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EXPERIMENTAL ANALYSIS OF FRICTION BEHAVIOUR FOR DIFFERENT LINEAR GUIDEWAYS

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Abstract:
The feed drive system for machine tool consists of rolling elements such as ball screw and linear guideways. It is well known that in the positioning of linear guideways using steel ball rolling, the contact surface has nonlinear spring characteristics. This phenomenon is deteriorating the accuracy of the machine tool. In this study, we have manufactured a feed drive system in which the physical contacts are only linear guides by using a linear motor as actuator. At first, we measured the responses to some fine feed amount for feed drive system. Next, the same experiment was performed by changing the linear guideways. This paper presents the transition of nonlinear spring characteristic region by considering the response to guideways.

Keywords: feed drive system; microscopic displacement; rolling element; nonlinear behaviour

1. INTRODUCTION

In recent years, positioning systems consisting of mechanically non-contact elements are increasing. These elements include the drive mechanism using the linear motor, and hydrostatic guideways using air or oil pressure. However, it is still dominating the positioning systems have contact elements such as ball screw, guideway using rolling and sliding for the cost and usage conditions [1]. The increase in the physical elements of the system means the increase in the elements to be considered in improving the accuracy of the system. The friction and spring behaviour caused by the mechanical contact of the elements have nonlinear characteristics, and the responses of the positioning system are changed by element size and displacement amount. For this reason, several studies improve the positioning accuracy by tuning the input force or control parameters and compensating for friction, respectively [2], [3].

The rolling guide often used as guideways for machine tools is well known to have three different spring characteristics depending on the displacement [4].

According to a study by Futami et al. decreasing the displacement, the hysteresis loop of displacement and friction force transit from steady rolling to nonlinear spring characteristics. If the displacement is further reduced, the relationship becomes not the hysteresis loop but linear. A similar analysis of rolling guideways using sinusoidal displacement is well done [5]-[8]. Since these studies are considering characteristics (hysteresis loop) for one linear guide, the spring characteristics when changing the linear guideways have hardly been studied. In addition, it is also reported that the nonlinear friction zones appear frequently when switching the forward and reverse rotation in sinusoidal displacement [9]. Also, a model called a brush model has been devised as one of the models of such nonlinear spring characteristics, and we will consider it based on the brush model [10]. The positioning accuracy is evaluated for step input, it is considered necessary to clarify the behaviour for microscopic displacement.

In this study, we will compare and consider the transition of spring characteristics caused by changing the size of the linear guideways (ball diameter) for the step input.

2. EXPERIMENTAL DEVICE

2.1. Feed Drive Mechanism

The drive device used in this paper is shown in Figure 1. This device consists of a table, a linear motor (made by GMC Hillston), guideways (made by NSK), and a base. This drives the table one axis. The linear motor used in this paper is shown in Table 1. The device table is attached with an encoder scale (made by Heidenhain), for displacement measurement, and an encoder head at the base using a jig. Guideways on height adjustment rails and encoders are mounted to achieve specified torque and parallelism. The encoder details in this paper are shown in Table 2.

The guideways used in this paper is shown in Table 1. These model numbers indicate the width of the guideways; for example, in the case of NS15, the rail width is 15 mm. These guideways are infused with the same grease before the experiment.

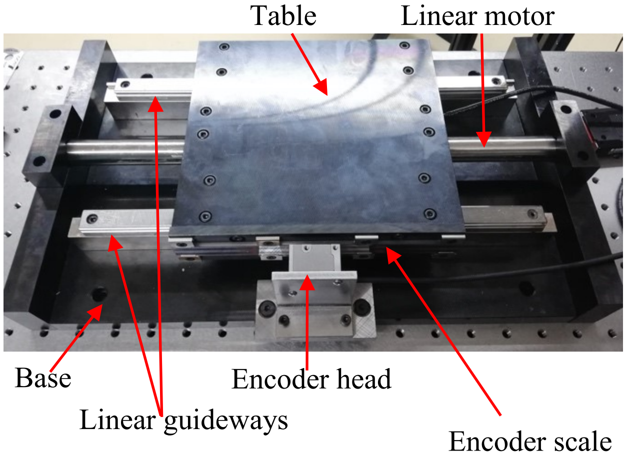


Figure 1: Drive device

Table 2: Encoder details

For Guideways	**NS15, NS25**	**NS35**
Scale	LIP201	LIF101
Head	LIP21	LIF18
Interface	EnDat 2.2	~1 V_{pp}

