The Application of Genetic Algorithm to Optimize Technical Parameters in Profile Grinding for Ball Bearing's Inner Ring Groove

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Abstract

In the profile grinding operation for ball bearing's inner ring groove, the quality of products and the productivity of the machining process mostly depends on the technology system's parameters such as normal feed rate (F_n), speed of part (V_p), depth of cutting (t), number of parts in a grinding cycle (N_p), etc. It is actually necessary to optimize technology parameters of the machining process. The article presents a method to optimize technology parameters of the profile grinding operation for 6208 ball bearing's inner ring groove on the grinder 3MK136B. The research is implemented by the least squares experimental planning method to determine the experimental regression functions between technical parameters and output elements of the machining process. Based on that, an optimal solution of the non-linear optimization problem has been solved by using a Genetic Algorithm, presenting the most appropriate technology parameters for profile grinding of 6208 ball bearing's inner ring groove on grinder 3MK136B as follows: F_n = 7.06 (μm/s); V_p = 9.39 (m/min); t = 19.97 (μm) and N_p = 19 (parts).

Keywords: Genetic algorithm, Profile grinding, Cutting mode.

1. Introduction

In a certainly invested technology system, cutting mode parameters are flexibly controlled. Meanwhile, such a system only generates high economic effectiveness when it operates under optimal cutting conditions. In accordance with previous researches, the machine productivity shall be boosted to 8÷10% if optimal cutting conditions are used [1]. For profile grinding operation of 6208 ball bearing's inner ring groove on grinder 3MK136B, setting up optimal cutting conditions increases machining process's productivity, enhances durability of grindstone and ensures quality of grinding part as well. The economic - technical targets of machining process will be directly affected by setting up optimal cutting condition. The optimization of cutting regime to determine and set up suitable cutting mode parameters is the most basic and effective method to control product quality, enhance machining productivity as well as the durability of grindstone.

The optimization of cutting process is actually the determination of optimal cutting condition for operation of a specific machining method. Its nature is to determine appropriate cutting parameters by solving the extremum problem based on forming a mathematic relationship between economic target function and a system of limited functions regarding technique, quality, organization of manufacturing facility and technology parameters. The optimization problem can be considered the problem of finding the best solution among an extremely large space of solutions. For small search space, traditional optimization methods can be suitable to solve (such as direct calculation method, graph method, Lagrange method, etc.), however, traditional optimization methods are not appropriate for a large domain and inefficient under a large survey range as well [1]. There have been other approaches to solve such types of problem. The application of Genetic Algorithm (GAs) has proved dominant advantages [2]. GAs simply illustrates natural evolution and selection by a computer starting with a random initial population [3]. Via selection, crossover and mutation process, GAs shall converge through generations in way of global optimization. GAs is expected to find a more optimal measure by combining good information hidden in a range of measures to generate a new one with good information inherited from parents [4]. This method is different from traditional ones in several special features as follows:

GAs solves the optimization problem by encrypting setting parameters instead of using such parameters to solve [1-4]. GAs works with a variable encryption set instead of the direct variable.

GAs searches from population of individuals (maintain and deal with a range of answers) instead of

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each individual (only handle one point in search space) [1-4]. GAs carries out a progress to find out optimal solution in different directions by maintaining a population of solutions, promoting information generation and communication among such directions. The population experiences an evolution process and generates the better solutions in each generation, meanwhile the bad solutions are rejected. To classify different solutions, the target function is used as an environmental role. This is one of the advantages of GAs which can increase the opportunity to reach global optimization points rather than local optimization points [1-4].

This article focuses on development of an optimization problem to determine a suitable cutting condition for a real technology chain and applies genetic algorithm to solve such optimization problem. Experiments have conducted on the grinder 3MK136B for 6208 ball bearing's inner ring groove. The experiment outcome also illustrated that the economic and technical effeciency of the specific machining process with the determined optimal parameters was enhanced.

2. Content of the study

2.1. Optimization problem model of technology parameters in profile grinding for 6208 ball bearing's inner ring groove based on application of genetic algorithm

The block diagram for solving the optimization problem of technology condition in profile grinding for 6208 ball bearing's inner ring groove is illustrated in Fig. 1. The initial population is the input parameters of process.

