

Experimental Study of Turning Temperature and Turning Vibration for the Tool of Different Wear State

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Abstract: By a vibration test device and Vib'SYS analysis system, a three-dimensional piezoelectric acceleration sensor and an infrared thermometer and its collection system, the turning experiments under different spindle speeds were carried out on three cutting tools with different wear states, and the change law of cutting temperature at the tool tip and change law of three-dimensional vibration with turning time were obtained. The results indicate that: (1) The temperature of the initial wear tool and the middle wear tool under a small turning parameter increased slowly with turning time; while under a greater turning parameter, the temperature of the middle wear tool varies significantly with time; (2) The temperature of the severe wear tool increased sharply at the later feeding stage; (3) The change laws of the tools vibration acceleration maximum with the spindle speeds are similar for the initial wear tool and the middle wear tool, which shows a trend of increasing at first and then decreasing; (4) the average value of vibration acceleration self-power spectrum of severe wear tool constantly increase with the spindle speed; (5) the maximum impact is along the radial direction for the tools of different wear state.

1 Introduction

During the turning process, the tool surface has a sharp friction with the workpiece, which withstand high temperatures and stresses at the same time. The tool under the action of the cutting heat, turning vibration and friction will gradually wear. Serious wear and tear of the tool will lead to deterioration of the accuracy of the workpiece and reduce equipment life. Therefore, automatic and



real-time monitoring of the wear status of the tool, including the monitoring of turning temperature and turning vibration are particularly necessary. Zhang et al.^[1] studied the effects of tools of different materials and their wear and tear on the turning temperature of titanium matrix. The research shows that the cutting tools of different materials had different turning temperatures. Yang^[2] and so on carried out aluminum rod turning test and establish the turning temperature on the turning parameters of the multiple regression model. Zhao et al.^[3] studied the tool front angle on the impact of turning temperature by the finite element analysis software. Li^[4] reviewed the research situation of turning heat and turning vibration. Song and Huang^[5] established an optimization model of cutting depth based on the tooling parameterization experiment of tool wear. Chen^[6], Ji^[7] and so on carried out the simulation of the turning temperature and obtained the overall distribution of cutting heat. Zhu^[8] introduced a variety of methods to obtain the turning temperature.

Many scholars have studied the vibration mechanism and characteristics of turning. In reference [9], the self-excited vibration is divided into primary flutter and secondary flutter. The primary flutter is mainly caused by the coupling of the tool-workpiece friction and the thermodynamic effect. The reference [10] reviewed the mechanism of cutting chatter, classification, etc. and summarized the flutter detection method. Zhang^[11] established the turning machining mechanics model by Matlab software simulation, which is consistent with ANSYS modal analysis of the simulation results. Guo^[12] established a dynamic model of flutter and simulated the vibration response of the tool. Shao^[13], Meng^[14] carried out the study of different turning parameters under the three-direction vibration of the tool. Zhang^[15] studied the vibration response of the upper and lower surfaces of the tool at different feed rates. Wu^[16] used the acceleration sensor to monitor the vibration signal and studied the tool wear and vibration signal relationship through the signal analysis. Xie^[17] studied the tool wear monitoring method based on vibration testing.

So far, there are many experimental results for turning vibration and turning heat, but the research on the correlation between turning vibration and turning heat, the quantitative properties of turning heat and vibration under different wear conditions is needed to be further explored. In this paper, the signals of three-directional vibration and turning temperature of the tool during the turning process are collected by turning test of three different tool wear states. The vibration response and the turning temperature of the tool under different wear conditions are studied by time domain and frequency domain analysis.

2 Test systems

The CNC lathe was used for turning test, and by the hand-held infrared thermometer the turning temperature of the target point is obtained as shown in Figure 1. The point for measuring temperature was located in the local area of tool tip contacting with the workpiece.