Table 1: Motor details

Model number	**NS15 (fine)**	**NS15 (middle)**	**NS25**	**NS35**
Preload / N	49	294	98	245
Ball Diameter / mm	2.7781		3.9688	5.5562
/ inch	7/64		5/32	7/32

Table 1: Guideways details

Model number	**S200Q**	**S250T**
Rated Force / N	38	60
Acceleration Force / N	152	240
Rated Current / A	0.6	1.3
Acceleration Current / A	2.4	5.1

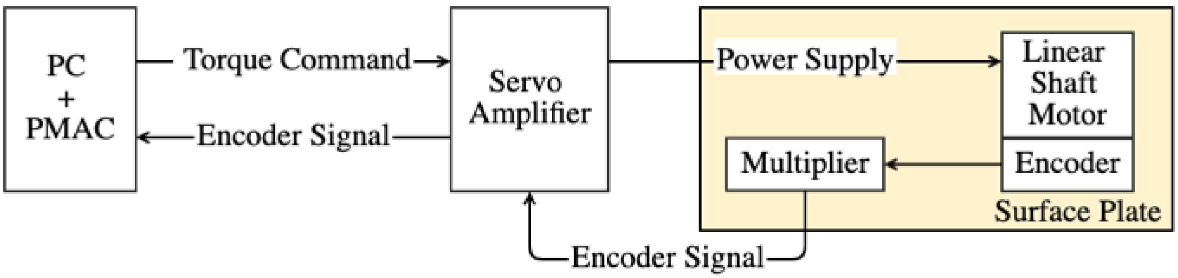


Figure 2: Control device diagram

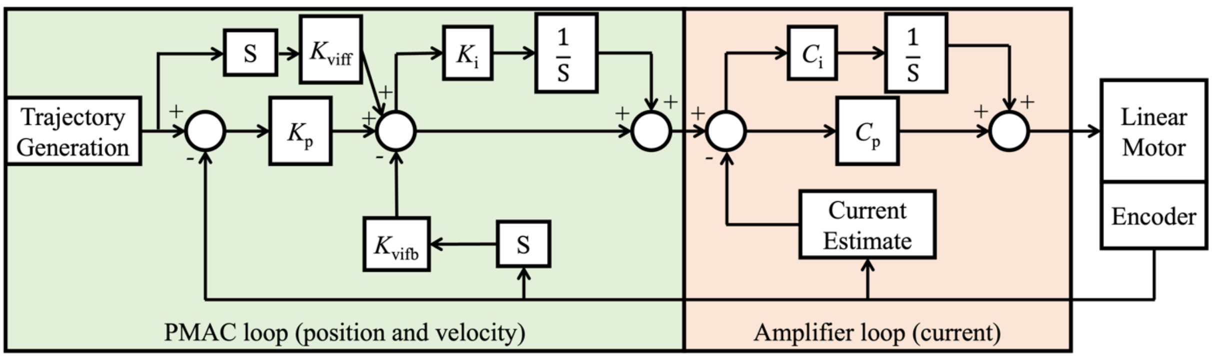


Figure 3: Control block diagram

2.2. Control Device

The control device diagram is shown in Figure 2. The servo amplifier is supplied with 100 V AC as the power supply for linear motor driving and 24 V DC for servo amplifier operation and encoder power supply. The power supplied to the amplifier is input after passing through a noise filter to reduce the disturbance.

In this experiment, three feed drive devices use a common control configuration system by switching the connection with the linear motor and the encoder from the servo amplifier. These are put on the same surface plate.

