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Preload control of ultrasonic actuator by piezoelectric clutch
圧電クラッチによる超音波アクチュエータの予圧制御

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1. Introduction

An ultrasonic motor (USM) is a rapid response by friction force drive between a stator vibrator and a rotor or a slider. Some control methods have ever been reported[1-2]. Driving voltage, frequency and phase are manipulated variables in those control methods, which exist in electromagnetic motor (EMM). A preload of USM is not only dominant quantity to decide the characteristics of the USM, but is also a manipulated variable in a control system. However, it is difficult to change the preload while driving. If the preload can be controlled during driving, it is expected that the expansion of the operating range and increased stability.

An ultrasonic actuator system (AS) that was able to electrically control a preload have been proposed by combining a USM with a piezoelectric clutch (piezo-clutch)[3-4]. In this paper, the examination of a preload control by the piezo-clutch is described. As a result, the revolution speed of the USM was stabilized by preload control using the piezo-clutch. In addition, to change preload in starting USM was effective to shorten a rise time with maintaining maximum speed.

2. Construction and Operating Principle

Figure 1 shows the construction of the proposed hybrid AS. That is composed of a USM and an EMM which generate the rotation, and a piezo-clutch/brake based on a mechanical amplifier which is used for adjustments of preload and braking force. The EMM is not used in this paper.

2.1. Ultrasonic motor

The stator of the USM consists of two multilayer piezoelectric actuators (MPAs) placed in V-shape in a metal holder with an alumina friction head and is set on the piezo-clutch, as shown in Fig. 1. When unipolar sinusoidal voltages with a phase difference of 90° are applied to each MPA, the head of the stator vibrates with an elliptical displacement. The rotor rotates due to a friction when the head is in contact with the rotor.

2.2. Piezoelectric clutch/brake

The piezo-clutch contains a pair of MPAs that can be expanded outward by applying a dc voltage and a mechanical amplifier. In general, a preload is applied between the head of the USM and the rotor. When the MPAs are expanded, both ends of the mechanical amplifier are pushed, and then the head of the USM moves to be separated from the rotor. At the time when the electric power supply to the USM is cut off, the clutch operates as a brake.

3. Performance characteristics of USM

The performance characteristics of the USM were measured under the condition that preload was 112N, that applied voltage to USM was constant at $40V_{p\text{-}p}$, 23.5kHz, and that applied voltage to piezo-clutch was changed from 40V to 120V. The revolution speed of the rotor was measured by an encoder wheel jointed on a rotating shaft. As measurement results, drooping characteristics that varied linearly with a load were obtained as shown in **Fig. 2**. In addition, the inclination of revolution speed lines was changed by the applied voltage of piezo-clutch. Such a characteristic was similar to the field control of a dc motor. As a result, the preload control of the USM might be able to analogize with the field control of EMMs.

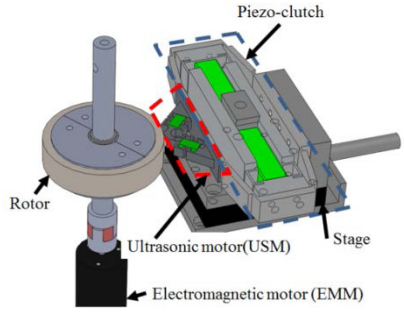

Fig. 1 Hybrid actuator system of USM, EMM, and piezo-clutch.

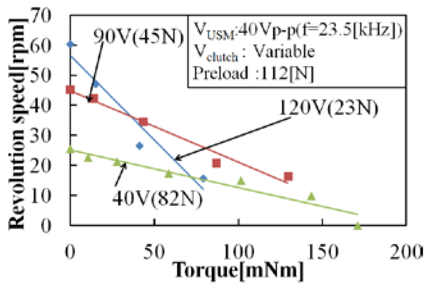

Fig. 2 Revolution speed vs. torque with preloads changed by applied voltage to piezo-clutch.

4. Constant revolution speed control by preload

First, the USM was operated at 40$V_{p\text{-}p}$, 23.5 kHz when the clutch voltage was set to 100V. The time change of clutch voltage and revolution speed without control shows in **Fig. 3**. The revolution speed fluctuated for the variation of the friction force between the rotor and the head of the stator.