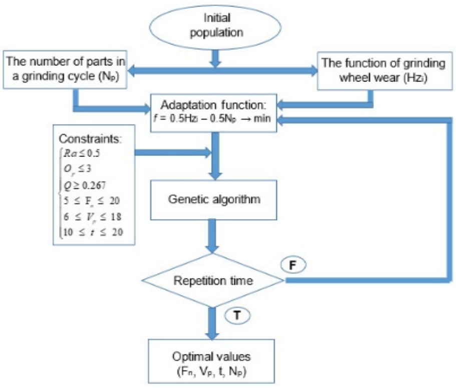

Fig. 1. Block diagram to solve the optimization problem of technology condition in profile grinding for 6208 ball bearing's inner ring groove [1]

In profile grinding process, grinding wheel needs regular repair. The precision of machined surface is closely related to grindstone repair during grinding process. After a certain machining period, when the grinding wheel's wear value exceeds an acceptable limitation value, the grinding wheel should be dressed. The purpose of such dress is to recover the cutting capability and the initial shape of the grindstone. It is important to determine the appropriate moment for dressing, which decides machining precision, grinding productivity and durability of the grinding wheel. In production, it is always expected that the amount of grinding wheel wear to be minimal, the number of parts in a grinding cycle to be the most, while the required productivity and precision of the grinding part is still ensured. Therefore, the target function in this study is the function of grinding wheel wear value and the number of parts. According to the weighting method [24], the multipoint function can be constructed as follows:

$$f = 0.5Hz_i - 0.5N_p \rightarrow \min$$

The constraints include function constraints and variable constraints. Function constraints in this problem are constraints in terms of machining process productivity and machining precision. Constraint variables are cutting condition parameters.

In profile grinding operation for ball bearing's inner ring groove, constraint variables of the grinding condition include the speed of cutting (V_w), the speed of part (V_p), the rate of normal feed (F_n) for rough grinding and fine grinding, the depth of cutting (t) for rough grinding and fine grinding, the number of parts in a grinding cycle (N_p). For grinding on a CNC grinder with a specific grinding wheel, the velocity of grinding wheel is usually chosen according to the specifications of the grinding wheel that has been give by the manufacturer. For examples, the grinding wheel of 500x8x203WA100xLV60 has the grinding wheel's speed (V_w) of 60 m/s. Some grinders are manufactured with fixed spindle speed value. In order to simplify the study without losing its general characteristic, this paper considers only four input parameters which are the rate of normal feed (F_n), the speed of part (V_p), the depth of cutting (t) and the number of parts in a grinding cycle (N_p). In addition, the cutting regime for rough grinding has insignificant effect on the quality of grinding parts. This article considers only cutting regime parameters for fine grinding to optimize technology parameters in the profile grinding operation for 6208 ball bearing's inner ring groove on the grinder 3MK136B. The four parameters of the cutting mode selected in this study are the normal feed rate for fine grinding (F_n), the speed of part (V_p), the depth of cutting for fine grinding (t) and the number of parts in one grinding cycle (N_p). The values of other parameters are kept constant throughout the experiment. Based on the mechanical notebook [7], the actual state of manufacturing and specification of shape grinder 3MK136B, variable constraint conditions of the optimization problem are presented as follows:

$$\begin{cases} 5\ (\mu\text{m/s}) \leq F_n \leq 20\ (\mu\text{m/s}) \\ 6\ (\text{m/min}) \leq V_p \leq 18\ (\text{m/min}) \\ 10\ (\mu\text{m}) \leq t \leq 20\ (\mu\text{m}) \end{cases}$$

