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Study on Parameter Optimization of Cutting Surface Roughness of Aluminum Alloy

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This study is to develop a parameter optimization strategy for cutting surface roughness of aluminum alloy. The machining and manufacturing process of metal parts is deeply studied, and the influence law and significance of parameters and interaction on target value are analyzed comprehensively, then the combination value of cutting parameters of aluminum alloy is optimized to ensure that the target value doesn't exceed the specified range value. Through a series of research and analysis, the quality characteristics of processed workpiece is understood, and the difference of cutting process between aluminum alloy and other metals is distinguished. Conclusion has been drawn that the research result of cutting surface roughness of aluminum alloy provides important reference for optimizing its parameters, so it has high application value.

1. Introduction

Along with the rapid development of social economy, the demand of various industries for metal parts has been increasing, especially for the quality of metal parts. Therefore, it is very important to optimize the machining parameters of metal parts. In view of the status quo of metal parts machining in China, it is found that in the machining and manufacturing process, numerical control programming personnel rely on personal previous working experience or inquiry manual in the stage of selecting machining parameters. This is one of the main reasons why the efficiency of metal parts machining has not been improved obviously. However, with the rapid development of high performance numerical control technology, the cutting parameters selected by traditional methods can't meet the requirements of modern social development and can't give full play to the actual machining performance of tools, so they are gradually wed out and even abandoned by the high performance numerical control technology industry. At the same time, with the computer technology level increasing, simulation software and CAM come into being, which makes many manufacturers set NC program for automatic target-specific optimization based on the characteristics of new software and new technology in order to enlarge the scale of development, and then select reasonable machining parameters. However, in the process of optimizing machining parameters by using related software, many manufacturers don't have a comprehensive analysis and research on the actual characteristics of tools, so the set program is not practical. Therefore, it is very necessary to study the machining and manufacturing process.

2. Literature review

At present, domestic and foreign research institutes have made some achievements in the study of surface roughness. The regression statistics and response surface method were applied to Long Zhenhai, Wang Xibin and Chiang in Beijing Institute of Technology, and the influence of factors on the surface roughness of aluminum alloy was analyzed with factorial and uniform design, and the empirical formula of surface roughness was established. The Zhang Lei of Nanjing University of Science and Technology was used to analyze the cutting parameters by using the orthogonal test. The influence of number on the surface roughness in high speed milling; the influence factor of surface roughness and the optimization of cutting parameters were analyzed by the application of Taguchi method in Yanbian University. The cutting force and surface roughness of the titanium alloy in the high speed cutting process of the Shandong University were studied by Tian Gang and Zhang Song. The prediction model of cutting force and surface roughness based on

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neural network is used to obtain the optimal combination parameters for reducing the cutting force and improving the surface quality as a constraint condition. The most widely used regression analysis method is used in the response surface method of Zhu Dairu and Liang Chun Chun in Harbin Institute of Technology. The surface roughness of milling microgrooves is predicted by the method of heart compound design and the model is established. The purpose of improving the metal removal rate and controlling the surface roughness of the micro milling is achieved. Meng Fanyu and Wang Longshan of Jilin University are using the method of laser atlas to measure the surface roughness of the outer longitudinal grinding. The requirement of on-line measurement in the process of circular grinding is convenient for a series of optimization work. The Fang of Dalian University of Technology has predicted the surface roughness of the ceramic surface, pre-evaluated the surface quality after grinding and adjusted the process parameters in time, so the numerical control based on neural network has been achieved. The study on the on-line prediction of the surface roughness of the parts during the turning process has made a good theoretical paving for the realization of the real-time optimization of the cutting parameters which can ensure the efficiency while ensuring the quality of the machining surface, but there is no real actual optimization proof (Fang et al., 2016); Wang and others in Tianjin University studied the influence of the factors on the milling force and the surface roughness of the typical refractory austenitic stainless steels L Crl8Ni9 in high speed milling. However, the analysis and comparison of various methods were compared, but the research conclusions were not tested, but the surface roughness based on artificial neural network was proposed and established. The prediction model, taking ultra-precision turning as the research object, further studies the optimization of turning processing parameters based on genetic algorithm, but only studies the relationship between the surface roughness and the cutting amount, and the application has limitations (Wang et al., 2016).