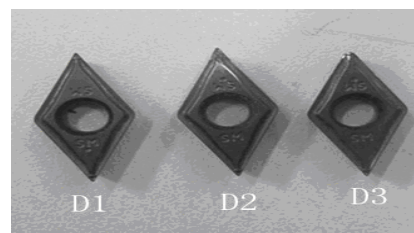
(a) CNC lathes and infrared thermometer

(b) Vibration measuring instruments and sensors

Figure 1 Test equipment

We use the matching OMEGASOFT IR OS5xx Access software and computer to display and record real-time temperature. The three-direction vibration signal of the tool is picked up by the piezoelectric three-direction acceleration sensor. The X, Y and Z directions of the sensor correspond to axial, radial and tangential vibration respectively. The material and size of the workpiece in each turning test are the same. The time of each turning test is 1 minute; the sampling frequency of the thermometer and the vibration signal is 1Hz and 1000Hz respectively.

The workpiece is an aluminum rod with a diameter of 45 mm. The three blades shown in Figure 2 are selected for the turning test: initial wear (D1), medium wear (D2), severe wear (D3).

**Figure 2** Three blades of the different wear states

3 Test plan

Plan 1: Study the effect of spindle speed n on the temperature of the three wear states. For each wear state of the tool, the diameter of the workpiece is the same, given the same feed rate 80mm / min and cutting depth 0.3mm, spindle speed n 800r / min, 1200r / min, 1600r / min. Perform the turning test, the test file name is S1-S9, as shown in Table 1.

Table 1 Turning test program

n (r/min)	f (mm/min)	e (mm)	blade		
			D1	D2	D3
800	80	0.3	S1	S2	S3
1200			S4	S5	S6
1600			S7	S8	S9

Plan 2: Study the influence of the spindle speed on the vibration of the three wear states. Test Number is S10 ~ S21, the test program is shown in Table 2.

Table 2 Turning test program

n (r/min)	f (mm/min)	e (mm)	blade		
			D1	D2	D3
800	80	0.3	S10	S14	S18
1200			S11	S15	S19
1600			S12	S16	S20
2000			S13	S17	S21

4 Test results and analysis

4.1 Effect of spindle speed on the temperature of the tool in different wear conditions

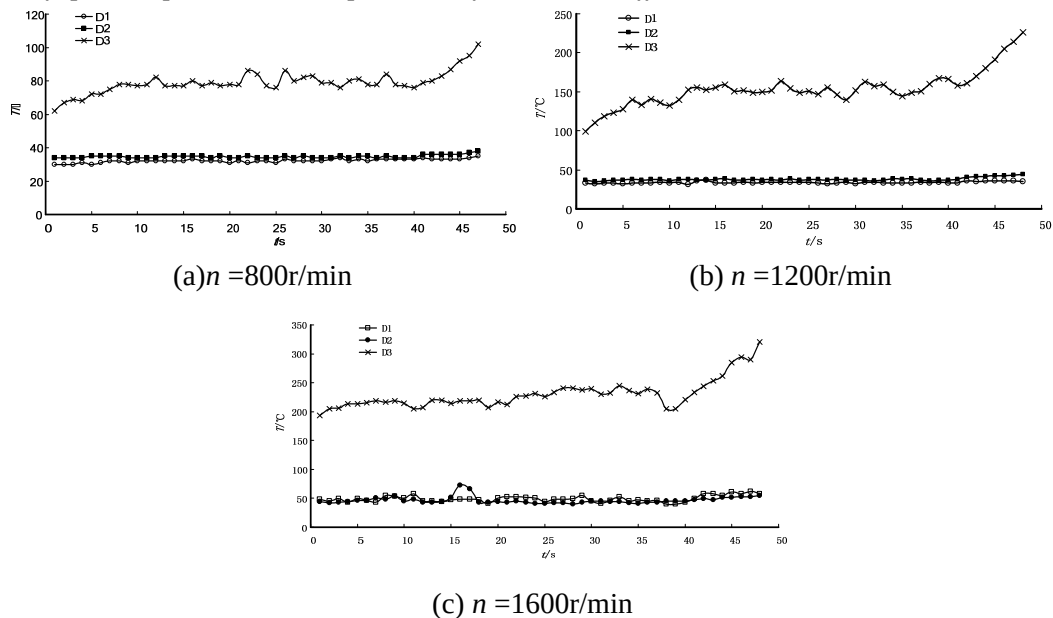


Figure 3 Time curves of turning temperature under different spindle speed

According to the turning test of plan 1, the temperature variation with different turning speed at the tip of the tool under three kinds of wear conditions can be obtained shown in Fig. 3a, b, c according to the turning tests.