For processing the groove surface, it is required not only the accuracy for dimension of groove bottom's diameter, groove's radius and distance from center line to head surface, but also the accuracy for form and correlation position, including the oval of groove bottom's diameter, the circular run-out of the groove central line in comparision to the head surface. The roughness of groove surface would be smaller than 0.5 µm (These requirements for the 6208 ball bearing's inner ring are shown as Fig. 2). The surface quality is highly required because it highly affects the working ability of parts including abrasion resistance, fatigue resistance, etc. The ball will rotate inside the groove surface when the ball bearing works. If the groove surface has a high roughness, there would be a big friction on the contact between the ball and groove surface. This causes quick abrasion and surface scuffing, decreases the longevity of the ball bearing. Based on the mechanical notebook [7] and the actual state of manufacturing basic tests, it can be realized that cutting conditions mostly affect the wear of grinding wheel, the surface roughness of part and the oval of groove bottom's diameter. Other precision parameters of part can be affected but insignificantly and the derivation is within allowable precision limit of the operation. There are two output factors selected to be in marginal condition constraints of the problem, which are surface roughness of part and the oval of groove bottom's diameter. Grinding wheel wear is selected to be the target function of the optimization problem. Based on grinding productivity and technical requirements of grinding operation for ball bearing's inner ring groove, constraint functions of the problem can be realized as follows:

$$R_a \leq 0.5\ (\mu\text{m});\ O_p \leq 3\ (\mu\text{m});\ Q \geq 0.264\ (\text{g/min})$$

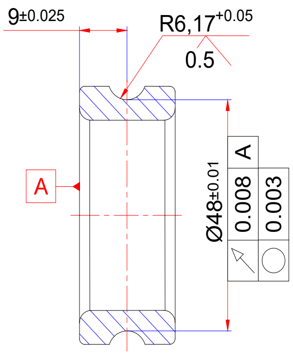

Fig. 2. Drawing illustrates technical requirements of the finish grinding operation for 6208 ball bearing's inner ring groove [8]

To implement a solution for the optimization problem here, it is necessary to carry out experiment and apply least square method to determine target function and constraint function.

2.2. Experiment to determine relation function between technology parameters and output parameters

Experiment was implemented on profile grinder 3MK136B to grind the inner ring groove of 6208 ball bearing. Experiment conditions are as follows:

- Experimental equipment is profile grinder 3MK136B made in China with a chinese grinding wheel marked 500x8x203WA100xLV60 to grind the inner ring groove of ball bearings (Fig. 3).

Fig. 3. Profile grinding machine 3MK136B

- Roughness measuring device: SJ400 roughness meter made in Japan.

- Equipment to measure the wear value of grinding wheel: A pneumatic measuring probe system is applied to measure grinding wheel wear during profile grinding for the inner ring groove of the ball bearing [9, 10] (Fig.. 4). The design of the probes as well as solution for signals acquisition and processing in these probes were presented in [9].

Fig. 4. The pneumatic measuring probe systems to measure grinding wheel's wear in profile grinding for the 6208 ball bearing's inner ring groove [9]

Equipment to measure the oval of groove bottom diameter: A Mitutoyo Indicator with resolution of 0.001 mm mounted on a specialized fixture equipment D022 made in China to determine position and the diameter of groove of the ball bearing's inner ring (Fig. 5). This measuring equipment applies comparison method to measure the oval level of groove bottom diameter.

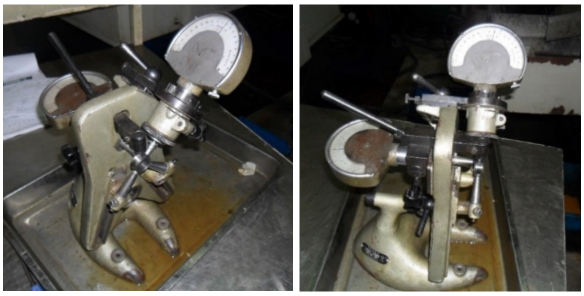

Fig. 5. D022 type equipment to measure the oval of groove bottom diameter of the ball bearing's inner ring

Cutting Mode: The speed of cutting (V_w) is equal to 60 (m/sec). The rate of normal feed (F_n) varies in 3 levels (5; 12.5; 20) µm/sec. The speed of workpiece (V_p) varies in 3 levels (6; 12; 18) m/min. The depth of cutting (t) varies in 3 levels (10; 15; 20) µm. The number of parts in a grinding cycle (N_p) varies in 3 levels (10; 20; 30) parts. These input parameters are selected via basic experiment and reference of machine manufacturing technology manual [7]. Each above factors varies in 3 levels. It is essential to select orthogonal experiment matrix $L_{81}(3^4)$, in other words, 81 experiments to be implemented. Each experiment is equivalent to a collection. For example: S1V1t2N3 means of F_n= 5, V_p=6, t=15, N_p=30.

