Research on Tool Wear Monitoring and Turning Simulation

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Abstract. The condition of cutting tool has a direct effect on processing quality, productivity and produce cost. So, it is very important to monitor tool condition in cutting process. The on line monitoring of tool wear is an important topic in the research of flexible manufacturing system. Cutting force is one of the important physical parameters in cutting process, which affects tool wear and machined surface quality. The correlation between cutting force and tool wear is experimentally analyzed. It is proposed that the change of tool cutting force is consistent with the change of wear. The simulation study of turning processing based on finite element analysis software Deform 3D. The size distribution of cutting force was simulated, the simulation results and the test results were compared and analyzed, which provided guiding significance for the determination of process parameters.

1. Introduction
The cutting tool can withstand higher temperature and mechanical shock during machining, which will cause the tool to wear, and the residual stresses will accelerate tool wear and influence the surface machining quality of the workpiece[1-3].

As an important part of advanced manufacturing technology, tool state intelligent monitoring technology is an emerging technology developed on the basis of modern sensor technology, signal processing technology, computer technology and manufacturing technology[4]. Many scholars at home and abroad are devoted to the research of on-line monitoring technology for tool wear, among them, R Teti et al. [5], JT Roth et al. [6] and JV abellan-nebot et al. [7] summarized the development status of tool wear monitoring technology from the perspectives of sensor signal selection, signal processing and pattern recognition.

304 stainless steel is a kind of universal stainless steel, which is widely used in the production of equipment and parts requiring good comprehensive performance. Cemented carbide has high hardness and good abrasion resistance. It is one of the commonly used tool materials for processing 304 stainless steel. Wc-co cemented carbide is widely used in cutting tools, mining tools and wear-resistant parts due to its high hardness, high red hardness, high strength and toughness[8-10].

There are two methods to monitor tool wear: direct measurement and indirect measurement. The direct method is to directly measure the size of the tool wear surface or the change of cutting edge shape when the tool is damaged. The advantage is high accuracy, but common direct measurement needs to stop monitoring, which can not achieve the purpose of online monitoring, thus affecting the processing efficiency[11]. The indirect method can obtain the working condition information indirectly by detecting the signal change between one or several parameters which have a strong internal connection with tool wear and damage. The advantage is that it can realize on-line real-time monitoring. Indirect measurement method is closer to the requirement of online monitoring[12], and cutting force monitoring method is adopted in this paper.

With the successful application of finite element method in the field of machining, the process of
tool wear can be predicted by studying tool wear mechanism, and the information of tool stress, strain and temperature distribution can be obtained through simulation, which is directly related to tool wear[13]. The simulation study of turning processing based on finite element analysis software Deform 3D. The size distribution of cutting force was simulated, the simulation results and the test results were compared and analyzed, which provided guiding significance for the determination of process parameters.

2. Experiment

2.1. Experimental equipment and materials
The equipment used in the experiment includes numerical control lathe, image measuring instrument and dynamometer. The experimental tool is YW1 carbide blade and the workpiece material is 304 stainless steel. Cutting conditions: dry cutting. The mechanical properties of YW1 tool are shown in Table 1. Mechanical properties of 304 stainless steel are shown in Table 2. The cutting parameters are listed in Table 3.

| Mechanical property            | YW1  |
|-------------------------------|------|
| Hardness /HRA                 | 91   |
| Bending strength /MPa         | 1290 |
| Tensile strength /MPa         | ≥1300|
| Density (g/cm³)               | 12.6~13.5 |

| Mechanical property            | 304 stainless steel |
|-------------------------------|---------------------|
| Hardness /HRB                 | ≤92                 |
| Tensile strength /MPa         | ≥520                |
| Yield strength /MPa           | ≥205                |
| Elongation/%                  | ≥40                 |
| Area reduction/%              | ≥60                 |

| Technics | Cutting speed (m/min) | Cutting depth (mm) | Feed rate (mm/r) |
|----------|-----------------------|--------------------|------------------|
| NA       | 50                    | 0.8                | 0.3              |
| NB       | 60                    | 0.8                | 0.3              |
| NC       | 70                    | 0.8                | 0.3              |

2.2 Experimental process
The cutting force sensor adopts the Kistler 9257B dynamometer manufactured by Swiss company. During the turning test, the cutting force was collected during the external round cutting process. The force in X, Y and Z direction was collected using Kistler 9257B piezoelectric dynamometer. The charge signal generated by the dynamometer was amplified by Kistler 5070 charge amplifier and transmitted to the computer through the data acquisition card. The block diagram of cutting force system design is shown in Figure 1.
The cutting tool is used for turning the outer circle on the numerical control lathe. During the experiment, after cutting the cutter for a certain distance, the blade was taken off, and the abrasion of the tool surface was measured with an image measuring instrument. Meanwhile, the cutting force was measured with dynamometer.

3. Results and discussion

3.1. Analysis of cutting force and wear
Cutting force is one of the important physical parameters in the process of cutting. Studying the rule of cutting force is helpful to analyze the process of cutting, which is of great guiding significance for determining reasonable cutting amount and improving machining efficiency.

The variation curve of the cutter's main cutting force and wear amount can be obtained by changing cutting speed without changing cutting depth and feed amount, as shown in Figure 2 and Figure 3.