The effect of cutting speed, radial cutting depth, axial depth and feed per tooth on surface roughness is studied by Khorasani and other AA2024 aluminum alloy. It is proved that the influence of axial depth on surface roughness is the most, and the influence of radial cutting depth is smaller (Khorasani et al., 2016). Sahoo and others have studied the effect of tool radial angle and rear angle on the surface roughness of AA6061 aluminum alloy (Sahoo et al., 2017). Horváth and Drégelyi-Kiss use a single blade high speed cutting tool for surface milling of AA7075T6. The blades are made of carbide and diamond, and the influence of cutting tool material, feed speed, cutting speed and depth on surface roughness is studied. Finally, the cutting speed of the best surface quality is 1524m/min, and the bigger the cutting depth, the worse the surface quality (Horváth and Drégelyi-Kiss, 2015).

Compared with the traditional full factorial test design, the response surface method can achieve more optimization experiments. To verify the effect of the radius of the nose, the width of the side and the cutting conditions on the residual stress and the surface roughness, the Santos and the response surface method were used to obtain the prediction model, and the variance analysis was used to verify the adequacy of the model and to determine the significant factors in the model. The nose radius has a significant effect on the surface roughness (Santos et al., 2016). Najiha and others studied the influence of cutting depth, spindle speed and feed rate on surface roughness by the response surface method and established the model to optimize the surface roughness under the prescribed constraints (Najiha et al., 2015). Prasad and others have studied the optimization of surface roughness of AA7075-T6 mold by combining response surface method and genetic algorithm. The effects of four factors on feed rate, cutting speed, axial cutting depth and radial depth of cut were considered, and the optimization model was established by response surface methodology (Prasad et al., 2015). The value of surface roughness is obtained by the third level full factor test design. Finally, the desired surface roughness is obtained by using genetic algorithm to optimize the cutting process. The results show that the genetic algorithm can improve the surface quality by about 10%.

To sum up, the optimization method based on modern optimization algorithm will be the development trend and direction of cutting parameter optimization research. However, based on the development of numerical control technology in China and the selection of most of the machining parameters of NC machining, the optimization method based on the experiment is a good choice in the process of actively guiding the NC machining towards the optimization parameter direction. It is not too complex, and it is easy to be in the CNC system. In the process of integration, it is easy to popularize. This paper will also focus on theoretical research and system embedment based on the experimental optimization methodand provide a useful reference for actual production.

3. Research Methods

(1) The orthogonal test is used to study several factors and interaction on surface roughness. It is not limited to study the influence of cutting three factors. In this study, the interaction of cutting angle, angle of bank and cutting three factors is added, which provides a reference for numerical control programming personnel to select cutting parameters more scientifically and reasonably. (2) This study is no longer limited to use

optimization algorithm to optimize the theoretical model. It is more targeted for the actual analysis of the specific dynamic characteristics of tools. The small calculation amount of the optimization algorithm doesn't affect the actual performance of the numerical control system, and the high memory required by other optimization algorithms is omitted. The general optimization parameter software can't complete this work. This ensures numerical control machining to give full play to the maximum capacity of enterprises' manufacturing system, improving the efficiency of enterprises' production. (3) The research and development of cutting parameter optimization based on experiment has high guiding value, which can provide a good reference for the research and development of multi-target parameter optimization system. (4) It gets rid of the dependence of the optimization work on the third-party software, and the optimization of cutting parameters can be completed on the self-developed numerical control system. In addition, we can independently develop optimization objectives according to the function parameters of our own needs. In this study, the optimization work will be subdivided to become transparent so that readers can clarify the ideas and principles of software writing so as to provide ideas for the development of relevant test data analysis software. Based on the actual machining data obtained from the orthogonal test, the optimal cutting parameter combination is obtained by the Taguchi method with minimum surface roughness as the goal, and the aluminum alloy impeller with smaller surface roughness is machined. The optimization algorithm can guide us to select cutting parameters scientifically. The experimental research method proposed in this study is closely combined with the actual machining, and the cutting verification is carried out on the TDNC-A1M6-H8 five-axis double-rotating numerical control machining center, which provides reference for the selection of cutting parameters of complex parts. This can effectively improve the machining quality of complex surface parts and make contributions to the research of related technologies of high-end digital manufacturing equipment. Figure 1 shows some complex surface parts, which are generally required to have a high surface quality. The surface roughness of mechanical products can affect their various functional properties, such as surface friction, wear, light reflection, heat conduction, lubrication, fatigue resistance. There are several ways to describe surface roughness, of which the most common is mean roughness value, marked as Ra which is defined as the arithmetic value of the contour deviating from the centerline within the measured length of the sample, as shown in Figure 2. X: contour direction; Y: contour curve; Z: average height; L: sample length; H: contour height.