It can be seen from Figure 3 that : (1) The temperature of the tool for the initial wear (D1) and the medium wear (D2) during the turning process is relatively gentle at the same spindle speed and the same workpiece size, and the temperature of D2 is slightly higher than that of D1; (2)The temperature of the serious wear tool (D3) was significantly higher than D1, D2, and it can reach 2-5 times of that of D1 and D2 tool ; (3) The D3 tool temperature rises sharply at the later stage of turning.

4.2 Time domain analysis of vibration signals

According to the plan 2 for turning test, use vibration equipment and Vib'SYS signal analysis

software to get the time-domain curve of tool vibration acceleration. Record the maximum acceleration $a_{\max}$ of three channels for the tool of different wear state at different spindle speed. Draw curves of $a_{\max}$ changing with the spindle speed n for the tools of different wear state as shown in Figure 4. a,b,c.

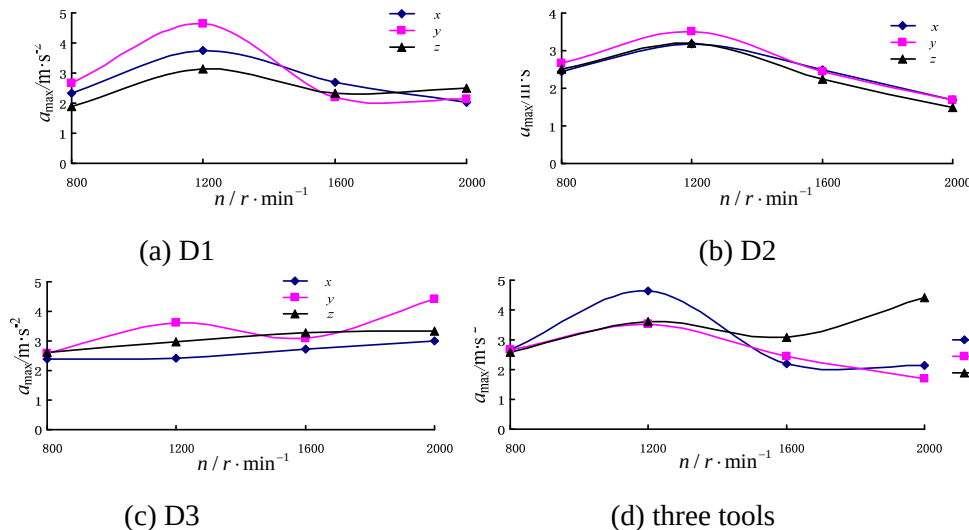


Figure 4 $a_{\max}$ - n curve of three-direction vibration of different cutting tool

According to Figure 4 we can see:

(1) With the spindle speed increases, the acceleration maximum $a_{\max}$ of the initial wear and normal wear tool first increased and then reduced; when the spindle speed is 1200r / min, acceleration $a_{\max}$ in three directions have reached the maximum.

(2) With the spindle speed increases, three-direction vibration acceleration $a_{\max}$ corresponding to serious wear tool also continue to increase;

(3) For the tools of the three different wear states, radial vibration acceleration $a_{\max}$ changes the most significantly.

Taking into account that for the three tools D1, D2 and D3 their axial vibration changes the most significantly, we draw their $a_{\max}$ - n curve as shown in Figure 4.d.

