Theoretical analysis and experimental verification of hole surface finishing parts

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Received 1 October 2014, www.cmnt.lv

Abstract

As the main method of improving surface quality, finishing technologies have been developed and applied rapidly in recent years, but they have certain limitations in the hole surface finishing. Based on the principle of centrifugal motion, a kind of hole surface finishing method with self-adaptive ability is putting forward in order to solve the finishing and cleaning problems effectively. The force of the grinding rod is analysed, so the relationship between speed and friction is defined by analysing the minimum speed of the finishing parts theoretically. Finishing parts are designed and experimental study is done. Research results show that hole surface roughness value Ra of seamless steel tube can reduce from 7.0μm to 0.3μm in 50s, which verifies the finishing effect and efficiency.

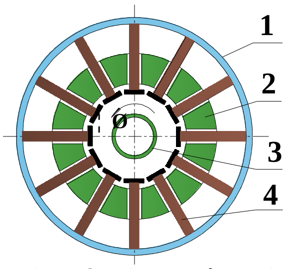
Keywords: finishing, hole surface, centrifugal principle, finishing effect

1 Introduction

In order to obtain lower surface roughness value and good physical-mechanical performance and improve cleanliness of the hole surface, there have been many kinds of precision machining methods to improve hole surface quality and service life. The traditional finishing methods mainly include honing, grinding, rolling, polishing, etc. Non-traditional finishing methods include magnetic abrasive finishing, electrochemical finishing, abrasive jet, ultrasonic grinding, thermal deburring, two-phase flow hole surface finishing, etc. [1-7]. Because of their different technological characteristics, they are difficult to finishing hole surface [1, 2, 8, 9]. Based on centrifugal principle [11], a kind of hole surface finishing method is putting forward in order to solve hole surface finishing and cleaning problem effectively.

As is shown in Figure 1, the whole finishing parts is placed in the hole of the workpiece, and the whole parts rotate in a certain speed driven by electric motor.

Under the centrifugal force, the floating grinding rods placed on the bracket would exert certain force on the hole surface and realize surface finishing finally under the action of relative rotational motion between grinding rods and the workpiece and the axial motion of the automatic feed device.



1) Workpiece 2) Bracket 3) Centre frame 4) Grinding rod
FIGURE 1 Schematic of flexible finishing parts

2 Theoretical analysis

2.1 THE MINIMUM SPEED OF THE GRINDING RODS

The force analysis of the grinding rod when it stays on vertical position is shown in Figure 2. The positive pressure F^n is zero because the grinding rods do not contact with the hole surface. When grinding rods accelerate at the starting moment, it would generate inertia force on the bracket, at the same time, the bracket reacts to the grinding rod. In Figure 2, the F^τ represent the tangential inertia force, F_1 and F_2 are the reactive force on the grinding rod, $F_1^{'}$ and $F_2^{'}$ are the friction force between the grinding rod and bracket.

The rods must overcome gravity and friction force in order to achieve the hole surface finishing, which is:

$$m\omega_0^{\ 2} r > mg + F_1^{'} + F_2^{'}, \qquad (1)$$

where, m is the quality of grinding rod, ω_0 is the minimum angular velocity of centrifugal motion of grinding rod, r is the radius between the centroid of grinding rod and the centre of finishing parts.

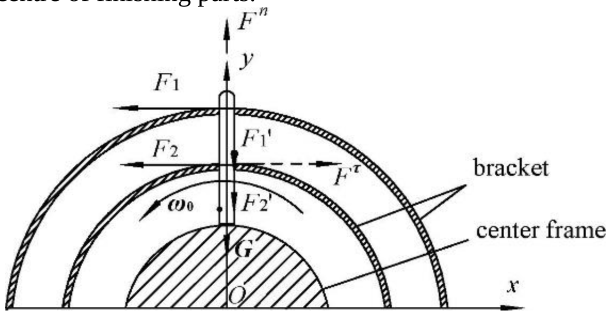


FIGURE 2 Force analysis of grinding rod when finishing parts start rotating

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Assuming the angular acceleration is α when the motor started, the tangential inertial force of the grinding rod is:

