 52
2.4.5 Joysticks, Trackballs, and Thumbwheels 52
2.4.6 Other Input Devices 54
2.5 Output Devices 55
2.5.1 Graphics Displays 56
2.5.2 Hardcopy Printers and Plotters 65
2.6 Hardware Integration and Networking 69
2.7 Hardware Trends 72
Problems 80
Bibliography 82

Chapter 3 CAD/CAM Software 84
3.1 Introduction 84
3.2 Graphics Standards 87
3.3 Basic Definitions 90
3.3.1 Data Structure 90
3.3.2 Database 90
3.3.3 Database Management System (DBMS) 95
3.3.4 Database Coordinate System 96
3.3.5 Working Coordinate System 98
3.3.6 Screen Coordinate System 102
3.4 Modes of Graphics Operations 104
3.5 User Interface 106
3.6 Software Modules 110
3.6.1 Operating System (OS) Module 110
3.6.2 Graphics Module 111
3.6.3 Applications Module 112
3.6.4 Programming Module 118
3.6.5 Communications Module 118
3.7 Modeling and Viewing 121
3.8 Software Documentation 126
3.9 Software Development 126
3.10 Efficient Use of CAD/CAM Software 126
3.11 Software Trends 128
Problems 130
Bibliography 131

Chapter 4 Microcomputer-Based CAD/CAM 133
4.1 Introduction 133
4.2 General Features 134
4.3 System Implementation 135

Scanned by TapScanner

4.4 Hardware Components and Configuration 136
4.4.1 Microcomputer Components 136
4.4.2 Display Systems 141
4.4.3 Storage Devices 141
4.5 Micro-Based CAD Software 142
4.6 Customizing the Software 143
4.7 File Translation 143
4.8 Operating Systems 144
4.9 Mechanical Applications 145
4.9.1 Two-Dimensional Drafting 145
4.9.2 Symbol Libraries 145
4.9.3 Report Generation 145
4.9.4 Parametric Design 146
4.9.5 Three-Dimensional Functions 146
4.9.6 Finite Element Analysis (FEA) 146
4.9.7 Manufacturing 147
4.10 MicroCAD Trends 147
4.11 Product Distribution Trends 148
Problems 148
Publications 149

Part II Geometric Modeling

Chapter 5 Types and Mathematical Representations of Curves 153
5.1 Introduction 153
5.2 Wireframe Models 155
5.3 Wireframe Entities 157
5.4 Curve Representation 171
5.5 Parametric Representation of Analytic Curves 177
5.5.1 Review of Vector Algebra 177
5.5.2 Lines 179
5.5.3 Circles 187
5.5.4 Ellipses 195
5.5.5 Parabolas 203
5.5.6 Hyperbolas 207
5.5.7 Conics 208
5.6 Parametric Representation of Synthetic Curves 212
5.6.1 Hermite Cubic Splines 213
5.6.2 Bezier Curves 219
5.6.3 B-Spline Curves 226
5.6.4 Rational Curves 236

Scanned by TapScanner

5.7 Curve Manipulations 237
5.7.1 Displaying 237
5.7.2 Evaluating Points on Curves 238
5.7.3 Blending 239
5.7.4 Segmentation 240
5.7.5 Trimming 243
5.7.6 Intersection 244
5.7.7 Transformation 245
5.8 Design and Engineering Applications 246
Problems 253
Bibliography 257

Chapter 6 Types and Mathematical Representations of Surfaces 259

6.1 Introduction 259
6.2 Surface Models 261
6.3 Surface Entities 263
6.4 Surface Representation 270
6.5 Parametric Representation of Analytic Surfaces 280
6.5.1 Plane Surface 280
6.5.2 Ruled Surface 284
6.5.3 Surface of Revolution 285
6.5.4 Tabulated Cylinder 286
6.6 Parametric Representation of Synthetic Surfaces 287
6.6.1 Hermite Bicubic Surface 288
6.6.2 Bezier Surface 295
6.6.3 B-Spline Surface 300
6.6.4 Coons Surface 304
6.6.5 Blending Surface 309
6.6.6 Offset Surface 310
6.6.7 Triangular Patches 310
6.6.8 Sculptured Surface 312
6.6.9 Rational Parametric Surface 313
6.7 Surface Manipulations 313
6.7.1 Displaying 314
6.7.2 Evaluating Points and Curves on Surfaces 314
6.7.3 Segmentation 318
6.7.4 Trimming 319
6.7.5 Intersection 320
6.7.6 Projection 322
6.7.7 Transformation 322
6.8 Design and Engineering Applications 329
Problems 333
Bibliography

