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Research on Technology of Variable Spindle Speed Noncircular Turning

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Abstract. To improve the stability and precision of noncircular manufacture process, the variable spindle speed turning is applied to noncircular turning process. The variable spindle turning system is designed. The character of variable spindle speed is analyzed. The linear servo unit available for variable speed noncircular turning process is designed. An active disturbance rejection control technique is applied to servo unit. The experiment results show that surface quality and tracking error of variable spindle speed noncircular turning are better than constant speed machining. The linear servo unit is able to track the desired trajectory of cutting tool motion.

Introduction

The noncircular parts are used in mechanical, optical products because of its unique advantages in transmitting motion and power. But the manufacture is a problem. Traditional process is milling or grinding. These ways have the deficiency such as poor precision, long period, high cost and so on. The noncircular turning is a new efficient and effective process in noncircular products machining. The principle of this process is that the encoder track cutting axle position instantaneously and this position information is feedback to the numerical control system. This system drives cutting tool to move to the goal. In this process, fasting tool servo (FTS) is the key to achieve noncircular turning. Its performance affects the machining accuracy and efficiency directly. At present, the FTS can be divided into hard and soft mode. Hard mode is using mechanical or hydraulic drive mechanism to drive cutting tool. This method has good stability, but the cost is high, machine adjustment period is long. Soft mode is used programming tool to control the driven mechanism. This method can achieve productivity, adaptability, accuracy of the noncircular machining process. To meet the high frequency response of large travel needs of FTS, the linear motor driven mechanism method is used.

With the more accuracy requirement, noncircular turning system is proposed a higher request. The tracking accuracy and the response speed of FTS become the key points. Because FTS has a certain response time in general, the cutting tool has a displacement with the target location. In order to improve the accuracy of the component, it must enhance the noncircular turning stability [1]. It has two ways to carry out this purpose. Firstly, FTS structure should be optimized, so the dynamic stiffness of system is enhanced and response error is reduced. Further more, the other approach to increase machining stability is to apply variable spindle speed machining (VSM), which refers to machining operations in which the spindle speed is continuously varied in a periodic fashion over some nominal constant speed.

Because VSM can enhance the process stability, it is applied in noncircular turning process to increases machining precision. The variable spindle speed noncircular turning structure is designed. FTS is controlled by the active disturbance rejection control (ADRC) technology. A NC lathe control system based on the programmable multi-axis controller (PMAC) is designed to realize the cutting tool motion synchronizing with the spindle rotation.

Noncircular turning structure design

The CNC noncircular turning system is shown in Fig.1, the system include a general CNC turning unit and a FTS unit. General CNC turning unit accomplishes the spindle speed control, the spindle angle measurement, Z-axis feed control and other functions. The lathe utilizes an asynchronous AC motor with a varying frequency modulator to control the spindle. The PMAC is utilized as NC system. The PMAC adopt Motorola DSP56001 device as its CPU. The FTS unit involves a driven linear actuator, an analog current amplifier, and a position sensor.

The FTS system synchronizes with the spindle through the PMAC time-base control. Using this method, the program defines a real-time input frequency (RTIF) from the master's position sensor. The motion program can be written for that RTIF. Therefore the movement of the spindle and procedures are linked together. The radial position is detected by raster sensor and sent this information into the PMAC controller, the FTS controller compares this result with setting value, produces the control signal and amplifies to drive the FTS system.

