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Predictive Analysis of Flutter Stability of Regenerative Cutting Chatter on Machine Tools

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Abstract: Flutter phenomenon is a factor that has a great influence on the stability during the machining process of a machine tool. It has a great limitation on the machining efficiency of the machine tool and the machining accuracy of the workpiece. This paper analyzes the mechanism of machine regrind chatter, and studies the stability of the lathe cutting process, and uses the simulation program developed to simulate the stability of turning.
Keywords: Regenerative chatter; stability; lobe diagram; prediction.

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1. INTRODUCTION

As we all know, chatter vibration refers to a kind of self-excited vibration phenomenon that occurs in the cutting process, and is a key factor that affects the machining efficiency. It will not only reduce the surface quality and machining accuracy of the parts being machined, but it will also damage the tools and machine tools, increasing production costs [1,2]. The stability lobe diagram is a graph that is used to predict whether the cutting is stable through dynamic modeling analysis, and the use of this graph can achieve efficient chatter-free cutting [3-6]. Some foreign researchers proposed the use of computer simulation methods to predict the stability limit of the machine tool cutting system [7-10], and select the cutting parameters for stable cutting, so that the cutting process in the stable area [11].

2. FLUTTER MECHANISM

2.1 Cutting Flutter Overview

The vibrations that occur during the metal cutting process are generally divided into two categories: forced vibration and self-excited vibration. Forced vibration is a kind of vibration that is induced by the external vibration of the machine tool or the internal cyclic excitation source to the machine tool structure. Self-excited vibration refers to the stable periodic vibration generated by the internal excitation and feedback interactions of the system without periodic external forces. Self-excited vibration system as shown Fig. 1 .

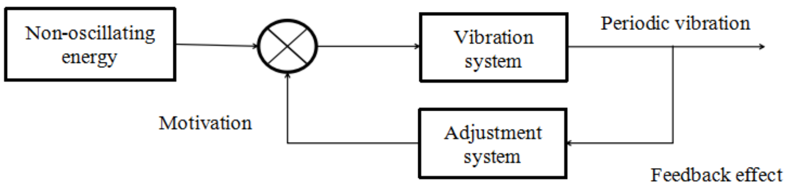

Fig. 1 Self-excited vibration system

As we all know, chatter vibration refers to a kind of self-excited vibration phenomenon that occurs in the cutting process and is a key factor that affects the cutting machining efficiency. It will not only reduce the surface quality and machining accuracy of the parts being machined, but it will also damage the tools and machine tools, increasing production costs. There are many types of chatter vibrations, such as friction chatter, coupled chatter, and regenerative chatter, and their mechanisms vary. They can be broadly divided into: the forced chatter generated by various forcing sources and the self-excited self-excited chatter, although there is no forced source. In the latter, regenerative chattering and frictional chattering are often encountered. Among them, the regenerative chatter is the form of chatter that has the greatest influence on the cutting process. The generation of regenerative chatter is due to the regenerative effect, and there is a regenerative effect in almost all actual cutting and grinding processes.

2.2 Mechanism of Regenerate Flutter

During the cutting process, the ripples left on the machining surface due to vibration during the previous cutting process cause the cutting force to fluctuate when the blade is cut again to the same place at the next time. This is the regenerative effect caused by Robert S. Hahn. In 1954, the paper was first proposed in the analysis of the grinding condition of the inner circle, and this phenomenon was named regenerative. The main cause of regenerative chatter vibration is the dynamic cutting thickness change caused by the phase difference between two consecutive chatter marks during the cutting process. When the dynamic cutting thickness changes to a certain degree, regenerative chatter vibration will occur phenomenon.Fig. 2 shows a sketch of dynamic cutting thickness