Figure 1: Common complicated curved surface parts (propeller, vane, impeller)

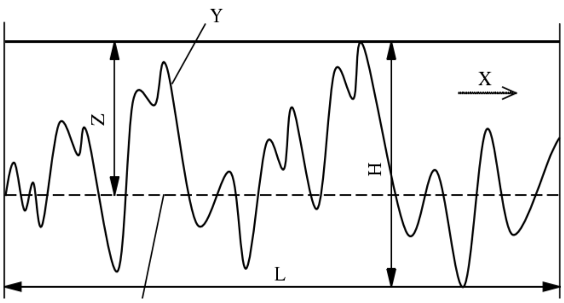

Figure 2: Surface roughness contour

4. Research Results and Discussion

4.1 Experimental design method

In this study, Taguchi experimental design method is used to optimize the cutting parameters: 1. parameter variables and levels that affect the surface roughness are selected and determined; 2. an appropriate orthogonal matrix is selected according to the controllable factors and the corresponding level; 3. test is conducted according to the selected orthogonal matrix (the noise factor is considered or not considered); 4. test data is analyzed the to determine the optimization level of controllable factors; 5. test is conducted to verify the predicted surface roughness. Taguchi method proposes that the machining design of any product must include three stages: system design, parameter design and error design.

In the system design stage, the designer uses the knowledge of science and engineering to design and establish the basic function original model. This stage includes the product design stage and the machining design stage. Product design includes selection of materials and components, and preliminary and tentative selection of product parameter values. Machining design includes the analysis of machining procedures and the selection of product machining equipment. In terms of product quality and cost, the system design doesn't cover optimization work and it is only the preliminary function design. The purpose of parameter design is to optimize a series of machining parameters for improving the performance characteristics of the product and to determine the corresponding performance target value of the product. In addition, we hope that the optimized parameter value obtained from the parameter design is less affected by environment variables or other noise as much as possible. Therefore, in the Taguchi design method, parameter design is a key step in achieving high quality without increasing cost. The parameter design stage is the most important part. In this stage, we will determine the characteristic parameters to measure the product quality of the machining process, and most importantly, we will put forward the optimization value of the parameters to achieve the quality characteristics of the machining product optimization.

4.2 Study on cutting process

After the numerical control simulation environment is set up in VERICUT, such as establishing coordinate system and tool system, setting collision check and route limit, and importing numerical control program, the numerical control program generated by CAM software (SolidCAM) can be simulated by VERICUT to determine the limit value of the angle. The cutting angle and angle of bank are continuously changed and simulated. The simulation process for determining the angle of bank is as shown in Figure 3. The correct simulation machining effect is shown in Figure 4. After the factors and factor levels are determined, they are summarized and listed in the factor level table as shown in Table 1.

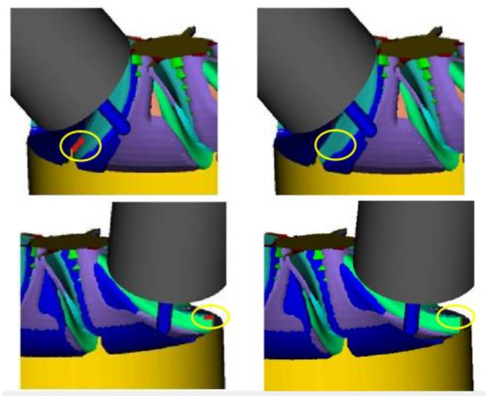

Figure 3: Determination of roll angles

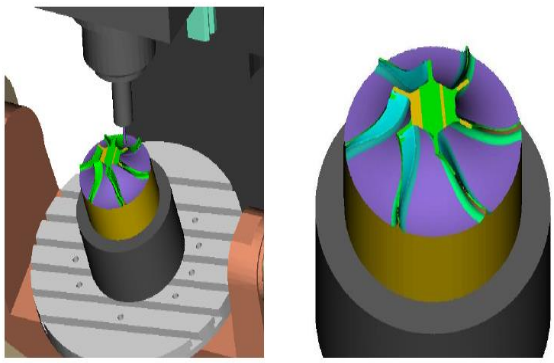

Figure 4: Impeller simulation machining with VERICUT

Table 1: Factor-Level table

factors	unit	The level of		
		1	2	3
Spindle speed S(A)	r/min	1500	2500	4000
Feed speed F(B)	mm/min	1000	1500	2000
Cutting dept a_p(C)	mm	0.1	0.2	0.5
Before and after the Angle		-5	0	5
Roll Angle (E)		-10	0	10