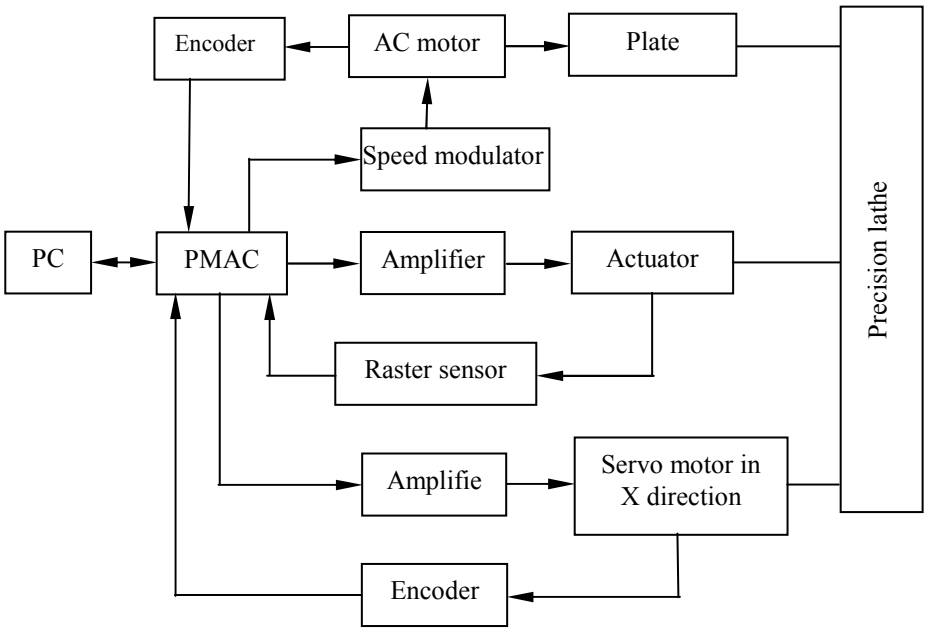

Fig.1 Variable spindle speed noncircular turning system

Description of variable spindle speed character

In VSM process, the spindle speed is variable in a basic rotational speed. The change rule can be express by some kind of function. Insperger [2] et al. have studied the different form variable spindle speed rules, and summarized that the sine function is the most superior, namely the variable spindle speed rule is:

$$\omega(t) = \omega_n + A\sin(2\pi ft + \varphi) = \omega_n(1 + RVA\sin(RVF\,\omega_n t + \varphi) \quad (1)$$

where ω_n is the nominal spindle speed, A the amplitude of the variation in speed, and f the frequency of the speed variation. $RVA = A/\omega_n$ and $RVF = 2\pi f/\omega_n$ are considered as nondimensional expressions. The general finding in the previous research is that increasing the values of RVA or RVF typically results in a reduction of chatter level.

The research results [2] indicated that the augment of RVA and RVF can reduce vibration and enhance stability of the system. But the speed change condition is limited, RVA and RVF are changed in the permission parameter area. So, the values of RVA and RVF are also limited by the performance of the spindle driving system.

Controller design of actuator

According to the principle of linear motor and mechanical structure, it can be simplified as a spring-damper system. The cutting force changes with time, so the whole system is a time varying system. The system dynamics equation can be expressed as

$$m\frac{d^2x}{dt^2}+c\frac{dx}{dt}+kx=F_a-F_d \tag{2}$$

where m is the mass of the moving assembly, c is the linear damping of the structure, k is the linear spring coefficient, x is the position of the actuator, F_a is the drive force of actuator, F_d is the cutting force.

In VSM noncircular turning process, the spindle speed is variable periodically. The FTS tracks spindle position and makes the radial reciprocation movement. The spindle position is measured by the rotary encoder, which produces the pulse train signal to trigger the sampling control of the FTS. The periodic variation of spindle speed makes the encoder sampling interval being time variable. This makes FTS control to be more complex. Tsao and Pong et al. [3] solved this difficulty by using the spindle angle as the independent variable. The rotation angle is measured by rotary encoder, the encoder sampling interval is constant and does not change with the speed. This may transform the time variable sampling interval to the angle variable. So the linear actuator is simply written as

$$\ddot{x}(\theta)+p(\theta)\dot{x}(\theta)+q(\theta)x(\theta)=b(\theta)u(\theta) \tag{3}$$

where x is the position of the actuator and $u(\theta)$ is the control signal in terms of angle. $p(\theta), q(\theta)$, and $b(\theta)$ are periodic coefficients.

In the process of noncircular turning, the cutting tool is maintained the nonlinear cutting force, machine vibration and other disturbances. It is a strong nonlinear coupling system. Therefore, the control system should have a high anti-interference performance and minimize the tracking error. The ADRC technology is applied in the system control.

If the effect of the cutting force and other external disturbances is considered, Eq. (3) can be rewritten as

$$\ddot{x}=f(x,\dot{x},\omega,\theta,w)+b_0u(\theta) \tag{4}$$

where w is the external unknown disturbance. $f(x,\dot{x},\omega,\theta,w)$,or simply f represents the combined effects of internal dynamics and external disturbance on acceleration. Reference [4] gives the architecture of ADRC controller as shown in Fig.2.