![Figure 2. The effect of cutting speed on main cutting force](image1)

![Figure 3. The effect of cutting speed on wear extent](image2)

It can be seen from Figure 2 that between different cutting speeds, the main cutting force in each segment decreases slightly as the cutting speed increases. Generally speaking, the cutting depth has the greatest impact on the cutting force, followed by the amount of feed and finally the cutting speed.

As can be seen from Figure 3, the cutting speed increases, the amount of wear increases slightly.

It can be seen from Figure 2 and Figure 3 that under the same process conditions, the main cutting force and wear curve of the cutter change consistently. The trend of subsection change in each process is also generally consistent. Therefore, the change of cutting force to monitor the change of wear has certain research value and scientific basis.

In order to test whether the result of tool state change is reliable by monitoring the change of cutting force signal, take process NA as an example, the cutting depth $ap=0.8\text{mm}$, the feed rate $f=0.3\text{mm/r}$, and the cutting speed $Vc=50\text{m/min}$. Figure 4 shows the change curve of main cutting force and wear.
Figure 4. Change curve of main cutting force and wear extent

It can be seen from Figure 4 that the tool wear goes through three stages, namely the initial wear, normal wear and severe wear. With the extension of the cutting process, the cutting force increases with the increase of cutting distance (time), mainly due to the sharp wear of the cutter and the increase of cutting edge radius in the cutting process, so the cutting force increases with the increase of cutting distance.

As the most stable and reliable signal in machining process, cutting force signal is closely related to tool wear and damage. In addition, the successful application of force sensor in industry makes the cutting force monitoring technology most widely used in the research field of tool wear monitoring, which is also the most advantageous method.

3.2. Analysis of cutting force simulation
In the process of metal cutting, the cutting force includes the main cutting force, feed force and back force. The main cutting force is to calculate the strength of the lathe, design the machine parts and determine the power of the machine tool. Therefore, the main cutting force is selected as the research object.

Figure 5 showed the diagram of the simulation analysis of turning process in Deform-3D environment.
The cutting model is used to describe the machining process by using feed rate \( f \), cutting speed \( V_c \), and cutting depth \( a_p \). The influence of these parameters on the machining process is analyzed by analyzing the degree of simulation and simulation results.

The orthogonal experimental parameter and numerical comparison of cutting force simulation and experimental results was shown in Table 4.

### Tab.4 Orthogonal experimental parameter and simulation and experimental results

| Number | \( a_p \) (mm) | \( f \) (mm/r) | \( V_c \) (m/min) | Simulation values (N) | Experiment values (N) | Error (%) |
|--------|----------------|----------------|-------------------|-----------------------|-----------------------|-----------|
| 1      | 0.5            | 0.15           | 50                | 806                   | 883.6                 | 9.6       |
| 2      | 0.5            | 0.2            | 60                | 841                   | 879.2                 | 4.5       |
| 3      | 0.5            | 0.25           | 70                | 874                   | 905.5                 | 3.6       |
| 4      | 0.8            | 0.15           | 60                | 862                   | 854.8                 | 0.8       |
| 5      | 0.8            | 0.2            | 70                | 883                   | 913.2                 | 3.4       |
| 6      | 0.8            | 0.25           | 50                | 958                   | 946.1                 | -1.2      |
| 7      | 1.1            | 0.15           | 70                | 894                   | 935.6                 | 4.7       |
| 8      | 1.1            | 0.2            | 50                | 956                   | 981.3                 | 2.6       |
| 9      | 1.1            | 0.25           | 60                | 982                   | 1012.2                | 3.1       |

It can be seen from Table 4 that the error is within 10%, considering that the failure and friction conditions of the material in the actual cutting are very complicated, so the simulation results are acceptable. The DEFORM simulation is under ideal conditions, there are various influencing factors in actual processing, and it can be seen that there is a certain error between the simulated value of cutting force and the experimental value. But the overall error is small, within acceptable limits.

In order to verify the reliability of the cutting results obtained by simulation, the same experimental parameters are used to compare the results of the cutting force measured with the simulation results. Such as \( a_p=0.5 \text{mm} \), \( f=0.2 \text{mm/r} \) and \( V_c=60 \text{m/min} \).

Figure 6 showed the experimental curve of the cutting force measured by the dynamometer. Figure 7 showed the 3D simulation curve of cutting force.

![Figure 6. The experimental curve of the cutting force](image-url)
Figure 7. The 3D simulation curve of cutting force

It can be seen from the Figure 6 and Figure 7 that when the tool cuts the workpiece, cutting force over a period of time will reach the steady value, and the value within a certain range, in the actual experiment, the image characteristics obtained by the dynamometer and software are consistent.

4. Conclusions
The on line monitoring of tool wear is an important topic in the research of flexible manufacturing system. Cutting force is one of the important physical parameters in cutting process, which affects tool wear and machined surface quality. During the turning process, the amplitude of the cutting force signal changes with the change of the cutting state. It is an ideal monitoring method to monitor the tool wear state by using cutting force.

In this paper, The correlation between cutting force and tool wear is experimentally analyzed, and it is suggested that the change of cutting force is consistent with the change of tool wear. The simulation study of turning processing based on finite element analysis software Deform 3D. The size distribution of cutting force was simulated, the simulation results and the test results were compared and analyzed, which provided guiding significance for the determination of process parameters.

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