Scanned by TapScanner

Chapter 7 Types and Mathematical Representations of Solids 335

7.1 Introduction 335
7.2 Solid Models 337
7.3 Solid Entities 340
7.4 Solid Representation 345
7.5 Fundamentals of Solid Modeling 352
7.5.1 Set Theory 352
7.5.2 Regularized Set Operations 357
7.5.3 Set Membership Classification 360
7.6 Half-spaces 364
7.6.1 Basic Elements 365
7.6.2 Building Operations 365
7.6.3 Remarks 368
7.7 Boundary Representation (B-rep) 368
7.7.1 Basic Elements 370
7.7.2 Building Operations 378
7.7.3 Remarks 387
7.8 Constructive Solid Geometry (CSG) 388
7.8.1 Basic Elements 398
7.8.2 Building Operations 407
7.8.3 Remarks 415
7.9 Sweep Representation 415
7.9.1 Basic Elements 416
7.9.2 Building Operations 417
7.9.3 Remarks 419
7.10 Analytic Solid Modeling (ASM) 419
7.10.1 Basic Elements 419
7.10.2 Building Operations 423
7.10.3 Remarks 425
7.11 Other Representations 425
7.12 Organization of Solid Modelers 426
7.13 Solid Manipulations 429
7.13.1 Displaying 429
7.13.2 Evaluating Points, Curves, and Surfaces on Solids 429
7.13.3 Segmentation 430
7.13.4 Trimming and Intersection 430
7.13.5 Transformation 431
7.13.6 Editing 431
7.14 Solid Modeling-Based Applications 431
7.15 Design and Engineering Applications 432
Problems 435
Bibliography 438

Scanned by TapScanner

Chapter 8 CAD/CAM Data Exchange 442

8.1 Introduction 442
8.2 Evolution of Data Exchange Format 446
8.2.1 Shape-Based Format 446
8.2.2 Product Data-Based Format 449
8.2.3 ISO Standard 450
8.3 IGES 450
8.3.1 Description 452
8.3.2 Data Representation 455
8.3.3 File Structure and Format 461
8.3.4 Processors 464
8.3.5 Remarks 471
8.4 PDES 471
8.4.1 Description 472
8.4.2 Data Representation 476
8.4.3 Remarks 476
Problems 477
Bibliography 477

Part III Two- and Three-Dimensional Graphics Concepts

Chapter 9 Geometric Transformations 481

9.1 Introduction 481
9.2 Transformations of Geometric Models 482
9.2.1 Translation 483
9.2.2 Scaling 485
9.2.3 Reflection 487
9.2.4 Rotation 490
9.2.5 Homogeneous Representation 499
9.2.6 Concatenated Transformations 502
9.3 Mappings of Geometric Models 504
9.3.1 Translational Mapping 505
9.3.2 Rotational Mapping 506
9.3.3 General Mapping 507
9.3.4 Mappings as Changes of Coordinate System 508
9.4 Inverse Transformations and Mappings 512
9.5 Projections of Geometric Models 514
9.5.1 Orthographic Projections 518
9.5.2 Perspective Projections 520
9.6 Design and Engineering Applications 522
Problems 523
Bibliography 525

Scanned by TapScanner

Chapter 10 Visual Realism 526
10.1 Introduction 526
10.2 Model Clean-Up 529
10.3 Hidden Line Removal 531
10.3.1 Visibility of Object Views 533
10.3.2 Visibility Techniques 534
10.3.3 Sorting 542
10.3.4 Coherence 543
10.3.5 Formulation and Implementation 543
10.3.6 Sample Hidden Line Algorithms 545
10.3.7 Hidden Line Removal for Curved Surfaces 551
10.4 Hidden Surface Removal 551
10.4.1 The *z*-Buffer Algorithm 552
10.4.2 Warnock's Algorithm 552
10.5 Hidden Solid Removal 553
10.5.1 Ray-Tracing Algorithm 554
10.6 Shading 564
10.6.1 Shading Models 565
10.6.2 Shading Surfaces 569
10.6.3 Shading Enhancements 572
10.6.4 Shading Solids 574
10.7 Coloring 579
10.7.1 Color Models 581
10.8 User Interface for Shading and Coloring 583
Problems 588
Bibliography 590