Next, the applied voltage to piezo-clutch was controlled by a control system using the software (MATLAB/Simulink, Math works) on a PC. For example, the measured result of revolution speed controlled at 45 rpm was shown in **Fig. 4**. The constant revolution speed was realized by PID control of preload, but some errors still remained in this control system.

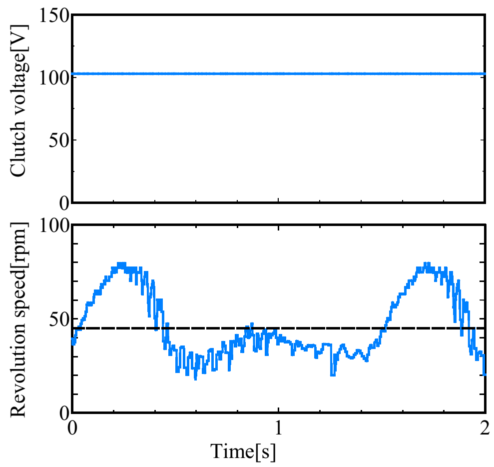

Fig. 3 Revolution speed of USM and clutch voltage without control.

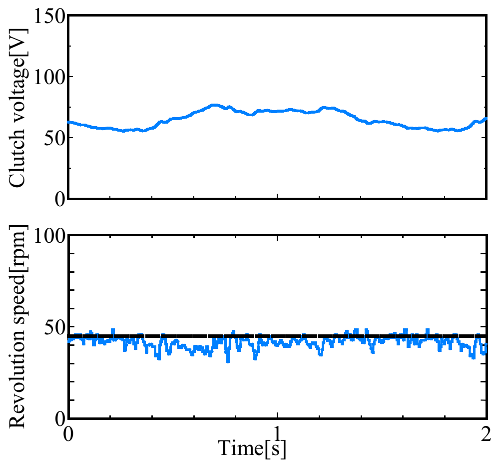

Fig. 4 Revolution speed of USM with PID control of preload.

5. Preload control drive

When the preload increases, the torque increases while the revolution speed decreases as shown Fig. 2. In general, a rise time of revolution speed at large preload is shorter than that at small preload. Hence if the preload changes from large value to small one in starting the USM, the rise time becomes shorter, as shown **Fig. 5**.

Figure 6 shows experimental results at the time when the USM was driven by changing preload from 82N to 38N. In this examination, the preload was switched when the revolution speed reached 20rpm. As a result, the rise time with preload control was shortened by 62% with maintaining maximum speed.

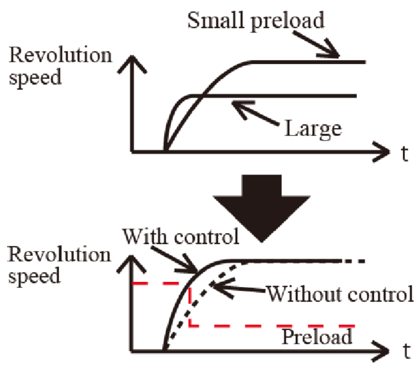

Fig. 5 Time chart of preload control drive.

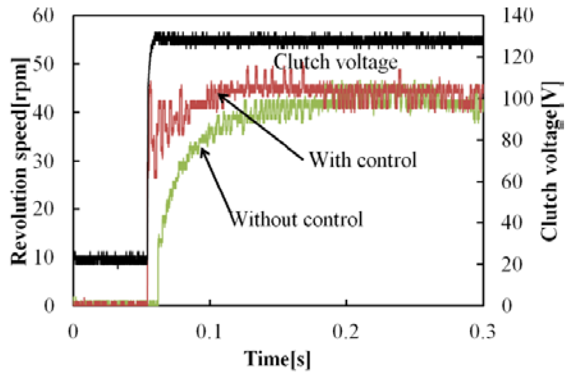

Fig. 6 Measured transient responses of revolution speed at starting USM with or without preload control.

6. Summary

A preload control by the piezo-clutch was examined. The revolution speed was stabilized by PID-controlled preload using the piezo-clutch. The rise time was shortened by preload control during transient rotation at starting the USM.

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