According to Figure 4.d we can see:

(1) At lower speed, vibration acceleration value of D1 tool is the largest. For the tool of initial wear state, due to the inhomogeneity of its surface roughness and stress distribution and due to the other reasons, in the turning process its wear is faster and the vibration changes are more significant. Increasing the spindle speed can effectively reduce the acceleration of initial wear tool.

(2) The normal wear tool, because the tool surface roughness and stress distribution is relatively uniform, its vibration acceleration gradually reduced as the spindle speed increases.

(3) Serious wear tool, which has been unable to use normally, its vibration acceleration increases significantly with the increase of the spindle speed.

4.3 Frequency domain analysis of vibration signals

By Frequency domain analysis we can obtain the self-power spectrum curve corresponding to

Figure 4. Calculate the power spectrum mean $\bar{\rho}$ and draw the $\bar{\rho}$ - n curves for three different wear tools as shown in Figure 5.

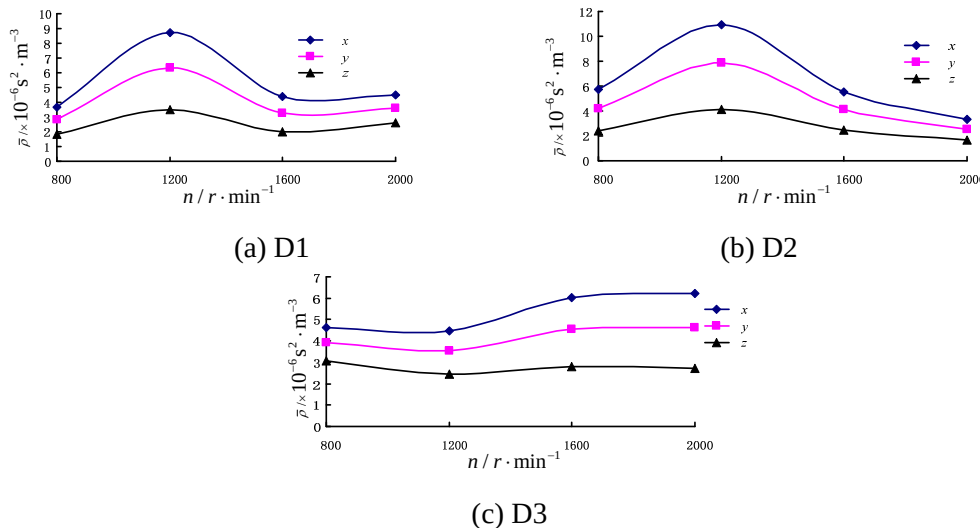


Figure 5 The $\bar{\rho}$ - n curves of different wear tools

According to Figure 5 we can see: (1) For initial wear and normal wear tool their basic change trend of the mean value $\bar{\rho}$ with the spindle speed is identical. The $\bar{\rho}$ value increases at first and then reduces with the spindle speed and it reaches the maximum at the speed of 1200r / min. (2) The $\bar{\rho}$ corresponding to the severe wear tool increases with the spindle speed and become stable when the spindle speed increases to 1600r / min. (3) At the same speed, self-power spectrum mean in the axial direction is maximum for the three wear tool.

5 Conclusions

By turning experiments under the same turning parameters and the same work-piece size on the three tools with different wear state, we have obtained the following conclusions: (1) The temperature corresponding to the tool of initial wear state increases with turning time slowly; (2) The temperature corresponding to the tool of middle wear state is slightly higher than that of the tool of initial wear state and its temperature has a significant change under the bigger turning parameter; (3) The temperature of the severe wear tool increased sharply at the later feeding stage; (4) With the increase in spindle speed the average turning temperature value increases and the average turning temperature of the severe wear tool is nearly five times of temperature of initial wear tool; (5) With the increase in spindle speed, the impact to the tools of initial wear and middle wear constantly decreases and the impact to the tool of severe wear constantly increases; (6) The vibration of the severe wear tool is the strongest and vibration of the middle wear tool is the weakest.

Acknowledgements

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