4.3 Design of test header with interaction and preparation of test scheme

For the test to investigate the interaction, the header design is the process of arranging the test factors and the interaction to be investigated into the columns of the orthogonal table. In the process of investigating the interaction, the interaction should be arranged in the interaction column of the selected orthogonal table and can't be arranged arbitrarily so as to prevent the "mixing" phenomenon of the design, which is an important characteristic and a key step of the interaction orthogonal test design. The design method based on the linear table method is shown in Figure 4. This chapter mainly introduces Taguchi experimental design theory and the three stages of Taguchi method design, the orthogonal experimental design with interaction, and the general flow of experimental design. Four key technologies are emphatically introduced: the determination of test purpose, requirement, assessment index, selection of factors, determination of level, listing of factor level table, the selection of orthogonal table with interaction, the design of test header and the preparation of test scheme.

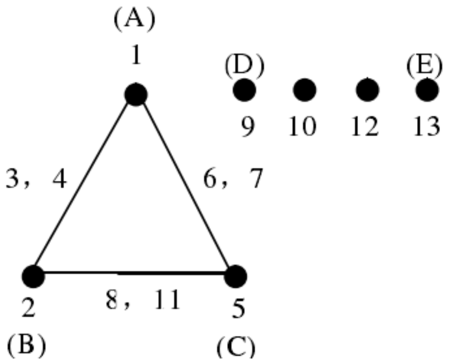

Figure 5: Design method of linear form

4.4 Selection of machining platform

In this study, TDNC-A1M6-H8 five-axis numerical control machining center of Tianda Jingyi Numerical Control Technology Development Co., Ltd. is selected for the machining test, as shown in Figure 3-2. The following reasons are considered: 1. the spindle speed of hardware configuration of machining center reaches up to 8000 r/min and the speed of fast movement is 10000 mm/min, which can meet the requirements of spindle speed and feed speed of this test; 2. the machining center is equipped with Germany peislor double turntable with large torque so that the five-axis linkage and the large dip angle can test can be realized; 3. TDNC-A1M6-H8 numerical control system is an open and embeddable frame system, making it convenient for embedding in optimization system automatically. According to the orthogonal test scheme table, a set of combined parameters is set for each flow channel in SolidCAM for carrying out the actual machining test.

Figure 6: TDNC-A1M6-H8 five-axis linkage machining center.

4.5 Measurement of surface roughness

In this study, American NANOVEA three-dimensional non-contact surface topography measuring instrument is selected to measure the surface roughness of impeller passage, as shown in Figure 3-3. The main reasons are as follows: 1. it is suitable to measure the material surface with high gradient and high tortuosity, and the highest gradient is close to vertical; 2. its measurement speed is fast, up to 1 m/s; 3. its measurement accuracy is high and minimum resolution of 2 nm can be obtained; 4. it has professional three-dimensional analysis software function. For the surface sample, it first flattens and then automatically gives the surface roughness value aR of the sample. In order to ensure the accuracy of the measurement result, three areas are randomly selected for each flow passage obtained by each group of combined parameters for measurement and recorded in the three columns a1R, a2R and a3R of Table 3-3. Figure 7 shows three-dimensional non-contact surface topography measurement.

Figure 7: Three-dimensional non-contact surface profilometer and measure area selection

5. Conclusions

Based on the demand analysis of the system, this study obtains the specific requirements conforming to enterprises' optimization system after considering the research results of the cutting generation optimization theory and the machining process. The design of the optimization system can be divided into three layers: optimization module layer, database realization layer and human-computer interaction layer. At the same time, in the process of system design, the overall scheme design content of the system is preliminarily determined after the operation habit and level of operators around the world are objectively analyzed. On this basis, the key technology of the optimization system is summarized, which makes the content of the aluminum alloy cutting system more perfect and provides theoretical basis for the optimization of its processing generation. After a series of research and analysis, it is found that in order to further optimize the cutting parameters of aluminum alloy, it is necessary to strengthen the research on machining technique and technology of metal parts according to the development needs of times and idea of keeping pace with the times so as to meet the requirements of social development and expand the scope of optimization, as well as continuously supplement the content of aluminum alloy cutting machining.

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