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Dynamic behaviours of driving torque of machine tools in microscopic motion

T. Yamazaki [a,*], S. Kaneko [b], R. Sato [b]

[a] Department of Mechanical Engineering, Oyama National College of Technology, 771 Nakakuki, Oyama, Tochigi, 323-0806, Japan

[b] Department of Bio-Mechanics and Intelligent Systems, Tokyo University of Agriculture and Technology, 2-24-16 Naka-cho, Koganei, Tokyo, 184-8588 Japan

* Corresponding author: E-mail address: yama@oyama-ct.ac.jp

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ABSTRACT

Purpose: This paper presented more details for control analysis of the dynamic behaviors of the feed drive systems that have been widely used in machine tools.

Design/methodology/approach: : In order to analyze the nonlinear behaviors of the feed drive system in microscopic motion, the dynamic driving torques were measured when the sinusoidal waves of the microscopic displacement are applied to the AC servo motor.

Findings: The experimental results showed that the distortion of the driving torque response to the sinusoidal wave input of the microscopic displacement becomes gradually evident as the input amplitude increases. With the particular input amplitudes of 200mm and over, it can be found that the driving torque response for the displacement show the periodic response. It is considered in the AC servo motor used by experiment that the vibration is caused whenever the motor rotates by 20 degrees. It is consider that it is affected by the structure of the motor.

Research limitations/implications: : The results of this research covered the feed drive system with the AC servo motor and rolling guide. However, because the dynamic behavior the rolling element was analyzed, it was also applicable the feed drive system with the linear motor and rolling guide.

Practical implications: This paper cleared more details of driving torque in microscopic motion, the performance of the feed drive system with rolling elements would be improved

Originality/value: The objective of this research project was to develop the feed drive system with the one mechanism and with the high accuracy.

Keywords: Machining; Feed drive system; Driving torque; Rolling element; Nonlinear behavior; Microscopic motion

1. Introduction

High accurate control performance of feed drive systems meet the requirements for machining industries through all ages. These systems generally consist of the AC servo motor, an amplifier and some rolling elements (ball screw etc.). The effect of a non linearity of rolling elements is the most of important factor for high motion accuracy. In the long history of the feed drive systems, though the analyses of static behavior have been done, the dynamic behaviors have not been examined. And the overall feed drive mechanism with the rolling elements will be needed to analyze in more detail.

Our final aim is how to control the nonlinear behaviors of the rolling elements and to operate the feed drive system with the accuracy of tens nanometers and the stroke of tens millimeters achieved by only one mechanism. In this study we observe the nonlinear behaviors of the feed drive system and investigate which of nonlinearities influences the motion accuracy of the feed drive system greatly. Concretely, the analysis of the dynamic driving torque when the sinusoidal wave input of microscopic displacement was applied to the AC servo motor and the detail analysis have been done. These results will contribute to mathematical modeling to illustrate the nonlinear behavior of the feed system with the rolling elements.

2. Experimental apparatus

The overall view of the experimental apparatus is shown in Fig. 1. Our controlled object is an XY table system using many machine tools. This system consists of two feed drive systems (corresponding to each of the X and Y axes). Either one of feed drive systems includes an AC servo motor and an amplifier, a ball screw and a table supported by linear ball guides. The AC servo motor and the ball screw are connected by a coupling. Also, The feed drive system contains some rolling elements, the bearing for the AC servo motor, the ball screw, the bearing that supports the ball screw and the linear ball guide. The nonlinear behaviors of the rolling element cause the degeneracy of motion accuracy of the feed drive system in microscopic motion [1-3]. Since there are some rolling elements in the feed drive system, we cannot indicate which element has strong influence on the motion accuracy. So, we focus on the dynamic behaviors of AC servo motor only.

