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Vibration control of a CNC lathe with a pipe structure frame by a PZT

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Abstract

The development of a small machine tool for the purpose of parts minimization has been approached through downsizing and increased precision. A new CNC lathe combining sufficient rigidity and space for chip treatment has been developed. The frame structure consists of pipes and joints, guaranteeing sufficient space. Active vibration control is applied in order to suppress the specific vibration mode using actuators driven by a PZT. The effects of vibration control are reported in the present paper.

Machine tool, NC lathe, pipe frame, vibration control, active control

1. Introduction

The development of a downsized machine tool to cope with the machining of smaller and lighter industrial products, and various structural designs have been proposed. Truss structures that are sufficient to ensure sufficient lightweight and rigidity by a bar arrangement have been widely adopted in the building sector and in the field of space structures. However, few studies have adopted a truss structure in machine tools. In the field of machine tools, in order to cope with miniaturization while satisfying high-precision and high-mix low-volume production, the development of the miniaturized machine tool complied with the workpiece size is strongly required. In the present study, we focus on a machine tool with a pipe frame structure.

When adopting a pipe frame structure for a machine tool, resonance problems related to the structure are determined by the mass and stiffness of the structure, and the shape accuracy deterioration of the workpiece due to the relative vibration between the tool and the workpiece is considered. In the present study, an active vibration control using a PZT actuator is applied to solve this problem.

In previous studies, control of the relative vibration between the tool and the workpiece by mounting an actuator on tool bytes was examined [1-6]. The actuator itself can be miniaturized. Considering the use of CNC lathes, since multiple tools are mounted, each tool post requires an actuator. In contrast, in the present study, we consider the low-frequency vibration based on the frame vibration, and as a driving source, the developed actuator with a PZT is positioned as a reinforcing brace rod pipe frame. The relative vibration between the spindle head and the tool post is suppressed by the active vibration control. The effects of vibration control are reported in the present paper.

2. Pipe frame structure for a CNC lathe

2.1. Basic structure

Figure 1 is a schematic diagram of the developed CNC lathe. As shown in the figure, the frame consists of linearly arranged pipes and joints between the respective pipes by chemical adhesion. Using this method, we can rearrange the pipe length and the block. This structure can take on various forms by adding pipes and blocks. In addition, it is possible to adjust the stiffness by adding a pipe as a reinforcing rod between the blocks. The moving table and the spindle moving table with a comb tool rest on the frame are assembled in order to realize conventional CNC lathe functions. Table 1 shows the specifications of the developed CNC lathe.

2.2. Dynamic characteristics of the CNC lathe

By adopting a pipe frame, the frame weight is reduced by more than 60% as compared to the conventional model. Thus, the effect of increasing the resonant frequency of the structure is expected. However, the rigidity is decreased compared to conventional castings or welded frames, and the resonant frequency acts in a direction that decreases the rigidity. Therefore, by considering a balance between light weight and stiffness, the resonance frequency due to the structure becomes adjustable by adjusting the brace bars.

Figure 2 shows the frequency transfer function obtained by impulse excitation. Although the characteristic resonance frequencies are seen, the resonance frequency between the X-axis table and the spindle is 35 Hz. Therefore, in the present study, the target frequency of vibration control is set to 35 Hz.

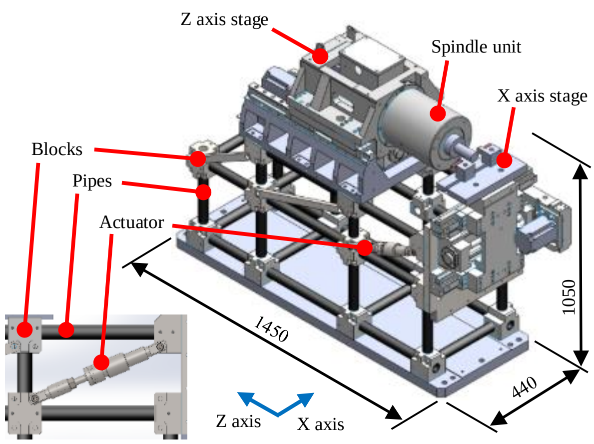

Figure 1. Schematic diagram of developed CNC lathe

Table 1 Specifications of the developed CNC lathe

Items		Specifications
Head stock	Chuck size	Collet chuck 3inch
	Maximum speed	10,000min^{-1}
Tool post type		Horizontal linear
Minimum resolution		0.0001mm
Size		440^{W}mm×1450^{L}mm×1050^{H}mm
Machine mass		502kg