$$F^{\tau} = mr\alpha . \quad (2)$$

As $F_1 + F_2 = F_{\tau}$, the friction force between the grinding rod and the bracket is:

$$F_s = F_1^{'} + F_2^{'} = (F_1 + F_2) f = mr\alpha f , \quad (3)$$

where, f is the static friction coefficient between the grinding rod and bracket, Fs is the static friction force between the bracket and the grinding rod. Leading to:

$$\omega_0 \geq \sqrt{\frac{g + r \cdot \alpha \cdot f}{r}} . \quad (4)$$

It can be seen from Equation (4) that the minimum angular velocity is related to the distance r, the friction coefficient f and the starting angular acceleration α.

2.2 RELATIONSHIP BETWEEN SPEED AND GRINDING FORCE

As grinding rods do circular motion along the hole surface, grinding rods will bear the maximum resistance at the vertical direction. Figure 3 shows the force of the grinding rod, where, N is the positive force, F_f is the friction force, F_a and F_b are the positive force on the grinding rod from the outer and inner end of the bracket, and ω is the angular velocity.

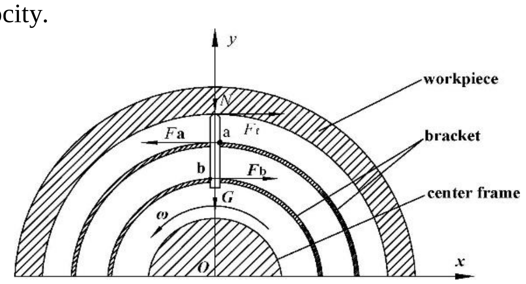


FIGURE 3 Force of grinding rod

Taking the rod as research object, the force balance equations of vertical and horizontal directions are as follows:

$$m\omega^2 r - mg - F_s = 0 , \quad (5)$$

$$F_a - F_f - F_b = 0 . \quad (6)$$

The moment balance equation from the section centre of point a is as follows:

$$F_f \cdot l_1 = F_b \cdot l_2 , \quad (7)$$

where, l_1 is the grinding rod length between the hole surface and the bracket outer end, l_2 is the inner and outer length of the bracket. So:

$$F_a = \left(1 + \frac{l_1}{l_2}\right) F_f , F_b = \frac{l_1}{l_2} F_f , \quad (8)$$

$$F_s = F_a^{'} + F_b^{'} = (F_a + F_b) f = \left(1 + \frac{2l_1}{l_2}\right) F_f f , \quad (9)$$

where, F_s is the static friction force between the bracket and the grinding rod. Synthesizing Equations (5)-(9), ω can be expressed as:

$$\omega = \sqrt{\frac{F_f}{f^{'} \cdot m \cdot r} + \frac{g}{r} + \frac{F_s}{mr}} , \quad (10)$$

thus:

$$\omega = \sqrt{\left(\frac{1}{f^{'} \cdot m \cdot r} + \frac{f}{m \cdot r} + \frac{2l_1 \cdot f}{l_2 \cdot m \cdot r}\right) \cdot F_f + \frac{g}{r}} , \quad (11)$$

so the relationship between angular velocity ω and friction force F_f is defined according to Equation (11). When the finishing parts is designed, f, f', m, r, l_1, l_2 are certain, and different F_f can be obtained with the change of ω, so finishing efficiency can be altered. Figure 4 is the simulation result of relationship between rotational speed n and friction force F_f.

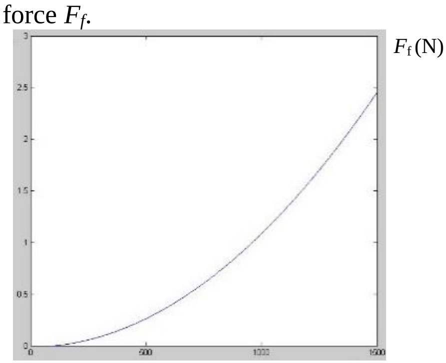


FIGURE 4 Simulation result of relationship between rotational speed and friction force

3 The structure of finishing parts

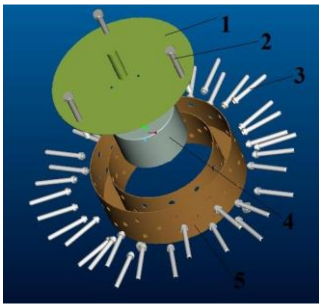
According to centrifugal principle, the structure design of finishing parts should meet the following requirements:

1) The structure of finishing parts should be reasonable and simple and the size should meet the need of flexible finishing.

