Design of Regenerative Flutter Stability Detection System in Machine Tool Cutting

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Abstract. Cutting chatter is a strong relative vibration between cutting tool and work piece in machining process, which will reduce cutting quality and cutting efficiency, and shorten the service life of cutting tool and machine tool. As long as cutting is carried out in production, vibration will occur, and chatter is a strong self-excited vibration between machining work piece and cutting tool. Flutter problem will occur in almost all cutting processes, which will cause a series of problems such as the reduction of dimensional accuracy of machined work pieces, tool damage and so on. In the dynamic design and dynamic analysis of machine tool structure, in order to evaluate and improve the ability of machine tool to resist chatter, and to select the cutting conditions without chatter, it is necessary to judge the cutting stability of machine tool. How to improve the advanced technology of manufacturing industry is an important topic for manufacturing researchers, and the research on the detection of cutting chatter stability has important practical significance for promoting the development of cutting manufacturing industry to high-end technology.

Keywords: Flutter, Cutting Processing, Machine Tool, Stability

1. Introduction

With the development of economy and science and technology, the world industrial structure is moving towards circular economy, energy saving and high information type, which makes machining must achieve high precision, high efficiency, high information and high intelligence [1]. For more than half a century, metal cutting chatter has been one of the most important factors affecting the performance improvement of machine tools. It not only seriously affects the cutting efficiency, reduces the surface quality and dimensional accuracy of work pieces, but also aggravates the wear of tools, produces noise and shortens the service life of machine tools [2]. Machine tool cutting is generally carried out on the surface with vibration lines, and regenerative cutting chatter caused by vibration lines regeneration effect is the main form of machine tool cutting chatter [3]. As long as cutting is carried out in production, vibration will occur, and chatter is a strong self-excited vibration between the work piece and the tool. As the research direction in recent ten years, the utilization of vibration plays an indelible role in manufacturing, military and civil products [4]. However, in machining, the occurrence of abnormal vibrations often brings negative effects. Cutting vibration is a dynamic and unstable phenomenon of the machine tool processing system, which is extremely
harmful. In the dynamic design and dynamic analysis of the machine tool structure, in order to evaluate and improve the ability of the machine tool to resist chatter, in order to select cutting conditions that do not occur, it is necessary to judge the stability of the machine tool cutting [5].

Since the dynamic cutting force of high-speed cutting is proportional to the chip thickness and the integrated self-excited system mode of the machine tool, it will cause the entire cutting system to be a divergent unstable system [6]. In the cutting process, vibration, especially chatter, will destroy the normal machining process and reduce the quality of parts and production efficiency, especially when there is strong vibration between the tool and the work piece, the work piece may even jump off the cutting edge or violently impact the tool [7]. For metal cutting, especially for finishing and super finishing of low-rigidity work pieces, chatter prediction and suppression are becoming more and more important. If chattering cannot be suppressed in high-speed cutting, the parts machined in this state will have a rough surface, and at the same time increase the wear of the tool and generate a large dynamic load on the cutting system. As far as the rigidity, damping and cutting rigidity of the machine tool structure are concerned, since they have clear definitions and can be determined by experiments, they do not have fuzzy uncertainties. High-speed cutting chatter significantly reduces the cutting efficiency and the machining quality of parts, and reduces the service life of tools and machine tools. It has become one of the main bottlenecks that hinder this technology from exerting its advantages. How to improve the high-precision technology of the manufacturing industry is an important topic for researchers in the manufacturing industry, and the research on the problem of cutting chatter is of great practical significance for promoting the development of my country's cutting manufacturing industry to high-end technology.

2. Dynamic modeling and stability analysis of regenerative turning chatter

To predict turning chatter, we must study the mechanism of chatter and analyze the stability of cutting system. Therefore, this chapter studies the mechanism of regenerative turning chatter, establishes its dynamic model, and then analyzes its stability [8]. The smallest change to be identified in the signal determines the resolution of the equipment used. The higher the resolution, the more intervals the whole signal range is divided into, the more accurate the signal changes can be detected, and the more authentic the sampled data are.

In the dynamic design and dynamic analysis of machine tool structure, people know from experience that if the machine tool structure has large stiffness, strong damping and small cutting stiffness during cutting, the stability of cutting process will be better. The variation of cutting thickness or modal coupling will cause regenerative chatter in the turning process. The vibration coupling relationship between regenerative turning chatter turning tool and work piece is shown in Figure 1.

