

Analysis of Removal Function Results of Permanent Magnet Polishing Device Test

Xiaoqin Zhou¹, Baoquan Sun², Haocheng Wang² and Hang Yu³ and Xiaoyang Wu³

School of Mechanical and Aerospace Engineering, Jilin University, Jilin Province, China

Email: ss15643249600@163.com

Abstract. Based on the test platform of the polishing device, the material removal function model of the workpiece is obtained by using the Preston empirical equation and the motion state of the polishing tool. The test platform is built and the material removal model is verified by polishing the workpiece. Using Matlab software, draw the mathematical model material removal function curve and the test material removal function curve, analyze and compare the material removal law of the workpiece, and analyze the surface quality before and after the workpiece polishing.

1. Introduction

Ultra-precision machining technology is a key technology for a country to manufacture high-end precision equipment and become a powerful country in equipment manufacturing. It is of great significance to people's quality of life and national development and construction [1]. In many fields, the shape of parts of mechanical equipment is more and more complicated, and even many parts have internal cavity structure, which greatly increases the difficulty of ultra-precision machining technology [2]. Because the surface roughness is universal and random on the surface of the workpiece, the performance of many devices is severely and complicatedly affected by the limited surface quality of the workpiece cavity [3].

Aiming at this situation, this paper designs a magnetic field teleoperation polishing tool, which is a test platform for directional polishing of the inner cavity surface of the workpiece. N52 NdFeB permanent magnet is used as the source of space magnetic field. The KR60-3 robot arm of KUKA and the DCX26L DC motor of Maxon are selected as the power drive system of the magnetic field generating device to control the six degrees of freedom of the permanent magnet generated by the magnetic field. . The smaller permanent magnet polishing tool is brought into contact with the inner cavity of the workpiece under a certain pressure by the external permanent magnet, and rotates on the surface of the inner cavity of the workpiece at a certain rotation speed, thereby polishing the inner cavity surface of the workpiece.

Based on the test platform of the polishing apparatus, a material removal function model was established to analyze the material removal amount and material removal error of the workpiece cavity surface. Select the appropriate polishing parameters, polish the surface of the workpiece cavity and measure the accuracy, and analyze the polishing results.

2. Permanent Magnet Device Polishing

The permanent magnet magnetic field generating device generally uses the property of the magnetic field around the permanent magnet to control the movement of the permanent magnet, and generates a



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

permanent magnet of the spatial magnetic field, which is called a magnetic field generating permanent magnet, and the remotely operated permanent magnet is called a target permanent magnet[4]. When the magnetic field occurs, the permanent magnet is stationary in a stable space environment, and the distribution of the spatial magnetic field around it is fixed. Therefore, when a changing magnetic field is required, it is generally achieved by changing the position of the permanent magnet to cause the magnetic field to generate permanent magnet motion.

Based on the permanent magnet magnetic field generating device, a device capable of polishing the surface of the inner cavity of the workpiece by using a magnetic field remote manipulation polishing tool is designed. The permanent magnet is selected as the magnetic field generating source of the magnetic field teleoperation system; the DC motor is used to drive the permanent magnet to rotate around its own axis to generate a degree of freedom of the permanent magnet; the six-axis mechanical arm is used to drive the permanent magnet to generate the remaining five degrees of freedom of the permanent magnet. Design the polishing tool structure to meet the requirements of use; and configure the polishing fluid. Finally, a polishing test platform was set up, and a suitable workpiece was selected to polish the inner cavity surface to explore the polishing effect.

3. Preston Empirical Equation

The material removal function refers to the functional relationship between the amount of material removed during processing and the individual polishing parameters. The construction of the polishing material removal function makes the whole process deterministic and is an important basis for the analysis of the workpiece polishing process [5]. The material removal function is used to set the polishing parameters, and the surface accuracy of the workpiece is corrected by planning the polishing tool motion path, eliminating the edge effect, calculating the processing residence time of the polishing tool, etc. [6-8]. At present, the widely used material removal function model is the Preston empirical equation proposed by Princeton in 1927 [9-10].

Preston empirical equation:

$$\frac{dh}{dt} = kPV \quad (1)$$

Where h is the amount of material removed; V is the speed at which the polishing tool moves on the surface of the workpiece; k is the Preston coefficient, which represents all other factors except P , V , and t , including the composition of the polishing fluid, the material of the workpiece, and the polishing environment. Such as the comprehensive factors, there is no mature theory can be analyzed and calculated, which can be obtained through experimental measurements (test measured: $k=2.79 \times 10^{-9}$). P is the pressure applied by the polishing tool to the workpiece. Assuming that the surface of the inner cavity of the polished workpiece is in perfect contact with the polishing tool and the pressure of the workpiece is uniform, then:

$$P = \frac{F_N}{\pi R^2} \quad (2)$$

For the material removal function, the following conditions are required:

- (1) The material removal efficiency of each point on the surface of the workpiece to be polished is the same;
- (2) In the case where the polishing parameters are determined to be constant, the material removal amount of the workpiece surface is proportional to the processing time thereof;
- (3) The material removal function remains stable throughout the polishing process and does not change due to an increase in the amount of removal and a change in the polishing position.

