Band-limited Cutting Force Control in Ultra-precision Turning

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Abstract

Ultra-precision cutting has recently attracted attention to produce optical parts such as lenses without a grinding and a polishing process. It is well known that unstable fluctuation in cutting force has a significant influence on a machined surface roughness and shape quality. Therefore, it is considered essential to control the cutting force in the ultra-precision machining. The sensor-less cutting force control based on the disturbance observer is a practical approach because it does not require any additional sensors. A cutting force is estimated by using the servo information. When the estimated cutting force is fed back to the controller, the sensor-less cutting force control is realized. In this study, the sensor-less cutting force control is applied at a certain range of frequency, and a position control is simultaneously employed. The effect of the proposed control method is evaluated by face turning tests.

1 Introduction

At present, the manufacture of molds and lenses has needed grinding and polishing after cutting process in order to improve the quality of the machined surface. On the other hand, for reducing the production cost and raising the energy efficiency, the ultra-precision cutting has recently attracted attention to produce these parts without grinding and polishing processes[1,2)]. In this study, we have focused on the behaviour of cutting force in ultra-precision machining. Altintas[3)] proposed to control the cutting force with dynamometer in the millimetre-scale machining. He had shown that the cutting force control improved the shape accuracy. As well as the conventional machining, it is considered to be essential to control the cutting force in the ultra-precision machining. As a practical technique to control the force, the sensor-less cutting force control is available [4)]. However, in case that the force control is used for the cutting process, the machining time could not be estimated. In this study, even as the position control is basically employed, a cutting force at a certain range of frequency is attempted to be controlled. The effect of the proposed cutting force control is experimentally evaluated by using the prototype ultra-precision turning machine.

2 Sensor-less cutting force control system design at a certain range of frequency

Figure 1 shows applied forces in feed direction to the X stage during face turning. Based on the motion equation of the X stage, a cutting force in feed direction F_{cut} is estimated from the current reference I_a^{ref}, the position response x^{res} and the friction force at the guide F_{fric}, as shown in Eq. 1.

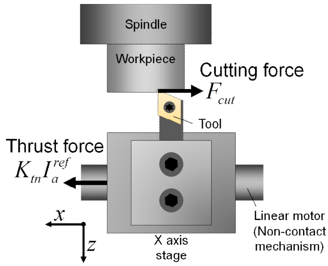

Figure 1 Forces applied to X stage

$$F_{cut} = K_{tn}I_a^{ref} - M_n\ddot{x}^{res} - F_{fric} \qquad (1)$$

K_{tn}: Nominal thrust force coefficient, M_n: nominal mass of carriage.

The friction force needs to be identified by idling tests in advance. When the estimated cutting force is fed back to the controller, the sensor-less cutting force control is realized. To retrieve the cutting force information at a certain range of frequency, a band-pass-filter (BPF) is set. To avoid the interaction between a position control and a force control, the position controller is designed as its wideband width is lower than that of the BPF. Then, the position controller and the force controller are integrated at the acceleration dimension, as shown in Fig. 2. a^{ref} represents the acceleration reference. To verify the validity of the designed control

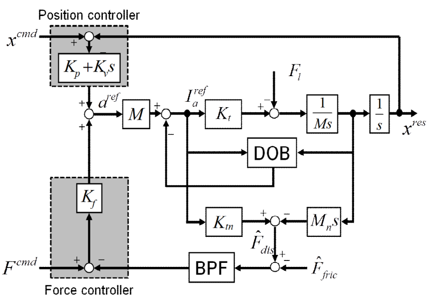

Figure 2 Band-limited force control system

Table 1 Control parameters

Sampling time	100 µs
Optinally nominal mass M_n	1.0 kg
Thrust force coefficient K_{tn}	16.4 N/A
Cut off frequency of DOB	160.0 Hz
Frequency band of BPF	5 Hz ～ 15 Hz
Velocity command (sim.)	0.1 mm/s
(exp.)	0.3 mm/s
Force command (sim.)	0.2sin(2π × 10t) N
(exp.)	0.3sin(2π × 10t) N

system, a simulation is performed under the condition listed in Table 1. Figure 3 shows the results of the velocity response and the estimated force after passing through the BPF. The average velocity response almost corresponds to the command value and the force response is obviously fluctuated at 10 Hz according to the force command. It is confirmed that a position and a cutting force can be simultaneously controlled by separating both frequency ranges without overlaps.

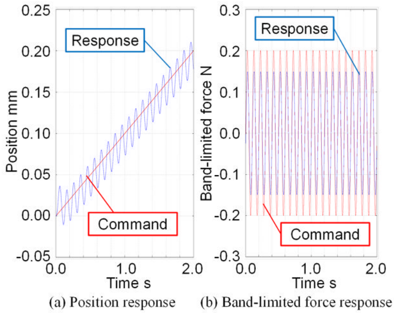

Figure 3 Simulation results of the control method

3 Experimental setup

Figure 4 shows the prototype ultra-precision turning machine which consists of the work spindle supported by aerostatic bearing and the linear motor driving carriage. Because the work spindle employ the non-contact mechanism, its friction force is almost zero, which enhance the accuracy of the sensor-less cutting torque control. In terms of the carriage, the friction force at the LM guides is identifed according to each position by the idling test. The carriage is driven by the linear motor and the optical linear encoder with 10nm resolution is attached at the side. The position-force-integrated contorol system is installed to the turining machine. The same control parameters are set as Table 1.

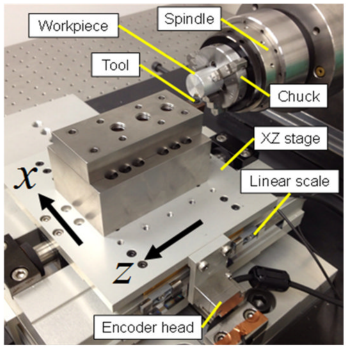

Figure 4 Prototype of ultra-precision turning machine

4 Experimental result

To investigate the performance of the proposed control method when a variable load is applied in feed direction to the tool set on the XZ-stage, the behaviours of the position and the band-limited force are experimentally evaluated by giving the velocity and force commands shown in Table 1. Figure 5 shows the relation between the position and the force in the x-direction. A quasi-static force is changed in accordance with the applied load because the position of the stage is controlled within the bandwidth of 5Hz. On the other hand, it is clear that the force ranging from 5Hz to 15Hz is effectively controlled. From the result, there is possibility to improve cutting process in terms of the cutting force and the machined surface quality by applying the proposed hybrid control method. We are planning to show some results of turning tests on site.

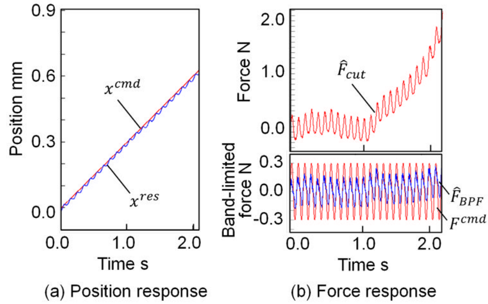

Figure 5 Behaviour of each response

5 Conclusion

A band-limited cutting force control method is proposed for the ultra-precision turning process. The validity of the proposed method is confirmed by the simulation and the experiment. In future work, optimum parameters to enhance the turning process will be investigated.

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