Part IV Interactive Tools

Chapter 11 Graphics Aids 595
11.1 Introduction 595
11.2 Geometric Modifiers 596
11.3 Names 598
11.4 Layers 599
11.5 Colors 601
11.6 Grids 602
11.7 Groups 604
11.8 Dragging and Rubberbanding 604
11.9 Clipping 606
Problems 606
Bibliography 608

Scanned by TapScanner

Chapter 12 Graphics Manipulations and Editings 609

12.1 Introduction 609
12.2 Entity Selection Methods 610
12.2.1 Individual Entity 610
12.2.2 All Displayed Entities 610
12.2.3 Groups 611
12.2.4 Enclosing Polygon or Window 611
12.2.5 Chaining Contiguous Entities 612
12.2.6 Width 612
12.3 Manipulation Operations 613
12.3.1 Verification of Model and Database Parameters 613
12.3.2 Entity Verification 613
12.3.3 Entity Copying (Duplication) 613
12.3.4 Geometric Arrays 614
12.3.5 Transformation 616
12.3.6 Entity Blanking/Unblanking 618
12.3.7 Geometric Measurements 619
12.3.8 Entity Offsetting 621
12.4 Editing Operations 621
12.4.1 Entity Trimming 621
12.4.2 Entity Division 623
12.4.3 Entity Stretching 624
12.4.4 Entity Editing 625
12.5 Design and Engineering Applications 625
Problems 628
Bibliography 629

Chapter 13 Computer Animation 630

13.1 Introduction 630
13.2 Conventional Animation 631
13.3 Computer Animation 633
13.3.1 Entertainment Animation 634
13.3.2 Engineering Animation 636
13.4 Animation Systems 637
13.4.1 Hardware Configuration 637
13.4.2 Software Architecture 639
13.4.3 Classification 641
13.5 Animation Types 642
13.5.1 Frame-Buffer Animation 642
13.5.2 Real-Time Playback 645
13.5.3 Real-Time Animation 645
13.6 Animation Techniques 646
13.6.1 Keyframe Technique 646
13.6.2 Simulation Approach 653
13.6.3 Hybrid Approach 654

Scanned by TapScanner

13.7 Animation-Related Problems 655
13.8 Animation of Articulated Bodies 657
13.9 Animation on Microcomputers 657
13.10 Design and Engineering Applications 658
Problems 660
Bibliography 662

Chapter 14 Mechanical Assembly 665
14.1 Introduction 665
14.2 Assembly Modeling 667
14.2.1 Parts Modeling and Representation 668
14.2.2 Hierarchical Relationships 669
14.2.3 Mating Conditions 669
14.3 Inference of Position from Mating Conditions 677
14.4 Representation Schemes 689
14.4.1 Graph Structure 689
14.4.2 Location Graph 690
14.4.3 Virtual Link 692
14.5 Generation of Assembling Sequences 695
14.5.1 Precedence Diagram 697
14.5.2 Liaison-Sequence Analysis 698
14.5.3 Precedence Graph 706
14.6 Assembly Analysis 709
Problems 711
Bibliography 716

Chapter 15 Interactive Computer Programming 717
15.1 Introduction 717
15.2 Requirements of Interactive Computer Programming 719
15.3 Types of Interactive Computer Programming 721
15.3.1 Elementary Level Programming 721
15.3.2 On-Screen Menu Programming 725
15.3.3 High Level Programming 725
15.3.4 Database Level Programming 732
15.3.5 Device Level Programming 735
15.4 Object-Oriented Programming 737
15.5 Development of Interactive Programs 738
15.6 Applications of Interactive Computer Programming 739
15.7 Design and Engineering Applications 740
Problems 750
Bibliography 754