The polishing tool is mainly divided into fixed-point polishing, linear motion polishing and curved motion polishing on the surface of the workpiece cavity. In this paper, the polishing tool is used to polish the surface of the workpiece cavity along the straight line, as shown in Figure 3.1.

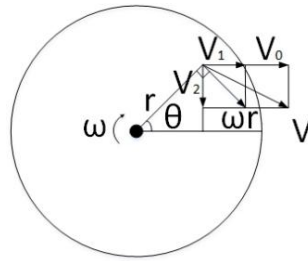


Figure 3. 1. The Speed at which the Polishing Tool Moves on the Surface of the Workpiece

According to Figure 3.1, the rotation speed of any point on the polishing tool is decomposed in the horizontal direction and the vertical direction:

$$\begin{cases} V_1 = \omega r \sin \theta \\ V_2 = \omega r \cos \theta \end{cases} \quad (3)$$

Where ω is the rotation angular velocity of the polishing tool; r is the radius length of the polishing tool at any point on the polishing tool from the center point of the polishing tool; θ is the angle between the arbitrary point on the polishing tool and the center point of the polishing tool relative to the horizontal line.

Find the speed at which any point on the polishing tool moves on the surface of the workpiece:

$$V = \sqrt{(V_1 + V_0)^2 + V_2^2} \quad (4)$$

In the formula, for the linear speed of the polishing tool, the finishing speed is V_0 :

$$V = \sqrt{(\omega r \sin \theta + V_0)^2 + (\omega r \cos \theta)^2} \quad (5)$$

Substituting $V_0 = 0$, the speed at which the polishing tool moves on the surface of the workpiece during fixed-point polishing is:

$$V = \omega r \quad (6)$$

Union Equation 1, Equation 2 and Equation 5:

$$\frac{dh}{dt} = - \frac{3k\mu_0 |\vec{M}| |\vec{m}| \cos \alpha}{5.6\pi^2 x^4 R^2} \sqrt{(\omega r \sin \theta + V_0)^2 + (\omega r \cos \theta)^2} \quad (7)$$

Substituting $V_0 = 0$, the material removal function of the polishing tool during spot polishing can be obtained:

$$\frac{dh}{dt} = - \frac{3k\mu_0 |\vec{M}| |\vec{m}| \omega r \cos \left(\tan^{-1} \frac{12\lambda R}{7x} \right)}{5.6\pi^2 x^4 R^2} \quad (8)$$

In the actual polishing process, the linear speed of the polishing tool is small and much smaller than the rotation speed of any point on the polishing tool, namely:

$$V_0 \leq V_1 \quad (9)$$

Therefore, when analyzing the material removal function model, we think that $V_0 \approx 0$ and V_0 are ignored. Using Matlab, the relationship between the material removal rate $\frac{dh}{dt}$ and the distance from the position of the polishing tool to the center of the polishing tool at different distances x is plotted.

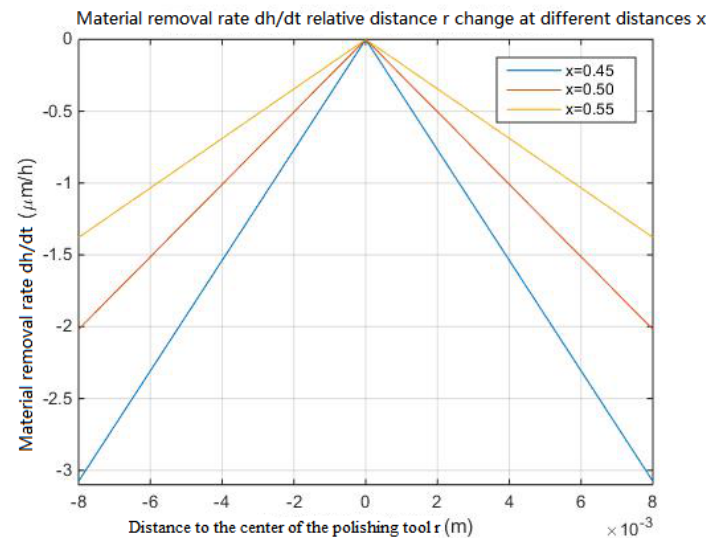


Figure 3. 2. Relationship between Material Removal Rate $\frac{dh}{dt}$ and Distance r at Different Distances x

As can be seen from Fig. 3.2, when the distance between the polishing tool and the permanent magnet x in the magnetic field remote control device is constant, the greater the distance r from the polishing point to the center of the polishing tool, the smaller the material removal rate $\frac{dh}{dt}$, and the larger the absolute value, that is, the same time. The greater the amount of material removed, and the linear relationship. When the distance from the polishing point to the center of the polishing tool is constant, the larger the distance between the polishing tool and the permanent magnet in the magnetic field remote control device, the larger the material removal rate $\frac{dh}{dt}$, and the smaller the absolute value, that is, the material removal in the same time. The smaller the amount.