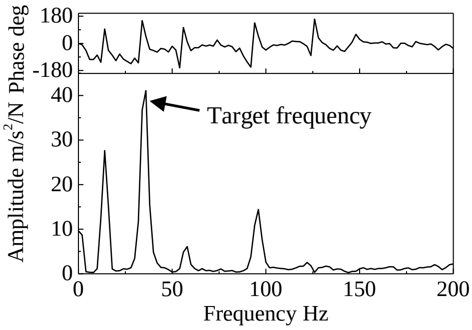

Figure 2. Transfer function by impulse hammer

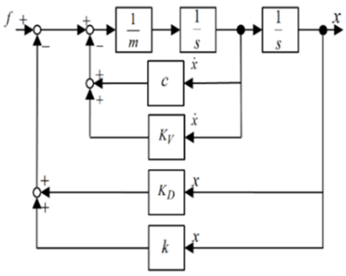

Figure 3. Block diagram of relative active vibration control

3. Vibration control method

3.1. Actuator for vibration control

In order to apply vibration control, it is necessary to place the actuator in the direction of motion of the vibration mode. Therefore, as shown in Figure 1, the vibration mode of 39 Hz occurred in the frame sides. Further, the actuator has been set a pre-load by on offset voltage to PZT. Therefore, the structural condition without control has a same function with the conventional rod attached to the base frame. In addition, in other vibration modes, if the vibration directions are the same to some extent, certain damping effects can be expected.

3.2. Vibration control system

The influence of external vibrations are analyzed by attaching a three-axis acceleration sensor to the spindle head and the tool post of the developed CNC lathe by measuring the relative vibration of the spindle head and turrets.

The resulting signal is detected during the active feedback control. Thus, by adjusting the damping coefficient and spring constant of the system, the dynamics of the system can be changed to suppress the relative vibration (LQ control). Figure 3 shows a block diagram of the control program. According to this control method, the spring constant and damping coefficient of the structure are changed simultaneously. As such, the resonance frequency can be changed to another frequency.

4. Verification of the control effect in air cutting

In order to confirm the performance of the constructed vibration control system, the relative vibration is measured at a spindle speed of 2,340 min^{-1}, which coincides with the resonant frequency of the CNC lathe, in order to compare the amplitude with and without control in the time domain or the frequency domain.

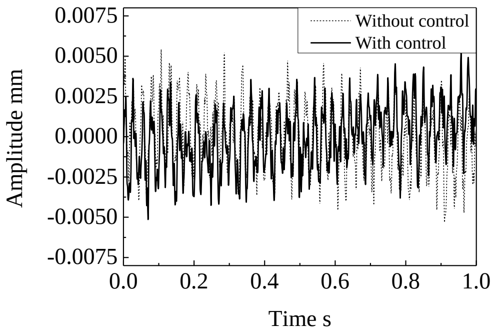

Figure 4. Effect of vibration control during air cutting in the time domain

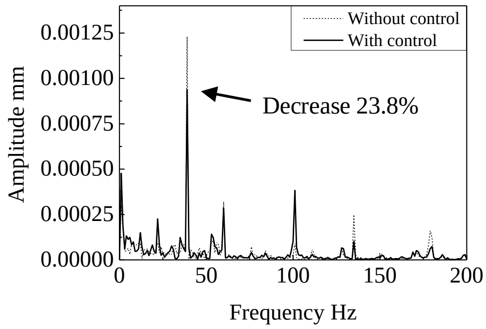

Figure 5. Effect of vibration control during air cutting in the frequency domain

Figure 4 shows a time-domain waveform of the relative vibration measurement result in air cutting. Based on the figure, the relative vibration can be reduced by applying the control. Figure 5 shows the frequency analysis results for the relative vibration of Figure 4. As shown in the figure, around the target frequency of 39 Hz, the vibration amplitude is reduced by approximately 24%, which indicates that control of the exciting force of the actuator is effective.

5. Conclusion

A pipe-frame-structure CNC lathe has been developed. The active vibration control was applied, and the following results were obtained.

(1) By measuring the dynamic characteristics of the pipe-frame-structure CNC lathe, the control point is determined from the mode at a particular frequency.
(2) At the control point, we have developed an active vibration control system using an actuator as a drive source with a PZT.
(3) As a result of applying the vibration control during air cutting, the vibration amplitude was reduced by 24%.

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