![Figure 1. Coupling relationship between regenerative turning chatter and work piece vibration](image)

It is very important to select cutting parameters properly in the actual turning process. With the turning process, the self-excited vibration becomes more and more intense due to the regenerative effect, and the system absorbs more and more energy, resulting in chatter in the turning system. The analysis and processing of signals can identify a large amount of information contained in the signals, obtain the inherent attributes and state attributes of mechanical equipment through different signal analysis methods, and describe the mechanical performance with static and dynamic indicators. Each random variable part in a random sequence can be described statistically with certain probability distribution characteristics [9]. Because statistical average characteristics reflect the probability
distribution characteristics of random variables, various statistical average characteristics of a random variable are the operation results of various functions of this random variable weighted by probability. By analyzing the influence of cutting dynamic parameters on the lobe diagram, it can be seen that increasing the equivalent damping ratio and equivalent stiffness of the cutting system will increase the stable region of the lobe diagram. However, increasing the cutting stiffness coefficient, direction coefficient and cutting overlap coefficient will reduce the stable area of Yuzryha lobe diagram, and increasing the natural frequency of the system will make it more difficult to stir up chatter in turning.

Flutter testing ranges from single variable to multi-variable, involving the capture and feature extraction of force, vibration and sound signals, and the choice of signal acquisition is broader. At the same time, the continuous improvement and innovation of signal analysis methods also make the collected signals have a more comprehensive analysis effect, and realize the accurate distinction between stable state and chatter state. Static characteristics of noise and vibration measurement system refer to the relationship between output and input of measurement system when the measured system is in a stable state, which is characterized by sensitivity, non-linearity, hysteresis, repeatability and resolution [10]. In order to predict the regenerative turning chatter phenomenon, it is necessary to find the chatter signal first in the experimental process, which is also the most basic step in the research of turning chatter prediction. It is a non-real-time signal analysis and processing process to collect multiple data and save them for subsequent reanalysis. For any signal analysis process, data acquisition is the most important link. Regenerative turning chatter occurs in the weak part of the cutting system, while turning tools and work pieces are often weak structures in the cutting process. Therefore, in the process of turning chatter test, artificially changing the size structure of work pieces and the structure of turning tools can affect the difficulty of chatter generation.

3. Possibility distribution of fuzzy stability limit cutting with set
Correct selection of sensor signals is the key factor to obtain flutter signals accurately. The selection of sensors should be based on accurate acquisition of measured signals, high signal-to-noise ratio of sensors, and simple installation of sensors. The regenerative chatter of machine tools originates from the self-excited vibration during chip formation, which may be caused by the mode coupling or the regenerative effect of chip thickness. When a certain mode of the machine tool-work piece system is initially excited by cutting force, ripples will be left on the work piece surface in the last turn of turning or the previous cutter tooth cutting, and ripples will also be left on the surface in the next turn or cutter tooth cutting due to the vibration of the machine tool structure. The cutting force-based sensor is inconvenient to install on the existing NC machine tools, while the piezoelectric acceleration sensor is small in size and convenient to install, so the acceleration sensor is finally selected to measure the turning vibration signal.

When turning chatter occurs, the vibration amplitude increases significantly when the vibration acceleration changes from stable state to unstable state, and the signal variance can reflect the trend of increasing amplitude, so the signal variance may be an ideal characteristic quantity of turning chatter, and its calculation formula is:

$$
\sigma^2_n = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{X})^2
$$

(1)

In which:

$$
\bar{X} = \frac{1}{N} \sum_{i=1}^{N} x_i
$$

(2)

$x_i$ is the vibration acceleration signal of the tool holder when I, n is the variance sample points, and n is the total sample points.
Simulation modeling analysis is used for vibration presentment or empirical treatment which is less affected by environmental factors, while experimental test analysis is used for feature analysis of complex environment or environment which is difficult to simulate. The selection of flutter monitoring signal is a crucial condition to determine the success of flutter monitoring. Appropriate monitoring signals should be related to the properties of cutting system and the related characteristics of chatter occurrence, and be sensitive to the occurrence process of cutting chatter, with high signal-to-noise ratio and convenient measurement of monitoring signals. The determined signal can be analyzed in frequency domain by Fourier transform, while the random signal is a kind of signal with infinite energy. The Fourier transform does not converge, so the spectrum of random signal cannot be determined. But for random signals, their power is not infinite, so we can use power spectrum to describe their frequency characteristics. In the process of cutting chatter, the surface of the machined part will also change, so the output of the photosensitive sensor will also change, so the displacement optical signal can also reflect the process of cutting chatter. However, the photosensitive sensor is very sensitive to the interference of ambient light, and the cleanliness and roughness of the part surface are also very high, especially the surface roughness signal is difficult to distinguish from the flutter characteristic signal, so the application of displacement optical signal is not much.