2) Lighter quality to reduce the startup load of the motor.

3) The guide hole of the grinding rod should be well-distributed and have good guidance and lubricity.

According to the above requirements, finishing parts are designed and consisted of bracket, centre frame and cover plate. As is shown in Figure 5, bolts connect the bracket and centre frame with cover plate, a certain gap is produced between bracket and mandrel. Placing grinding rod into the bracket and the centre frame, grinding rods are supported into the guide hole. The size of bracket and centre frame can be adjusted to meet the need of finishing. Figure 6 is the photos of finishing parts in different positions.



1) Cover plate 2) Bolt 3) Grinding rod 4) Centre frame 5) Bracket
FIGURE 5 Structure of flexible finishing head

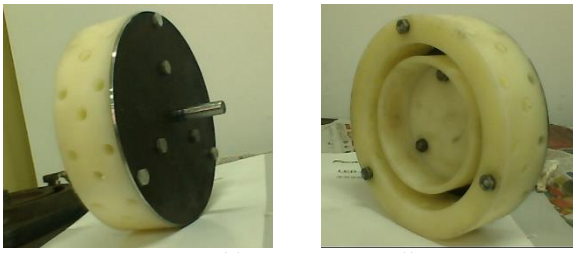
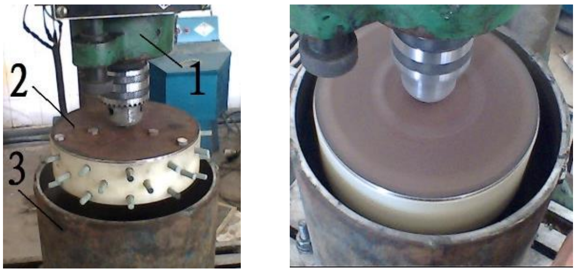


FIGURE 6 Photos of finishing parts in different positions

4 Experimental analysis

Clamping finishing parts on the spindle of the drilling machines, the workpiece (inner diameter is 180mm seamless steel tube in $45^{\#}$ steel) is fixed on the workbench, Figure 7 shows the experimental device and finishing status.



1) Drill 2) Finishing parts 3)Workpiece
FIGURE 7 Photos of experimental device and finishing status

4.1 EFFECTS OF MOTION PARAMETERS ON FINISHING

The motion parameters of finishing parts mainly include rotational speed and feed speed [9, 12]. Figure 8 shows the change curves of surface roughness value Ra along with finishing time with silicon carbide abrasive of 200 meshes and the spindle rotational speed of 800r/min and the axial feed speed of 2m/s and 4mm/s.

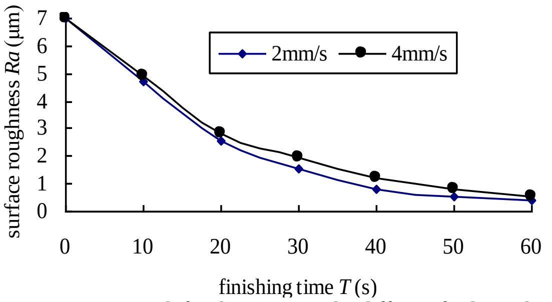
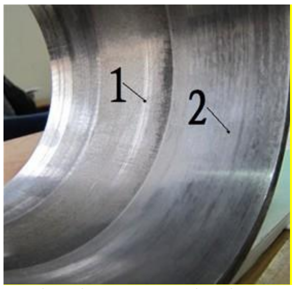


FIGURE 8 *Ra* with finishing time under different feed speed

The contrast photos before and after finishing is shown in Figure 9. The results show that *R*a can be reduced to 0.41μm from 7.0μm within 60s. The time of grinding rods contacting with the certain position of the hole surface depends on the axial feed speed. The lower feed speed is, the longer finishing time on the same position is and the better effect during the same time. *R*a decreased significantly when the feed speed varies from 4mm/s to 2mm/s.