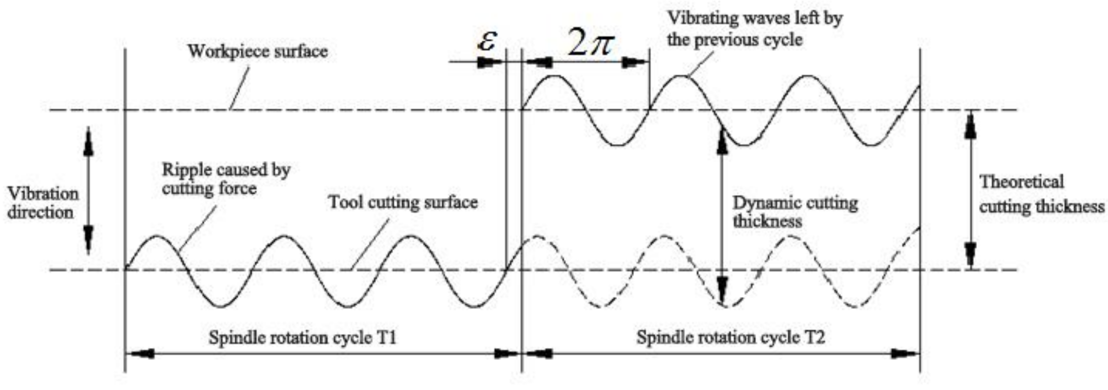

Fig. 2 Dynamic cutting thickness generation diagram

3. DYNAMICS MODELING ANALYSIS

3.1 Machine Tool Dynamics Modeling

Machining of machine tools is generally performed on a surface with chatter marks. Regenerative cutting chatter caused by the chattering effect is the main form of chipping chatter.

The kinetic differential equation of the kinetic model of the regenerative cutting flutter system is

$$m\ddot{x}(t)+c\dot{x}(t)+kx(t)=f_d(t)\cos(\beta-\alpha) \quad (1)$$

Where:

$f_d(t)$ is dynamic cutting force, N;

m is the equivalent mass of the machine tool vibration system, N·s^2/mm;

c is the equivalent damping of the machine tool vibration system, N·s/mm;

k is the machine tool vibration system equivalent stiffness, N/mm;

β is the angle between the $f_d(t)$ and y axes;

α is the angle between the main vibration direction y and the vibration sensitive direction y coordinate axis.

As shown in Fig. 3 , $x=\dfrac{y}{\cos\alpha}$,

Bring it into equation (1)

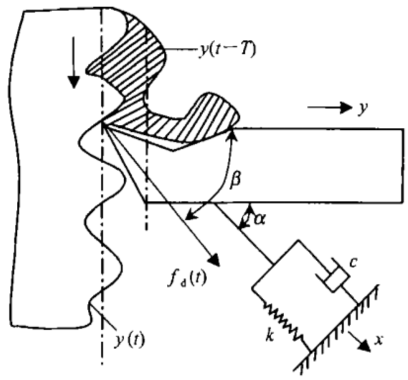

Fig. 3 The dynamic modal of regenerative chatter system

$$m\ddot{y}(t)+c\dot{y}(t)+ky(t)=f_d(t)\cos(\beta-\alpha)\cos\alpha \quad (2)$$

The corresponding frequency response function of the system in the y direction is

$$\Phi(i\omega)=\frac{1}{-m\omega^2+k+ic\omega} \quad (3)$$

For a single degree of freedom turning system considering the regenerative effect, the critical stability cutting thickness can be expressed as

$$b_{\lim}=\frac{-1}{2K_f\,\mathrm{Re}(\Phi(\omega))} \quad (4)$$

Where:

K_f is the cutting force coefficient of the material feed direction;

Re is a real function.

Assuming that the flutter frequency is f_c, the number of vibrating ripples remaining on the workpiece surface is

$$f_c T = \frac{f_c}{\Omega} = s + \frac{\varepsilon}{2\pi} \tag{5}$$

In the formula:

T is the cutting cycle;

Ω is the spindle speed;

s is the integer number of ripples produced during one week of cutting;

ε is the internal and external modulation phase difference , can be expressed as

$$\varepsilon = 2\pi - 2\arctan\frac{\mathrm{Re}(\Phi(\omega))}{\mathrm{Im}(\Phi(\omega))} \tag{6}$$

From this analysis, the relationship between the spindle speed and the critical cutting width can be obtained.