After carrying out experiments and collecting results, data is analyzed and processed. In the article, Matlab software used to determine experimental regression function under traditional least square method. Based on that, the experimental regression functions between the output parameters and the technology parameters is determined as follows:

Target function regarding grindstone wear:

$$Hz_i = 2.1688 \cdot F_n^{0.0965} \cdot V_p^{0.0657} \cdot t^{0.0557} \cdot N_p^{0.3772}$$

By the least squares method (BPNN), the average error (θ_{tb}) is equal to 0.2%, the error dispersion (σ) is equal to 0.13.

Limited function regarding part's surface roughness:

$$Ra = 0.163 \cdot F_n^{0.1224} \cdot V_p^{0.10002} \cdot t^{0.1005} \cdot N_p^{0.1194}$$

By the least squares method (BPNN), the average error (θ_{tb}) is equal to 0.3%, the error dispersion (σ) is equal to 0.27.

Limited function regarding the oval level of groove bottom diameter of part:

$$O_p = 1.4498 \cdot F_n^{0.19996} \cdot V_p^{-0.1127} \cdot t^{0.1966}$$

By the least squares method (BPNN), the average error (θ_{tb}) is equal to 4.58%, the error dispersion (σ) is equal to 2.94.

Constraint function regarding productivity of grinding process:

$$Q = 0.1616 \cdot F_n^{0.0973} \cdot t^{0.1004}$$

By the least squares method (BPNN), the average error (θ_{tb}) is equal to 0.01%, the error dispersion (σ) is equal to 0.1.

2.3. Application of generic algorithm for determination of optimal technology paramaters in profile grinding for 6208 ball bearing's inner ring groove

The experimental regression functions show that the specific requirements of the optimization problem for technology parameters in profile grinding for 6208 ball bearing's inner ring groove are as follows:

$$f = 0.5Hz_i - 0.5N_p \rightarrow \min$$

With the constraint conditions as follows:

$$\begin{cases} Ra = 0.163 \cdot F_n^{0.1224} \cdot V_p^{0.10002} \cdot t^{0.1005} \cdot N_p^{0.1194} \le 0.5 \\ O_p = 1.4498 \cdot F_n^{0.19996} \cdot V_p^{-0.1127} \cdot t^{0.1966} \le 3 \\ Q = 0.1616 \cdot F_n^{0.0973} \cdot t^{0.1004} \ge 0.264 \\ 5 \le F_n \le 20 \\ 6 \le V_p \le 18 \\ 10 \le t \le 20 \end{cases}$$

To optimize the technology parameters so that the target function regarding the number of parts (N_p) to be biggest and grindstone's wear value (Hz) to be smallest, on the basis of application of genetic algorithm, a software program was directly implemented coding on Matlab. After running the program several times, the results are shown in Table 1, while Fig. 6 illustrates the progress on which the program searched for the solution, running on Matlab environment.

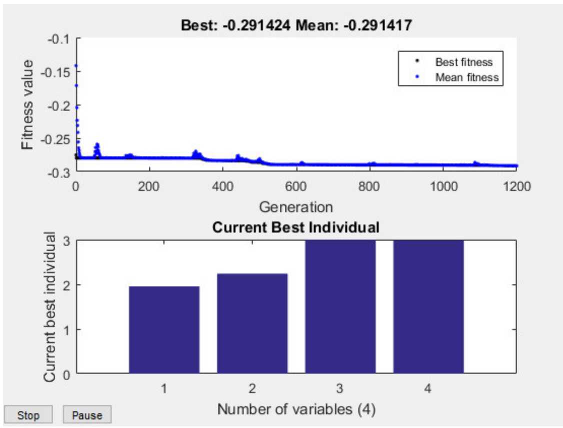

Fig. 6. Diagram of optimal result of technical parameters with GAs

Table 1. Results found by the Matlab program using GAs

F_n (µm/s)	V_p (m/min)	t (µm)	N_p (parts)	Hz (µm)
7.06	9.39	19.97	19	10.9

Experimental results with above optimal input parameters are shown in Table 2. The error between optimal result and real one is within 6% of the range.

