Influence of Milling Parameters on Milling Performance of 300M Ultra High Strength Steel

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Abstract. The influence of cutting parameters (cutting speed \( v \), feed per tooth \( f_z \), cutting depth \( a_p \) and cutting width \( a_e \)) on cutting force and cutting temperature is analysed by orthogonal test method, and the prediction model of cutting force and cutting temperature is established. The results show that the cutting force decreases with the increase of cutting speed, but the cutting force increases with the increase of feed per tooth and cutting width, and cutting force increases with the increase of cutting depth, and the effect of cutting depth on cutting force is most significant. The cutting temperature increases with the increase of the four cutting parameters, and the effect of cutting width on cutting temperature is most significant. The prediction model of cutting force and cutting temperature can provide reference for choosing cutting parameters in actual machining.

1. Introduction
The aircraft landing gear is subjected to tremendous impact and load during the take-off and landing of the aircraft [1]. 300M ultra-high strength steel as aircraft landing gear manufacturing materials, with high strength, high hardness, low thermal conductivity and other significant characteristics, and it is a typical aviation difficult-to-cut material [2]. It has many problems such as cutting force, tool wear and low efficiency in machining. [3] Milling is an indispensable technological step in aircraft landing gear technology. Milling force is one of the important physical parameters in the milling process. The study of cutting force in the milling process is very important to the efficient machining and process analysis of 300M steel [4].

At present, scholars have done many researches on 300M steel, mainly focusing on the microstructure and properties, tool wear and so on, while the research on milling properties of 300M steel is relatively less. Liu Weimin et al. based on the orthogonal test method, the empirical formula of tool life for high-speed turning of 300M steel with Al\(_2\)O\(_3\)-based ceramic tools was established [5]. Liu Yizhi et al. established the forecasting model of the temperature field of the workpiece end of the orthogonal Turning-Milling complex difficult-to-machine material; and the model was verified by the orthogonal Turning-Milling test of 300M steel [6]. Xie Junxian et al. milling 300M steel with coated cutter was studied experimentally, and the mechanism of tool wears in milling 300M steel was analyzed, [7]. Chen Xiaomin et al. studied the hot deformation behavior and microstructure evolution of 300M steel through experiments, and analyzed the stress-strain curves at various temperatures [8]. Liu
yinggang et al. performed a high temperature thermal deformation compression test on 300M steel, observed the metallographic structure under various deformation conditions [9].

In this paper, a three-dimensional simulation model is established by using the Third Wave AdvantEdge FEM software. The influence of different cutting parameters on cutting force and cutting temperature in the milling process of 300M steel is analyzed, which provides a parameter basis for milling optimization of 300M steel.

2. Simulation Test
In this paper, the AdvantEdge FEM simulation software is used to carry out three-dimensional milling of 300M steel and predict the change of cutting force and cutting temperature in the cutting process. The workpiece material is 300M steel (550Bhn), the chemical composition is shown in Table 1, the mechanical properties are shown in Table 2, and the tool material is CBN. Considering the interaction between cutting parameters, orthogonal experiment is used to simulate cutting force and cutting temperature. The orthogonal level is shown in Table 3.

### Table 1. Chemical Composition of 300M Steel (%)

| C   | Mn  | Si  | Cr  | Ni  | Mo  | V   | P   | S   | Fe  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.43| 0.775 | 1.625 | 0.825 | 1.825 | 0.375 | 0.05 | 0.035 | 0.04 | Bal. |

### Table 2. Mechanical properties of 300M steel

| Tensile strength σ₀/MPa | Yield strength σ₀.2/MPa | Reduction of area ψ/% | Elongation δ/% | Elastic modulus E/GPa |
|--------------------------|--------------------------|-----------------------|----------------|----------------------|
| 1970                     | 1655                     | 34%                   | 9.5%           | 199                  |

### Table 3. 300M test factor level table

| Level | v(m/min) | fz (mm/z) | ae (mm) | ap (mm) |
|-------|----------|-----------|---------|---------|
| 1     | 200      | 0.05      | 2       | 0.4     |
| 2     | 250      | 0.06      | 4       | 0.6     |
| 3     | 300      | 0.07      | 6       | 1.8     |
| 4     | 350      | 0.08      | 8       | 1.0     |

3. Simulation result analysis

3.1. Cutting temperature and cutting stress analysis
Fig. 1 is a cutting temperature distribution diagram of the cutting area. As can be seen from Fig. 1, the cutting temperature is mainly distributed in the primary deformation and the secondary deformation zones. Among them, the cutting temperature of the contact area between the workpiece and tool tip is the highest, the highest cutting temperature is 941 °C, and the cutting temperature is gradually reduced along the cutting area. As can be seen from Fig. 1, the temperature of the chip is higher and the average temperature is 883 °C. During the entire cutting process, the chips carry a lot of heat and play an important role in the heat dissipation process. Fig. 2 is a stress distribution diagram of the cutting area. As can be seen from Fig. 2, the cutting stress is mainly distributed in the primary deformation zone, and the maximum stress is concentrated on the intersection of the tool, workpiece and chip, and gradually decreases along the end of the chip. Among them, the maximum stress at the contact area between the chip and the tool tip is 1000 MPa.
3.2. Cutting parameter analysis

Fig. 3 is the effect of cutting parameters on cutting force and cutting temperature. As shown in Fig. 3(a), in the range of parameters obtained in the simulation test, the cutting force gradually decrease with the increase of cutting speed, and the cutting temperature gradually increase with the increase of cutting speed. As shown in Fig. 3(b), the cutting force and the cutting temperature increase with the increase of feed per tooth. As shown in Fig. 3(c), the increases, the cutting force and the cutting temperature gradually increase with the increase of cutting width. As shown in Fig. 3(d), the cutting force and the cutting temperature gradually increase with the increase of cutting depth.

