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Feasibility of Sensor-Feedback Phase Control to Suppress Self-Excited Chatter in Cylindrical Grinding

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Abstract

Self-Excited Chatter phenomenon is often seen in finishing process of cutting. This is caused by that the phase difference between inner-modulation and outer-modulation meets the natural frequency of system stiffness between tool and work-piece. Therefor one of the solutions to suppress the Self-Excited Chatter is to control phase difference by means of speed-control between tool and work-piece. It, however, is never clarified whether the method of speed-control between tool and work-piece is effective in grind process as well.

Thus in order to confirm whether the speed control is effective not only in cutting but also in grinding, a cylindrical grinding system with sensor feed-back has been developed. The system can control the rotational speed of work-piece while detecting the displacement of arbor with wok-piece. Meanwhile to bring about self-excited chatter in every grinding experiment, computer simulation is executed, and arbor with workpiece to obtain primary-mode of chattering easily in experiment is designed.

After the basic system working is confirmed, grinding experiment for Self-Excited Chatter control is executed. The experimental results show the system is feasible and triangle-speed control is effective not in cutting but also in grinding.

Keywords: Grinding, Vibration, Control, Sensor, Surface.

1. Introduction

There are many studies that analyze and clarify mechanism of chatter vibration in cutting. There, however, are few reports that consider measurement and control of it and execution of them in grinding, despite of that grinding is utilized for finishing process. Therefore, the purpose of this study is to develop way of detection and control of chatter vibration in cylindrical grinding.

2. Consideration of self-excited chatter vibration control

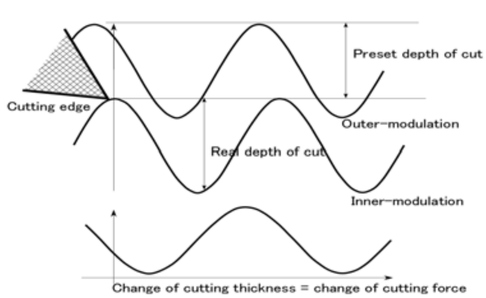


Fig. 1 Actual thickness of cut produced by difference of inner and outer modulation

Self-Excited Chatter occurs when change of cutting force matches with natural frequency of cutting (or grinding) system. Fig.1 describes how actual depth of cut, which is produced by difference of modulation of work surface between pre and current cutting edge trajectories, changes [1].

Takemura, et. al. [2], reported that frequent change of work-spindle revolution such like triangle wave speed control is effective to suppress Self-Excited Chatter in lathing. Kasahara, et.al.[3], extend chatter-suppression theory of 2-dimensional cutting to 3-dimesional cutting. And they proved that the theory to suppress Self-Excited Chatter is also effective. In their reports, new measuring system that can record the phase difference between inner and outer modulation in chattering had been developed, it was clarified that change of cutting thickness occurred in traverse-feeding of cutting tool crossing to work rotation too.

Although the many studies of Self-Excited Chatter in cutting accomplished chatter-suppression function of current machine-tool, in grinding, not only equipment of chatter-suppression function but also study about in-process chatter control does not progress yet. Because it is more difficult to monitor contact area between work-surface and tool in grinding than that in cutting, and grinding tool cannot guarantee better linearity of tool performance than that of cutting tool since the performance of grinding tool depends on surface condition of the tool [4-5]. Y. Altintas,et. Al.[4], also proposed active control of chatter suppression by means of installing piezo-actuator into main spindle or around the spindle. It, however, is difficult to obtain the space where the actuator should be installed.

Therefore, this study selects the method, which Takemura proposed, that is chatter-suppression method by means of controlling relative speed of work-tool. It is confirmed whether the method is effective in grinding as well.

3. Experimental set-up

Table 1 Experimental conditions

Cylindrical Grinder	Toyota RU28-50
Grinding wheel	WA60J6V 305×50×127
Work	S55C
Preset depth of Grind	2-4μm
Feed direction & speed	Traverse 120mm/min
Work rev.(normal)	60 min^{-1}
Work rev. (for chatter suppression experiment)	From 50 to 70 min^{-1} with 0.1Hz oscillation triangle wave control

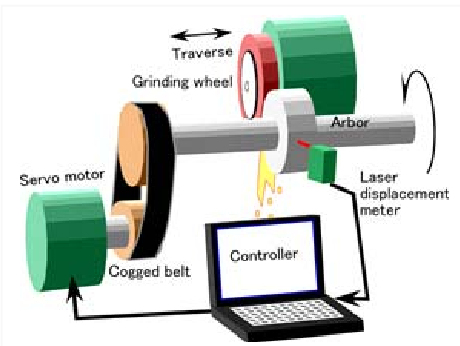


Fig. 2 Illustration of experiment

Fig.2 illustrates experimental system in this study.