Scanned by TapScanner

Part V Design Applications

Chapter 16 Mechanical Tolerancing 757

16.1 Introduction 757
16.2 Tolerance Concepts 759
16.2.1 Limits and Fits 763
16.2.2 Tolerance Accumulation 769
16.2.3 Tolerance/Cost Relationship 770
16.2.4 Surface Quality 772
16.3 Geometric Tolerancing 775
16.3.1 Datums 777
16.3.2 Types of Geometric Tolerances 782
16.4 Drafting Practices in Dimensioning and Tolerancing 795
16.5 Dimensioning and Tolerancing in Manufacturing 796
16.6 Tolerance Modeling and Representation 798
16.6.1 Modeling 799
16.6.2 Representation 803
16.7 Tolerance Analysis 813
16.7.1 Worst-Case Arithmetic Method 815
16.7.2 Worst-Case Statistical Method 817
16.7.3 Monte Carlo Simulation Method 819
16.7.4 Other Methods 821
16.8 Tolerance Synthesis 822
16.8.1 Arithmetic Method 823
16.8.2 Statistical Method 824
16.8.3 Taguchi and Other Methods 824
16.9 Design and Engineering Applications 825
Problems 829
Bibliography 833

Chapter 17 Mass Property Calculations 836

17.1 Introduction 836
17.2 Geometrical Property Formulation 837
17.2.1 Curve Length 837
17.2.2 Cross-Sectional Area 838
17.2.3 Surface Area 842
17.2.4 Volume 844
17.3 Mass Property Formulation 846
17.3.1 Mass 846
17.3.2 Centroid 847
17.3.3 First Moments of Inertia 847
17.3.4 Second Moments and Products of Inertia 848
17.3.5 Property Mapping 849
17.4 Property Evaluation 853
17.5 Property Evaluation Based on Solid Modeling 862

Scanned by TapScanner

17.6 Properties of Composite Objects 867
17.7 Mass Property Calculations on CAD/CAM Systems 868
17.8 Design and Engineering Applications 869
Problems 874
Bibliography 876

Chapter 18 Finite Element Modeling and Analysis 877
18.1 Introduction 877
18.2 General Procedure of the Finite Element Method 879
18.3 Finite Element Analysis 881
18.3.1 Development of Integral Equations 882
18.3.2 Continuum Discretization 893
18.3.3 Assembly of Element Equations 911
18.3.4 Imposing Boundary Conditions 914
18.3.5 Lumping External Applied Loads 915
18.3.6 Solution of Global Equations 915
18.3.7 Other Finite Element Analyses 916
18.3.8 Convergence of Finite Element Solutions 917
18.4 Isoparametric Evaluation of Element Matrices 918
18.4.1 Element Mapping 918
18.4.2 Shape Functions by Inspection 920
18.4.3 Evaluation of Element Matrices 922
18.5 Finite Element Modeling 925
18.6 Mesh Generation 927
18.6.1 Mesh Requirements 928
18.6.2 Semi-Automatic Methods 929
18.6.3 Fully Automatic Methods 938
18.7 Design and Engineering Applications 947
Problems 947
Bibliography 952

Chapter 19 Design Projects with CAE Focus 955
19.1 Introduction 955
19.2 Project Requirements 956
19.3 Project Formulation 957
19.4 Design and Engineering Applications 958
Problems 971
Bibliography 972

Part VI CAD and CAM Integration

Chapter 20 Part Programming and Manufacturing 975
20.1 Introduction 975
20.2 Part Production Cycle 976

Scanned by TapScanner

20.3	Manufacturing Systems	978
20.4	Manufacturing Processes	980
	20.4.1 Removing Processes	981
	20.4.2 Forming Processes	982
	20.4.3 Deforming Processes	982
	20.4.4 Joining Processes	983
20.5	Integration Requirements	984
20.6	Process Planning	987
	20.6.1 Manual Approach	988
	20.6.2 Variant Approach	995
	20.6.3 Generative Approach	998
	20.6.4 Hybrid Approach	1000
	20.6.5 Geometric Modeling for Process Planning	1000
20.7	Part Programming	1001
	20.7.1 Fundamentals of NC	1002
	20.7.2 Basics of NC Programming	1009
	20.7.3 NC Programming Languages	1012
20.8	Tool Path Generation and Verification	1019
	20.8.1 Generation of Tool Paths	1019
	20.8.2 Verification of Tool Paths	1025
20.9	Design and Engineering Applications	1025
	Problems	1031
	Bibliography	1033
	Index	1037

Scanned by TapScanner