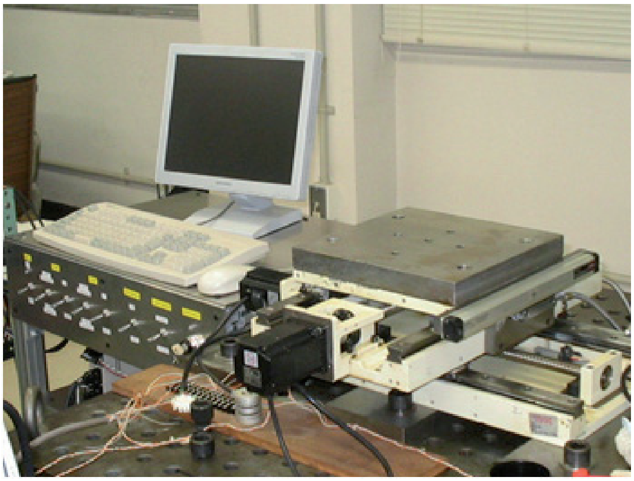


Fig. 1. Experimental apparatus

In this study, we examine only the characteristics of the AC servo motor controlled by a full closed feedback loop. In general the feedback signal is the rotational angle from a rotary encoder installed in the AC servo motor. But, it is convenient for us to define the linear displacement to express the dynamic behaviors of feed drive system in microscopic motion. We adopt the feedback signal converted from the rotational angle to the linear displacement. In our experiments apparatus the lead of ball screw is 5mm and the output of rotary encoder is 17 bits, so that 131,072 pulses are equivalent to one rotation. Consequently, theone pulse of the rotary encoder corresponds to the linear displacement of 38nm.

The electric current and the output velocity of the AC servo motor can be successfully controlled by a servo amplifier. That is, the servo amplifier has the inner control loop. The rotary encoder acquires the displacement signal of the table and sends it to the control unit (the DSP board included in the PC). In this way, the feed drive system makes it possible to control the output displacement of the table as the controlled variable. The driving torque applied to the AC servo motor can be measured with an analog monitoring function installed in the servo amplifier. Through an analog monitoring terminal, the electric voltage signal can be measured as the driving torque, in which the rated torque of the motor corresponds to the electric voltage of one volt. Since the voltage signals are introduced into the DSP board through AD converters, all data can be easily recorded simultaneously. The parameters for the control system of the AC servo motor are listed in the reference [4] by our first report.

3. Experimental result and discussion

3.1. Driving torques for various input displacement (short distance)

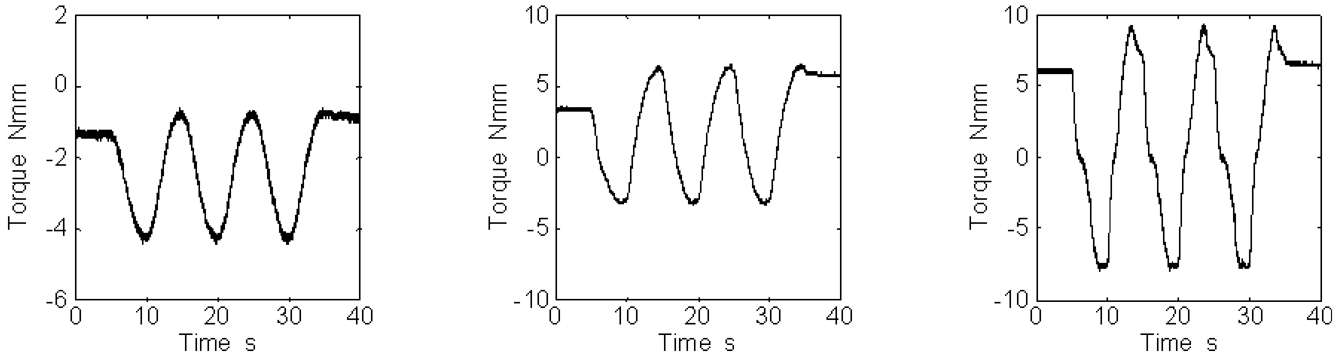
Fig. 2 is shown the driving torque curves for the sinusoidal wave input. A series of the experiments ranging from the input displacement 1 μm (a) to 100 μm (c) with the 0.1Hz have been carried out. It is very interesting from these figures that the driving torque curves are the exactly same as the sinusoidal waves in case of the smaller input amplitudes such as 1 μm, but as the input amplitude increases, the distortion of the sinusoidal waves becomes gradually evident.

Table 1.
Period of displacement

A(μm)	T(μm)	Deg.
200	255	18.36
400	261	18.79
	280	20.16
800	289	20.81
	274	19.73
	279	20.09
	279	20.09