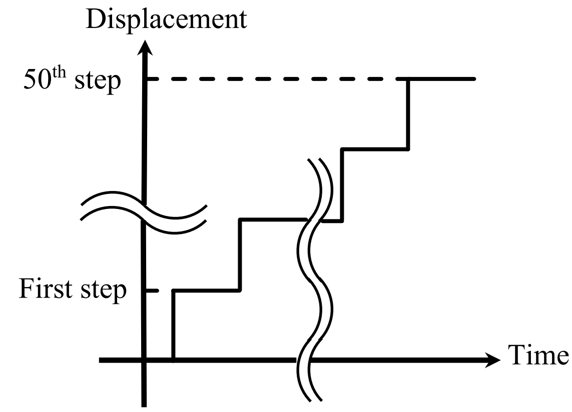


Figure 4: Input command outline

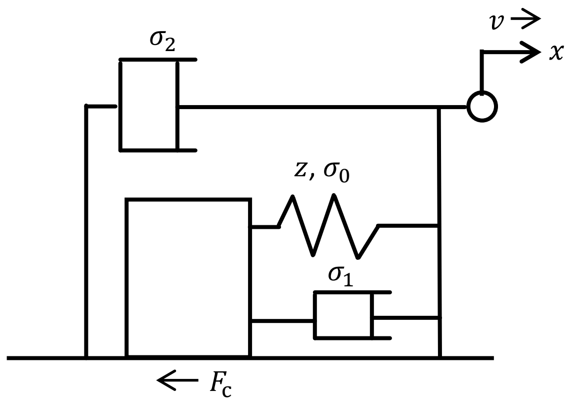


Figure 5: Friction model outline

For control, Programmable Multi-Axis Controller (made by OMRON, after this, it is called PMAC) is used as a host device, and PMAC is operated by the software of the PC. Torque commands from PMAC are transmitted to the servo amplifier, the servo amplifier supplies power to the linear motor to drive the table. The encoder reads the displacement, and the signals passing through the multiplier are feedback to the servo amplifier and PMAC.

2.3. Control System

The control block diagram is shown in Figure 3. The control system is controlled by PMAC, PC, and servo amplifier. Also, PMAC can select either velocity or torque control. In this experiment, the position loop and velocity loop are performed by PMAC which is torque control that transmits current signals to the servo amplifier. The current loop is performed by the servo amplifier, which supplies power to the linear motor.

3. FEED EXPERIMENTS

3.1. Experimental Conditions

The servo amplifier does not support Maximum resolution. For this reason, the signals from the multiplier were divided and the encoder resolution was set to 0.5 nm (NS15, NS25), 1 nm (NS35). The servo amplifier and PMAC gains were set to that proportional gain K_p is 0.01 (NS15, NS25), 0.07 (NS35), integral gain K_i is 0.01 (NS15, NS25), 0.03 (NS35), current loop proportional gain C_p is 1000 (NS15, NS25), 1200 (NS35), current loop integral gain C_i is 0 (NS15, NS25), 300 (NS35) and other is 0.

In this paper, 50 steps of input were performed using the displacement of each step input changing, and measured displacement and drive force. The dwell time for one step was set to 1000 ms. The input command outline is shown in Figure 4.

3.2. Parameters of interest

In this experiment, we focus on the important parameters that make up the simulation model to be produced in the future. The friction model currently used as a reference for considering the parameters is shown. The LuGre model proposed by Cannudas et al. is shown below [11],

$$\frac{dz}{dt} = v - \sigma_0 \frac{|v|}{g(v)} z \,. \tag{1}$$

The v is the velocity, z is the amount of deflection of the brush, σ_0 is brush stiffness. A typical shape of $g(v)$ takes values in the range $F_c \le g(v) \le F_s$.

$$F = \sigma_0 z + \sigma_1 \dot{z} + \sigma_2 v. \tag{2}$$

The σ_1 is brush damping, σ_2 is viscous friction.