1) before finishing 2) after finishing
FIGURE 9 Contrast photos before and after finishing

With the axial feed speed 2mm/s and rotational speed 1000r/min and 1500r/min under the other same conditions, the change curves of surface roughness value *R*a along with finishing time are shown in Figure 10. The results show that *Ra* can be reduced to 0.3μm from 7.0μm within 50s, which indicates that finishing efficiency will be improved with the increase of rotational speed within certain limits at the same feed speed and the grain size. Experimental results are consistent with theoretical analysis.

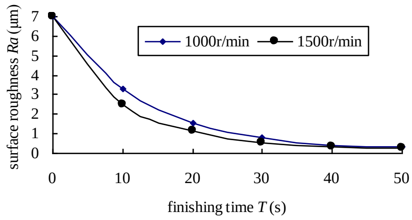
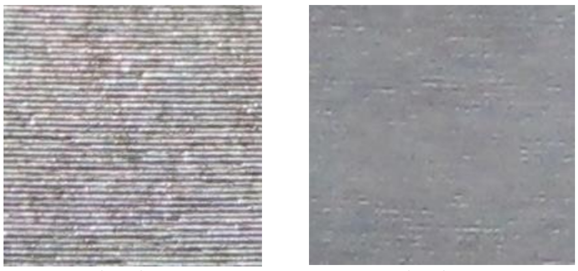


FIGURE 10 *Ra* with finishing time under different rotational speed

Figure 11 shows the surface texture of the workpiece before and after finishing. Results show that surface texture varied from anisotropy to isotropy, which indicates the surface texture has been significantly improved.



a) before finishing b) after finishing
FIGURE 11 Surface texture before and after finishing

4.2 EFFECTS OF THE GRAIN SIZE OF GRINDING ROD ON FINISHING

In order to improve processing efficiency, the grain size of grinding rods should be coarse-grained as soon as possible to meet the requirements of the surface quality. Under the condition that rotational speed is 800r/min, the feed speed is 2mm/s and the grain size of grinding rod is 320 meshes and 600 meshes, the change curves of the surface roughness along with finishing time are shown in Figure 12. The results show that the efficiency of the large grain size is higher than that of the small grain size in a certain range within the same rotational speed, but the surface roughness value is higher under the larger grain size.

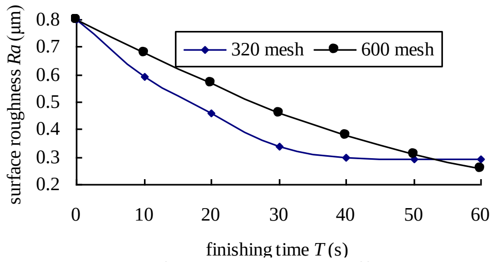


FIGURE 12 *Ra* with finishing time under different grain size of grinding rod

5 Conclusions

Based on centrifugal principle, a kind of hole surface finishing method is put forward in order to realize hole surface finishing and cleaning effectively. The minimum speed and the relationship of speed and grinding force were derived from theoretical analysis of the grinding rods, which provide theoretical basis for the design of finishing parts and experimental study. Experimental study shows that hole surface roughness value *R*a of seamless steel tube has reduced from 7.0μm to 0.3μm in 50s and the surface texture has been significantly improved, which indicates that it has good finishing effect and efficiency.

The structure characteristics of the finishing parts can be described as follows:

1) Good adaptability. The size of finishing parts is flexible and finishing strength can also be controlled. It is suitable for finishing a range of tenuous holes, variable diameter hole, curve hole, elliptical hole and other special hole.

2) Finishing and repairing large parts. For large parts that are not easy to carry, the device can be directly placed on the workpiece to realize finishing and cleaning of the hole surface.

Acknowledgments

This project is supported by national natural science foundation of China (50675149) and provincial natural science foundation of Shanxi (2011021021-4).

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