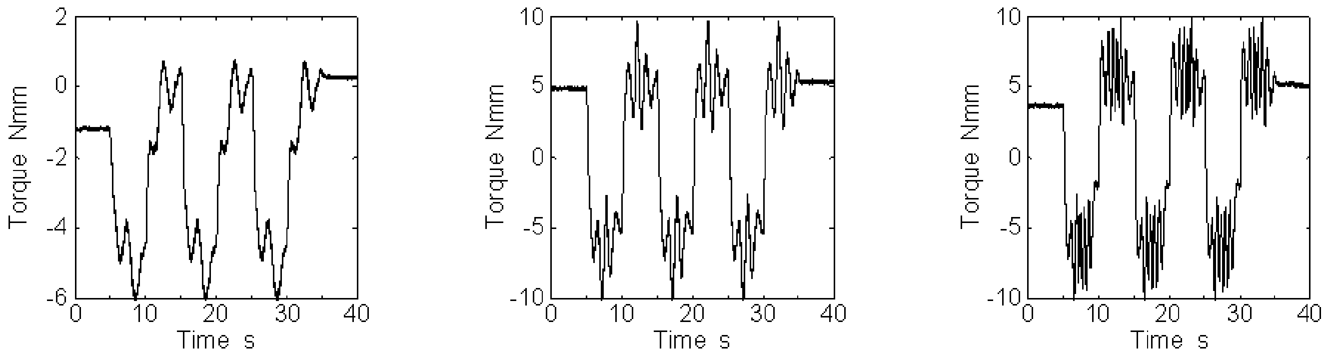
3.2. Driving torques for various input displacement (long distance)

Fig. 3 are shown the driving torque curves for the sinusoidal wave input with more long distance. A series of the experiments ranging from the input displacement 200 μm (a) to 800 μm (c) for the sinusoidal wave input with the 0.1Hz have been carried out. In these results, the magnitudes of torque are almost same, but it can



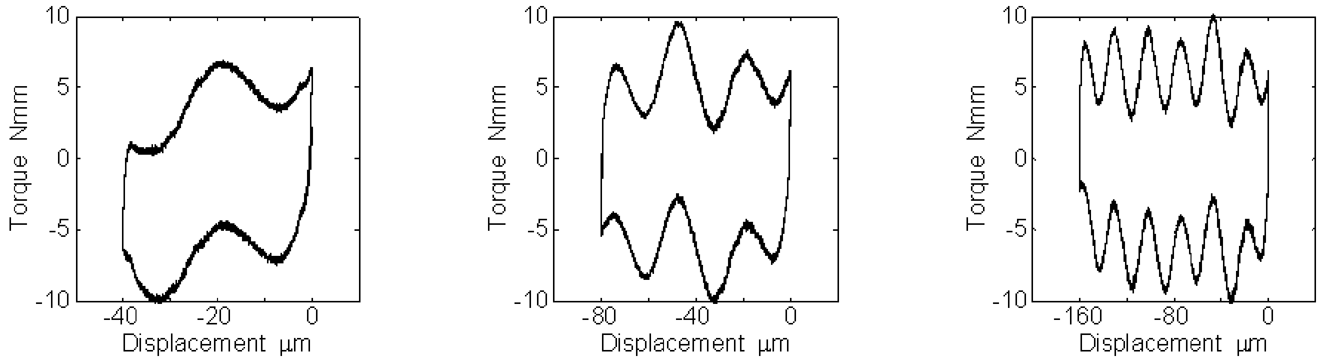
(b) A=1μm (d) A=10μm (f) A=100μm

Fig. 2. Driving torques for various input displacements



(a) A=200μm (b) A=400μm (c) A=800μm

Fig. 3. Driving torques for various input displacements



(a) A=200μm (b) A=400μm (c) A=800μm

Fig. 4. Relation between displacement and driving torque

be found that the number of vibration has increased as moved distance becomes long.

Fig. 4 demonstrates the relation of the output displacement and the driving torque, (a) is for Fig. 3(a), and (b) and (c) are also similar. It is clear that displacement vibrates. Table 1 is listed the period of displacement, respectively. From these results, because the periods of displacement are almost 274μm, considering 5mm the length of ball screw, the vibration is caused whenever the motor rotates by 20 degrees. It is consider that it is affected by the structure of the motor.

4. Conclusions

The objective of this research project was to control the nonlinear behaviors of the rolling elements and to develop the feed drive system with the one mechanism and with the high accuracy.

This paper examined the control performance of the driving torques of an AC servo motor used in the feed drive system. The experimental results showed that the distortion of the driving torque response to the sinusoidal wave input of the microscopic displacement becomes gradually evident as the input amplitude increases. With the particular input amplitudes of 200μm and over, it can be found that the driving torque response for the displacement show the periodic response. It is considered in the AC servo motor used by experiment that the vibration is caused whenever the motor rotates by 20 degrees. It is consider that it is affected by the structure of the motor.

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