Table 2. Experimental results with the cutting mode of F_n=7.06 µm/s; V_p=9.39 m/min; t=19.97 µm; N_p=20 parts

Hz (µm)	Error	Ra (µm)	Error	O_p (µm)	Error	Q (g/min)	Error
10.4	4.81%	0.49	1.43%	2.83	5.97%	0.265	0.38%

3. Conclusion

Results obtained from experiment and operation of genetic algorithm program coded on Matlab show that it is recommended to carry out grinding with optimal technology condition of F_n = 7.06 (µm/s); V_p = 9.39 (m/min); t = 19.97 (µm) and N_p = 19 (parts) during profile grinding for 6208 ball bearing's inner ring groove on grinder 3MK136B. In the optimal cutting mode, the number of parts (N_p) is the biggest, grindstone's wear value (Hz_i) is the smallest, but the productivity and technical requirements of grinding operation still assure. Such research results would help manufacturers determine and set up optimal parameters of grinding condition in order to enhance economic and technical effectiveness of grinding process.

References:

[1]. Nguyễn Tuấn Linh, "Tối ưu hóa đa mục tiêu quá trình mài thép hợp kim trên máy mài tròn ngoài", Luận án tiến sĩ kỹ thuật Cơ khí – Đại học Bách khoa Hà Nội, 2015.

[2]. Lại Khắc Lãi, Đặng Ngọc Trung, "Ứng dụng giải thuật di truyền cho bài toán điều khiển tối ưu đa mục tiêu", Tạp chí khoa học công nghệ, Đại học Thái Nguyên, 2010.

[3]. Trần Kim Hương, "Giải thuật di truyền (GAs) và các ứng dụng", Hội nghị NCKH Khoa sư phạm Toán tin, Trường Đại học Đồng Tháp, 2015.

[4]. Nguyễn Đình Thúc, "Trí tuệ nhân tạo lập trình tiến hóa", Nhà xuất bản giáo dục, 2015.

[5]. Bùi Ngọc Tâm, Phùng Xuân Lan, "Sử dụng giải thuật tối ưu để dạy học mạng Nơron và ứng dụng để lựa chọn dụng cụ cắt trên máy phay CNC", Hội nghị KH-CN toàn quốc về Cơ khí Động lực, 2016.

[6]. Nguyễn Thị Lan Phương, "Nghiên cứu ứng dụng công nghệ gen vận hành liên hồ chứa sông ba mùa lũ", Luận văn thạc sĩ khoa học, Trường Đại học khoa học tự nhiên – Đại học Quốc Gia Hà nội, 2014.

[7]. Nguyễn Đắc Lộc, Lê Văn Tiến, Ninh Đức Tốn, Trần Xuân Việt "Sổ tay công nghệ chế tạo máy tập 1,2,3", NXB Khoa học và kỹ thuật (2005).

[8]. Nguyễn Viết Tiếp, Vũ Toàn Thắng, Nguyễn Anh Tuấn, "Nghiên cứu công nghệ gia công vòng trong và vòng ngoài của vòng bi 6205 và ảnh hưởng của lượng chạy dao ngang đến nhám bề mặt đối với nguyên công mài định hình rãnh lăn vòng bạc ổ bi", Tạp chí Cơ khí Việt Nam, số 2, 2015.

[9]. Vu Toan Thang, Nguyen Anh Tuan, Nguyen Viet Tiep, "Evaluation of grinding wheel wear in wet profile grinding for the groove of the ball bearing's inner ring by pneumatic probes", Journal of Mechanical Science and Technology, 2018.

[10]. T M A Maksoud, A A Mokbel, J E Morgan - In process detection of grinding wheel truing and dressing conditions using a flapper nozzle arrangement", Proceeding of the Institution of Mechanical Engineerings, số 211, 1997.