$$g(v) = F_c + (F_s - F_c)e^{-\left[v/v_s\right]^{\alpha}}. \tag{3}$$

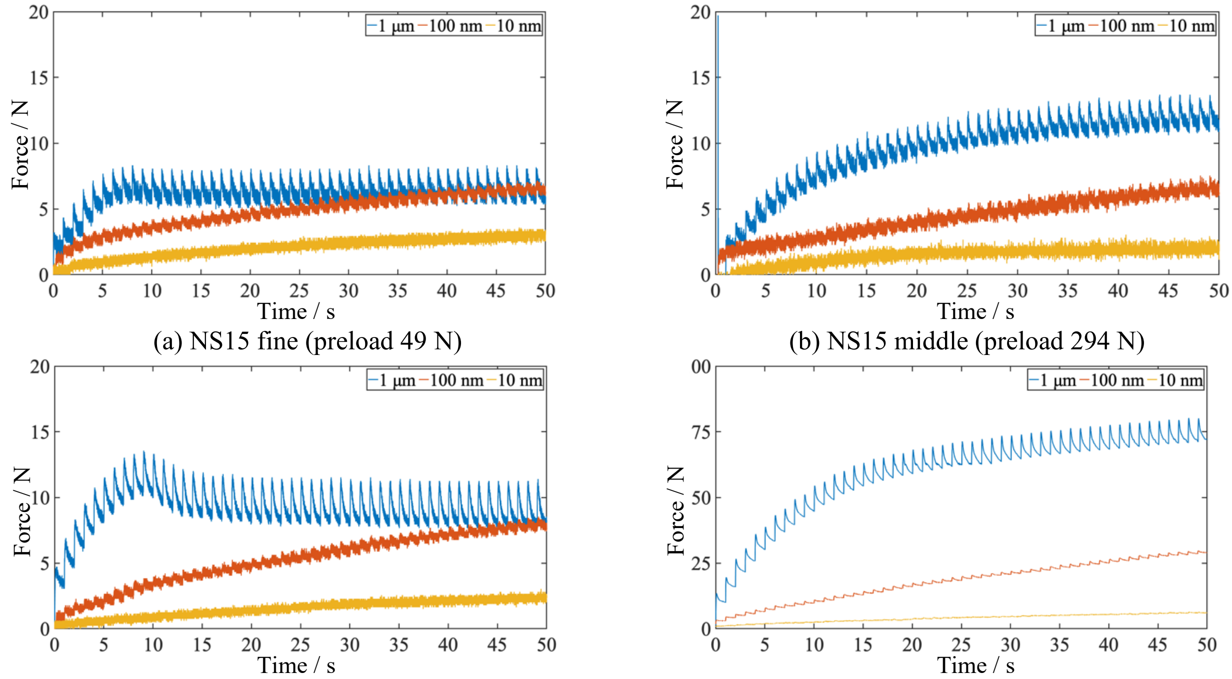
The F_s corresponds to the stiction force, is the Coulomb friction force F_c, and v_s determines how quickly $g(v)$ approaches F_c. The value $\alpha = 1$ is suggested in while finds values in the range 0.5 to 1. The friction model diagram is shown in Figure 5. It is considered that the friction of the model reaches the Coulomb friction depending on the amount of displacement. For the reason, $g(v) = F_c$ is set (Ignore the Stribeck speed term). In this study, we consider the amount of deflection z of the brush and the Coulomb friction force F_c from among these.

4. RESULT

Figure 6 shows the driving force of each guideways. In this paper, from the result of experiments, the one step displacement is shown at 10 nm, 100 nm, and 1 µm, respectively.

Figure 6 shows that for all the guideways with a one step of 10 nm and 100 nm, the force increases linearly with the input.

From Figure 6 (a), for NS15(fine) with 1 µm step, the increase in force disappears when the displacement is larger than 5 to 10 µm. The frictional force in this steady rolling region was about 6 N. From Figure 6 (b), for NS15(middle) with 1 µm step, the increase in force disappears when the



(a) NS15 fine (preload 49 N)

(b) NS15 middle (preload 294 N)

(d) NS35 fine (preload 245 N)

(c) NS25 fine (preload 98 N)

Figure 6: Driving Force

displacement is larger than 5 to 10 μm. The frictional force in this steady rolling region was about 12 N.

However, from Figure 6 (a)(b), for NS15 series with 10 nm and 100 nm, the behaviour of force is almost similar. This is because when the size of the steel ball is the same regardless of the preload, the spring constants in the linear spring region will be the same.

From Figure 6 (c), for NS25, the increase in force is not observed when the displacement is larger than 10 μm. The frictional force in this steady rolling region was about 9 N.

From Figure 6 (d), for NS35, the force is higher than that of the other guideways, and no steady rolling friction is observed. From the results of NS15 and NS25, it is considered that the steady rolling friction increases as the diameter of the steel ball increases. Therefore, it is considered that the displacement amount does not reach the steady rolling friction within the range of this experiment.

5. SUMMARY

In this paper, we performed steps input experiments with different displacements using 4 types of linear guideways. As a result, the larger the diameter of the steel ball, the larger the frictional force in the steady rolling region and the spring region until it reaches it. In addition, even when the preload was increased, the frictional force in the steady rolling region and the spring region until reaching it increased, but the spring constant remained unchanged.

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