3.2 Drawing and Analysis of Turning Stability Lobe Diagram

Assuming that the transfer function and cutting force coefficient of the structure at the cutting point K_f are known or have been measured, the drawing process of the stability blade diagram has the following steps:

(1)Select the machine flutter frequency where the real part of the resulting transfer function is negative ω_c;

(2)Use equation(5) to calculate the critical cutting speed;

(3)Calculate the spindle speed from the equation with each stable blade $k = 0,1,2...$;

(4)The flutter frequency is scanned near the natural frequency of the machine tool structure and the above steps are repeated.

This paper studies a single degree of freedom system with a natural frequency of $\omega_n = 240$, a damping coefficient of $\xi = 1.2\%$, a stiffness coefficient of $k = 2.26\times10^8 N/m$, and a cutting force coefficient of $K_f = 1000Mpa$. Then use Matlab software to write the program for drawing the stability graph, and run the program to get the stability limit diagram as shown in Fig. 4 .

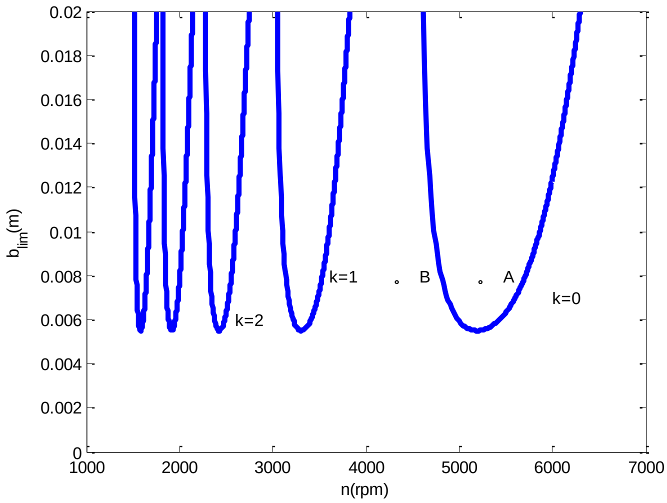

Fig. 4 Flutter stability lobe

The Fig. 4 can be analyzed, the system has a conditionally stable cutting area, in this area, as long as the axial depth of cut is less than the limit value, even if the spindle speed is high, cutting can be carried out smoothly, but the area The depth of cut is severely limited, and cutting operations that require depth of cut are still cut in other areas; the area within each lobe represented by point A is called the unstable cutting area. Cutting in the area, regardless of the axial depth of cut and how to select the spindle speed, the cutting process is unstable, there will be chattering, so usually should avoid cutting in this area; and in the unconditional stable cutting area and The region represented by point B outside the unstable region is called a conditionally stable cutting region. In this region, the appropriate cutting depth and spindle speed can be selected for cutting without flutter, but at the same depth of cut. Next, changing the spindle speed will change the cutting system between the conditional cutting zone and the unstable zone. of. For example, given a cutting depth of 8 mm, the system is stable when cutting at point B in Figure 4 (at this time the spindle speed is 4300 r/min), and when the spindle speed is increased to 5200 r/min At point A in the figure, the system enters the unstable cutting area. At this time, the machining is unstable and chatter vibration may occur. The processing of the system in this area can not only meet the requirement of large depth of cut, but also increase the rotation speed, thereby improving the machining efficiency and is an ideal cutting area. The size of the selected integer k of the vibrational wave determines the sequence of distribution of each earlobe line in the stable leaflet diagram. When k = 0, the first earlobe line is determined. This earlobe line determines that the system does not experience chattering. Spindle speed range; k = 1 to determine the second earlobe line, so in order to determine the remaining earlobe line, the earlobe line constitutes a periodic stability blade diagram. This figure shows the relationship between the spindle speed and the axial depth of cut during the cutting process. This can be used as a reference to prevent chatter in the machining process.

4. CONCLUSION

The method for predicting the stability limit of the cutting system of a regenerative machine tool proposed in the paper can help engineers and technicians to correctly select the cutting parameters so that the cutting process can always be performed in a stable area. Under the condition that the same processing quality can be obtained, the cutting efficiency of the machine tool can be significantly improved. , Give full play to the cutting ability of machine tools and tools.

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