4. Polishing Test Removal Function Analysis

4.1. Material Removal

When the polishing tool is polished in a linear motion on the surface of the workpiece cavity, the amount of material removed by the polishing tool through a fixed point is the sum of the material removal points of the points on the polishing tool passing through the fixed point, as shown in Figure.

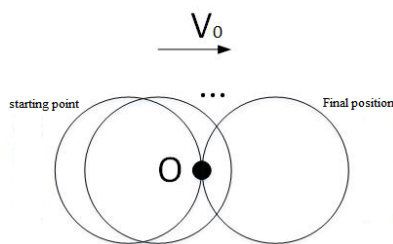


Figure 4.1.a Material Removal at a Fixed Point on the Workpiece

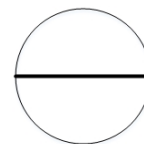


Figure 4.1.b Schematic Diagram of the Simplified Analysis of Removal

Figure 4.1. Analysis of Material Removal

In Figure 4.1a, the polishing tool polishes the O point and moves linearly from the starting position to the final position at a speed of V_0 . The material removal amount at point O is the sum of the material removal amount of each point on the polishing tool $p \frac{dh}{dt}$ passing through the fixed point, that is,

the integral of the polishing material removal efficiency at each point of the horizontal diameter on the polishing tool with respect to time t in Fig. 4.1b, namely:

$$h = \int_0^{\frac{2R}{V_0}} \int_0^R - \frac{6k\mu_0 |\vec{M}| |\vec{m}| \omega r \cos\left(\tan^{-1} \frac{12\lambda R}{7x}\right)}{5.6\pi^2 x^4 R^2} dr dt \quad (10)$$

Solved by Matlab, the material removal of the O point is:

$$h = \int_0^R - \frac{6k \frac{2R}{V_0} \mu_0 |\vec{M}| |\vec{m}| \omega r \cos\left(\tan^{-1} \frac{12\lambda R}{7x}\right)}{5.6\pi^2 x^4 R^2} dr \quad (11)$$

4.2. Polishing Test Verification

A polishing test platform is built to perform fixed-point polishing on the surface of the workpiece cavity. In this paper, the 2207 surface profilometer is used to measure the surface removal of the workpiece. Model 2207 surface profile measuring instrument, including contour measurement, roughness measurement, straightness measurement, waviness measurement and other systems, can be used to measure surface roughness, material removal, straightness and other parameters.

When the polishing parameter is $\omega=10(s^{-1})$, $x=0.05(m)$, $t=1(h)$, the relationship between the material removal amount h and the distance r is obtained, as shown in Fig. 4.2.

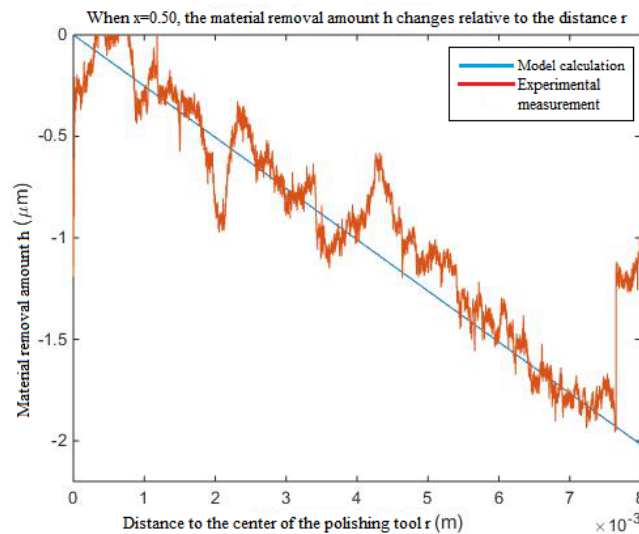


Figure 4.2. Comparison of the Relationship between Material Removal Amount h and Distance r

In this paper, the Zygo NewView 8300 white light interferometer is used to detect the surface quality of the workpiece after polishing. The white light interferometer measures the surface profile of the workpiece based on white light interference technology.