Turning chatter phenomenon is characterized by the change of amplitude, turning force, acceleration, temperature, sound and so on. Therefore, alternative sensors include displacement sensor, force sensor, acceleration sensor, temperature sensor and sound level meter. The dynamic characteristics of cutting process, that is, the transfer function of cutting system, is a prerequisite for analyzing machining stability. The input of the transfer function is the dynamic cutting force, and the output is the vibration displacement response. The structural dynamic test is carried out by using modal experimental analysis method, and the cutting stability under actual machining conditions is judged by using the limit cutting depth condition [11]. The first step of flutter testing technology is the acquisition of flutter signals, which can not be separated from sensors. Sensors capture some sensory physical information and turn it into electrical signals for output according to certain theoretical transformation requirements, which provides convenience for later information transmission, processing, storage, display, recording and control.

According to the characteristics of stable cutting and chatter cutting in time domain. Matlab simulation is used to generate a stable cutting vibration signal (Figure 2) and a cutting chatter vibration signal (Figure 3).

![Figure 2. Simulate stable cutting signal](image)

![Figure 3. Simulated cutting chatter signal](image)
The chatter signal in turning is a non-stationary nonlinear signal. With the study of nonlinear problems, the process of turning chatter is divided into three stages, namely stable turning stage, chatter transition stage and chatter turning stage. By calculating the complexity of these three machining stages, and then dividing the complexity interval, the interval is used to judge the chatter, so as to achieve the purpose of turning chatter prediction. Both dynamic cutting force signal and vibration acceleration signal are suitable as characteristic signals of chatter monitoring, but the sensor of dynamic cutting force signal is inconvenient to install in non-circular cutting tool holder, and will affect the rigidity of tool holder, so it is not suitable for the later research of non-circular cutting chatter monitoring and control project. The non parametric power spectrum estimation, that is, the classical spectrum estimation method, still depends on the general discrete Fourier transform method in essence, which assumes that all the values of other sequences are zero except the limited data detected, but in fact, all the values of those signals that are not monitored are not zero. This will inevitably lead to large estimation variance and poor general resolution, especially in the case of some short data, the above shortcomings are more obvious.

To detect the amplitude of work piece in turning, only non-contact displacement sensor can be used, and laser displacement sensor has higher precision. The working principle of the laser displacement sensor is to pick up the optical signal through its internal photosensitive element, and its output changes with the distance between the sensor probe and the measured work piece surface. The advantage of using sound level meter to obtain noise signal is that it can obtain noise in a large frequency band, and the noise signal can effectively reflect turning chatter [12]. In practical application, the signal obtained by sound level meter is still greatly influenced by environmental noise, so it is not widely used to monitor flutter. In actual processing and production, the installation and price of force sensors are weak. Different from the cutting force signal, the vibration sensor signal is less limited by the experimental conditions, and it is more convenient to operate, cheap and efficient [13]. Before collecting data, the sampling frequency or the maximum analysis frequency should be calculated according to different analysis frequency ranges. In practical application, when collecting steady-state data, the sampling frequency can be set larger first, so that the observed frequency range is large, and the transformation between high frequency and low frequency can be seen.

4. Conclusion
At present, with the development of industry, the requirement of condition monitoring in production and processing is getting higher and higher. In the process of turning, the transition time from stable turning to turning chatter is very short, so it is a difficult problem to predict turning chatter more quickly. Machining is the main part of manufacturing, and flutter is the main instability phenomenon during machining, so the real-time monitoring technology of flutter has far-reaching significance. In actual processing and production, the installation and price of force sensors are weak. In practical application, when collecting steady-state data, the sampling frequency can be set larger first, so that the observed frequency range is large, and the transformation between high frequency and low frequency can be seen. In the process of turning chatter test, artificially changing the size structure of work piece and the structure of turning tool can affect the difficulty of chatter. In the process of using the machine tool, cutting parameters can be selected reasonably, and the cutting process can be controlled anthropomorphically to improve the machining quality and productivity. To realize fast online prediction of turning chatter, it is necessary to improve the calculation efficiency of computer and other hardware and optimize the software algorithm.

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