4. Establishing the Prediction Models

4.1. Establishing the Prediction Models

In high-speed milling condition, cutting parameters are the main factors that affect cutting force and cutting temperature. According to the statement of metal cutting, the least square method is used to establish the prediction model of cutting force and cutting temperature:
Figure 3. Effects of cutting parameters on cutting forces and cutting temperature.

\[
\begin{align*}
F &= K_F V^{b_1} f_z^{b_2} a_e^{b_3} a_p^{b_4} \\
T &= K_T V^{b_1} f_z^{b_2} a_e^{b_3} a_p^{b_4}
\end{align*}
\]  
(1)

Where $K_F$ is the correction factor which is determined by the processing material and cutting conditions, and $v$ is the cutting speed, $f_z$ is the feed per tooth, $a_p$ is the cutting depth and $a_e$ is the cutting width; $b_1$, $b_2$, $b_3$ and $b_4$ are the index of each variable which is to be determined. Under high-speed milling condition, the prediction models of cutting forces can be expressed as:

\[
\begin{align*}
F_z &= 1560.2709V^{-0.0095} f_z^{0.4239} a_e^{0.0381} a_p^{0.8457} \\
F_x &= 578.6287V^{0.0091} f_z^{0.5003} a_e^{0.2681} a_p^{0.5574} \\
F_y &= 284.0534V^{-0.0261} f_z^{0.2856} a_e^{0.0539} a_p^{-0.0040}
\end{align*}
\]  
(2)

Similarly, under high-speed milling condition, the prediction model of cutting temperature can be expressed as:

\[
T = 446.3751V^{0.1685} f_z^{0.1173} a_e^{0.0741} a_p^{-0.0156}
\]  
(3)
4.2. Significance test of prediction models

The significance of the prediction models is confirmed by F distribution test. Significant level $\alpha=0.05$, $F_{0.05}(p, n-p-1) = F_{0.05}(4, 11) = 3.36$. It can be seen from Table 4 that the F value of $F_x$, $F_y$ and $T$ is greater than $F_{0.05}=3.36$. The $F_z$ test value is less than $F_{0.05}=3.36$ and the prediction model of cutting force $F_z$ fitting degree is low.

Table 4. Significance analysis of prediction model

|       | Square sum | Freedom | Mean square | $F_{0.05}$ |
|-------|------------|---------|-------------|------------|
| $F_x$ | 0.272      | 4       | 0.068       | 157.438    |
| $F_y$ | 0.192      | 4       | 0.048       | 3.634      |
| $F_z$ | 0.010      | 4       | 0.003       | 1.846      |
| $T$   | 0.011      | 4       | 0.003       | 6.235      |

4.3. Significance test of prediction models

The significance of the model coefficients is confirmed by t-test. Significant level $\alpha=0.05$, $t_{0.025}(n-p-1) = t_{0.025}(11) = 2.201$. As shown in Table 5, the effect of cutting depth on cutting force $F_x$ and $F_y$ is most significant, and the effect of feed per tooth on cutting force $F_z$ is most important, and the effect of cutting width on cutting temperature is most important.

Table 5. Significance analysis of prediction model

|       | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\beta_4$ | $t_{0.025}$ |
|-------|-----------|-----------|-----------|-----------|-------------|
| $F_x$ | 0.162     | 6.170     | 1.625     | 23.968    | $\beta_4>\beta_2>\beta_1$ |
| $F_y$ | 0.028     | 1.316     | 2.066     | 2.857     | $\beta_4>\beta_3>\beta_2>\beta_1$ |
| $F_z$ | 0.251     | 2.341     | 1.296     | 0.064     | $\beta_2>\beta_1>\beta_3>\beta_4$ |
| $T$   | 2.843     | 1.688     | 3.121     | 0.437     | $\beta_3>\beta_1>\beta_2>\beta_4$ |

5. Conclusion

In this paper, the influence of different cutting parameters on cutting force and cutting temperature in high speed milling of 300M steel is studied by the Third Wave AdvantEdge FEM software. The results show that the cutting force decreases with the increase of cutting speed, but the cutting force increases with the increase of feed per tooth and cutting width, and cutting force increases with the increase of cutting depth, and the effect of cutting depth on cutting force is most significant. The cutting temperature increases with the increase of the four cutting parameters, and the effect of cutting width on cutting temperature is most significant. Therefore, higher cutting speed, moderate cutting width, feed per tooth and lower cutting depth should be selected in actual machining. The prediction model of cutting force and cutting temperature can provide a certain reference for the selection of cutting parameters in actual machining.

Acknowledgments

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