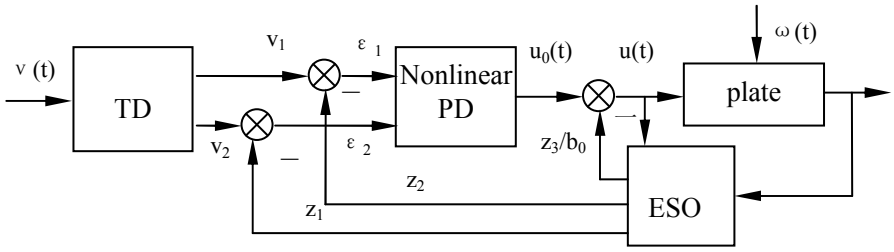

Fig.2 Architecture of ADRC controller

The tracking differential (TD) controller is the role of transition arrangement and gives the process the differential signal. Extended state observer (ESO) gives z1 (t), z2 (t) (the estimation of object state variables) and z3 (t) (real-time affection $a(t)=f(x,\dot{x},\omega,\theta,w)$ estimation of disturbance). The feedback of z3 (t) / b0 plays a role of disturbance compensation. This is an automatic compensation system. In fact, the volume of this structure is divided into two parts, namely

$$u(t)=u_0(t)-z_3(t)/b_0 \tag{5}$$

where $z_3(t)/b_0$ is the component of compensation for disturbance, $u_0(t)$ is the component of which the nonlinear feedback of state error is used to control the integrator. The control law (6) is called that using b_0u achieve disturbance rejection control.

Stability analysis and experimental results

The VSM noncircular turning system is a periodic time variable system. The vibration frequency f is variable in a jagged formulation [1]. The cutting process flutters in the stability and instability region alternately along with the spindle speed. This kind of cutting condition disturbs the regeneration flutter. It is a self-excitation vibration. When cutting process is stability, the system vibration response approximates to zero. On the other hand, noise vibration of the cutting tool is a kind of frequency conversion excitation response in instability state. Its peak-to-peak value is smaller than constant speed turning. This causes VSM can reduce the cutting tool noise vibration, thus enhance the noncircular turning stability.

In the turning experiment, both the workpiece geometry and machining process were as same as those in literature [7]. The VSM noncircular turning parameter is ω_n=62.8rad/s， RAV=0.2， RAF=0.05. In order to contrast with the constant speed turning, two kind of experimental results are show in Table1. The results illustrate that VSM noncircular turning method has been reduced the tracking error and surface quality comparing to the constant speed processing method.

Tab.1 Experimental tracking errors

	No.	1	2	3	4	5
Constant speed	Maximum tracking error(μ m)	12.5	14.6	10.8	13.5	15.7
	RMS tracking error(μ m)	5	6	4.4	5.4	5.2
Variable speed	Maximum tracking error (μ m)	6.6	7.3	6	7	6.3
	RMS tracking error (μ m)	2.7	3	2.4	2.8	2.6

Conclusions

The application of ADRC controller and the angle domain concept method is applied in the VSM noncircular turning process. The vibration in machining can be suppressed and the stability is enhanced. Through the experimental verification, the following conclusions may be made based on the analytical and experimental verification: (1) the structure of FTS based on ADRC is safe and reliable. It has the better tracking performance and robustness. (2) The VSM system can improve the turning accuracy, reduce the tracking error and suppress machining vibration comparing with the constant speed system. (3) VSM using a simple sinusoidal speed trajectory has the potential to suppress self-excited chatter vibration over the wide range of nominal speed studied. The appropriate RVA/RVF parameters can optimize the noncircular turning processing quality.

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References

[1] J.Yu, X.Wang, f.Yang, B.Wu: Chinese Journal of Mechanical Engineering Vol.31 (1995), p. 11-16, in Chinese.

[2] T.Insperger, G.Stepan: Journal of Vibration Control Vol.10 (2004), p. 1835–1855.

[3] T.C.Tsao, K.C.Pong: North American Manufacture Research Conference Vol.9 (1991), p. 183-190.

[4] J.Han: Systems Science and Mathematical Sciences Vol.4 (1989), p.328–335.

[5] D.Wu, K.Chen, X.Wang: International Journal of Machine Tools and Manufacture Vol.47 (2007), p. 2207–2217.

[6] D.M.Alter, T.C.Tsao: Journal of Engineering for Industry Vol.116 (1994), p. 298–307.

[7] H.Cao, S.Li: Machine Design and Research Vol.27 (2011), p. 77-79, in Chinese.