When the polishing parameters are $\omega=10(s^{-1})$, $x=0.05(m)$, $t=1(h)$, the surface roughness of the inner cavity surface after polishing of the workpiece is shown in Fig. 4.3, Fig. 4.3a is the surface roughness of the inner cavity before polishing, and Fig. 4.3b is the surface roughness of the inner cavity after polishing. The surface roughness of the workpiece is processed from $0.102 \mu m (Sa)$ to $0.029 \mu m (Sa)$.

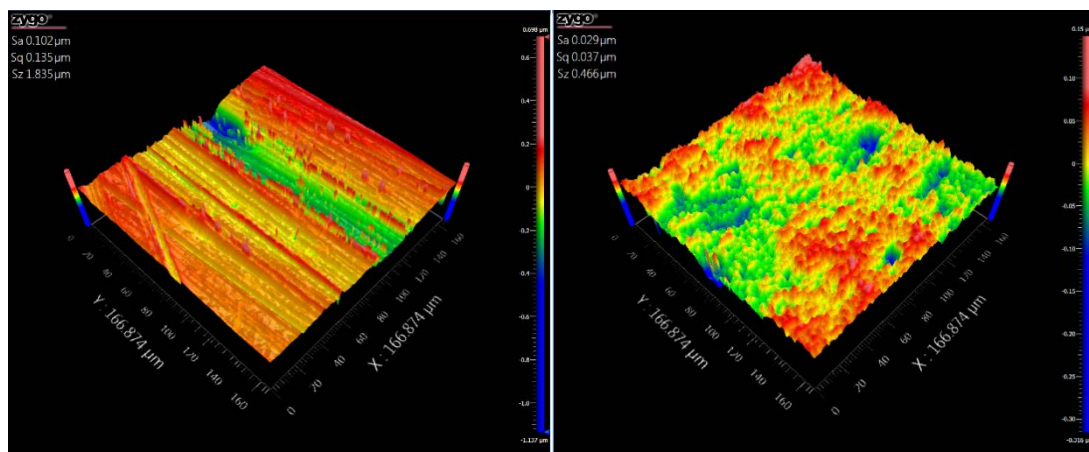


Figure 4.3a Before the Workpiece is Polished Figure 4.3b After the Workpiece is Polished

Figure 4.3. Surface Quality before and after Workpiece Polishing

5. Conclusion

In this paper, we use the Preston empirical equation to obtain the material removal function model of the workpiece. Using Matlab software, draw the material removal function curve, and obtain the material removal rule of the workpiece: when the distance between the polishing point and the permanent magnet x in the magnetic field teleoperation device is constant, the distance r from the polishing point to the center of the polishing tool is larger, the same The greater the amount of material removal during the time; when the distance from the polishing point to the center of the polishing tool is constant, the distance between the polishing tool and the permanent magnet x in the magnetic field remote control device is larger, and the amount of material removal in the same time is smaller. A polishing test platform was built to perform fixed-point polishing on the surface of the workpiece cavity, and the material removal function of the workpiece was verified.

6. Acknowledgment

This work was funded by International Cooperation Project of the Ministry of Science and Technology, China (No. 2016YFE0105100).

7. References

- [1] Li Fuli. Ultra-precision machining technology and its development trend [J]. Shandong Industrial Technology, 2016(24):34-34.
- [2] Zhou Zhixiong, Zhou Qinyuan, Ren Yinghui. Research Status and Development Trend of Complex Surface Machining Technology [J]. Journal of Mechanical Engineering, 2010, 46(17): 105-113.
- [3] Li Na. Research on the influence of surface roughness on the electrical properties of high precision microwave electronic equipment [D]. Xidian University, 2012.
- [4] Mahoney A W, Abbott J J. Managing magnetic force applied to a magnetic device by a rotating dipole field [J]. Applied Physics Letters, 2011, 99(13): 134103.
- [5] Yang Hang, He Jianguo, Huang Wen, et al. Micro-decomposition coupling method for magnetorheological polishing removal function acquisition [J]. Intense Laser and Particle Beams, 2015, 27(8).
- [6] Zhang Wenzhao. Theoretical study on removal function based on computer controlled small grinding head polishing [D]. Tianjin University, 2014.
- [7] Zhang Yanfu, Wang Achun, Wang Bo, et al. Removal Function Model of Atmospheric Pressure Plasma Jet Processing Material[J]. Nanotechnology and Precision Engineering, 2013, 11(4): 354-359.
- [8] He Ting, Shao Jianda, Wei Chaoyang. Research on Femtosecond Laser Polishing Removal

- Function Characteristics [C]// Strong Laser Materials and Components Symposium and Laser Destruction Symposium.
- [9] Zhang Feng. Numerical Control Chemical Mechanical Polishing of Silicon Modified Layer on Aspherical Silicon Carbide Surface [J]. Editorial Office of Optics and Precision Engineering, 2013, 21(12): 3015-3020.
- [10] Yuan Bo. Polishing of viscoelastic materials polishing tools [D]. Jilin University, 2015.