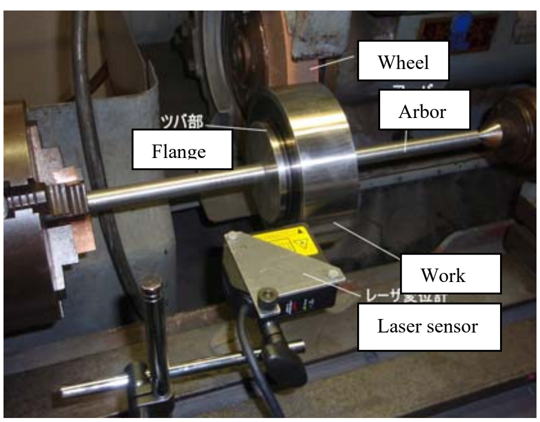


Fig. 3 Arbor & Sensor setting

In order to produce Self-Excited Chatter easily, thin arbor with work piece is utilize as shown in Fig.3 The work piece on the arbor is diameter φ=150mm, length l=50mm of S55C. The work-piece can be separated to be replace easily and only the surface of the workpiece is ground. Grinding force displace arbor, and the displacement is measured in-processing with laser-displacement sensor which is installed opposite-side of grinding wheel. The data of the measured displacement is simultaneously monitored by means of Analog-Digital (A/D) converting. Before experiment threshold level of displacement is programed on Personal Computer (PC). If chattering displaces arbor beyond the programed threshold level, feedback control of work spindle is executed, while PC transmits command of speed control to servo controller. In order to control precise work-spindle revolution and phase difference between inner and outer modulation, a cogged belt drive is adopted for work spindle instead of conventional V-belt drive, as shown in Fig.4.

Fig.5 shows program flow of PC. Based on this chart, triangle-wave signal, as shown in fig.6, is generated and transmitted to servo controller of machine tool spindle.

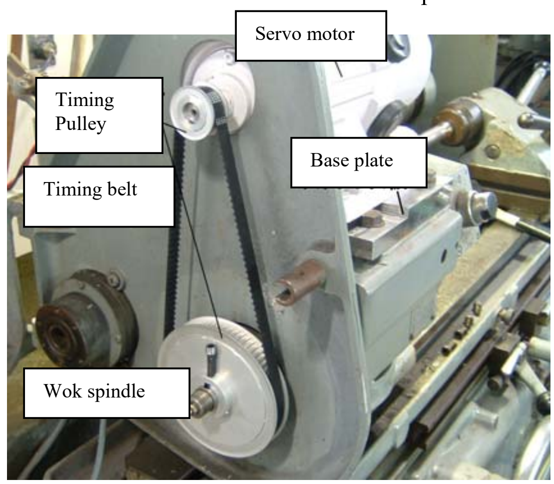


Fig. 4 Cogged belt drive

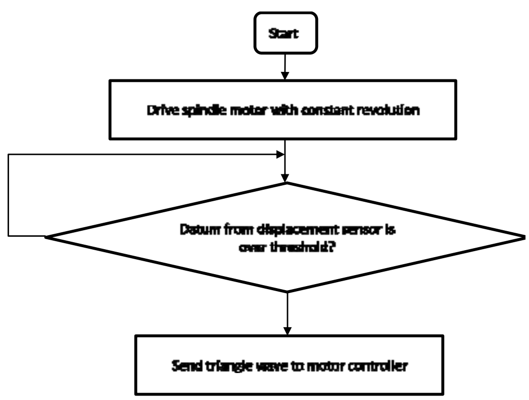


Fig. 5 Flowchart

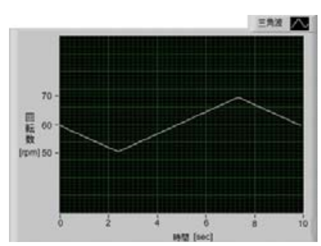
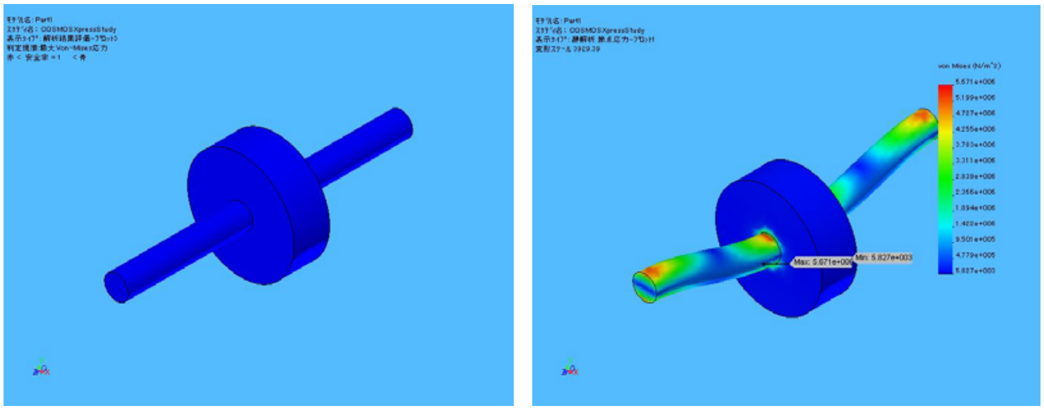


Fig. 6 Applied triangle wave and for chatter suppression



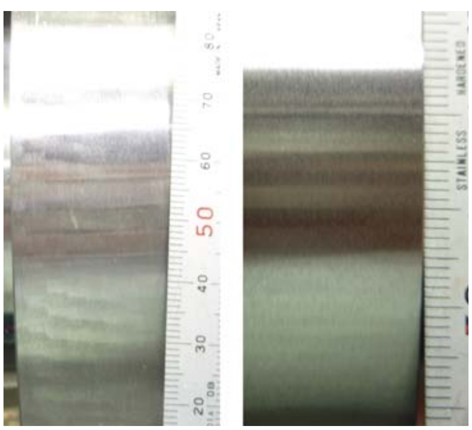
(a)Without load (b)with grinding force 500N

Fig. 7 Deformation simulation of arbor

4. CAE simulation of Arber vibration

In cylindrical grinding, the primary-mode vibration of a double-end support-beam which is generated by change of cutting force is basically observed. Thus in order to confirm vibration mode of arbor, CAE simulation about arbor is executed before experiments. In the simulation, estimated 500 N of tangential grinding force is given in contact zone. Fig.7 is the obtained result. The designed arbor can show the primary-mode along with the estimation.

5. Results and discussion



(a)without control (b)with control

Fig. 8 Ground surface

Fig.8 shows ground surface with or without feedback control beneath the grinding condition table 1.

In fig.8 (a) of constant grinding speed without oscillation of workpiece, chatter mark is clearly observed. The direction of chatter mark can be seen that it is taking right-down direction. This demonstrates that Self-Excited Chatter by phase difference between inner and outer modulation. The size of chatter mark for rotational direction is measured, and the length is 4.1mm. From grinding conditions, frequency of regenerative vibration is calculated as following,

$$f = \pi D/_{l} = \pi 150/_{4.1} \cong 114 \text{ [Hz]}$$

Meanwhile, the simulated primary-mode frequency of arbor is 118 [Hz]. Therefore, the arbor can realize the simulated vibration as CAE result.

Fig8(b) is the surface is produce with feedback control. There are no chatter mark on the ground surface.

Therefore, it proves that triangle-wave speed-control in grinding is as effective as that in cutting, the proposed our system can suppress Self-Excited Chatter.

6. Conclusions

In order to confirm that speed control between tool and workpiece in grinding is as effective as that in grinding for Self-Excited Chatter suppression, experimental grinding system which can control rotational speed of workpiece in-processing is developed. In the experiment, arbor holder of work piece is designed based on CAE simulation, and triangle speed control is adopted while detecting the displacement of the work. The results demonstrates that the developed system work well and triangle speed control which Kasahara et. Al poposed is effective in grinding as well as that in cutting.

7. Acknowledgement

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8. References

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