

DRIVING FORCE MEASUREMENT FOR FEED DRIVE SYSTEM IN MICROSCOPIC MOTION

A. Akio Kochi /Presenter, B. Takanori Yamazaki

Tokyo Denki University, Saitama, Japan, 16rmt17@ms.dendai.ac.jp
Tokyo Denki University, Saitama, Japan, yamazaki@mail.dendai.ac.jp

Abstract: In all ages it is always required to improve the accuracy for machine tools. It is well known that the nonlinear behaviors of the rolling elements influence the motion accuracy of the feed drive system in machine tool. In this study the feed drive system using the linear motor is constitute, and the rolling element is limited only to the linear guide. The dynamic behavior of driving force when micro displacement is input for this system will be examined in detail, and it is clarify the behavior of rolling elements.

Keywords: Force measurement, Dynamic behaviour, Microscopic motion, Feed drive.

1. INTRODUCTION

The feed drive system for the machine tools widely uses rolling elements such as ball screws, linear guide way and rolling bearings. It is well known that these rolling elements show different characteristics depending on the displacement region, and it has been reported that highly accurate positioning is possible in each region⁽¹⁾⁽²⁾. However, There are not many researches to investigate the dynamic behavior of rolling elements when transitioning each displacement region.

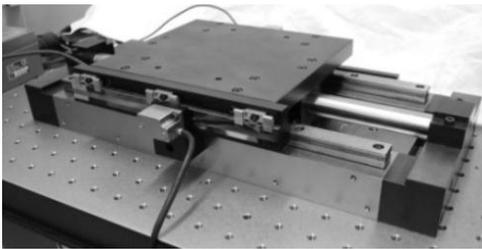


Fig. 1 Feed drive system with shaft motor

The final goal of this research is to show the dynamic behavior from the fine to the coarse region with one mathematical model. In this paper, the dynamic behavior is analyzed focusing on the driving force when moving the feed drive system in each region.

2. FEED DRIVE SYSTEM

The experimental setup is a one-axis feed drive system consist of a rod-type linear motor (S200Q made by GHC, rated force: 38 N), a table, a set of linear roller guides (NS15 made by NSK, pre-loaded: 49 N) and a linear encoder (LIP481 made by Heidenhain, signal period: 2 μ m), as shown in Fig. 1. Using the multiplier (IBV660 made by Heidenhain), the final resolution of this feed drive system is 1.25 nm.

The feed drive system is controlled by a personal computer (PC) with a digital signal processor (DSP) board. (DS1104 made by dSPACE). The reference position is input to the controller from the PC. The block diagram of position control is shown in Fig. 2. The velocity control and current control are performed by a servo amplifier (SVFH made by Servoland), and the proportional control is applied to all loops.

In the positional loop, reference value is input from dsp board through positional gain (K_p) and reference gain (K_{ref}) and feedback actual position (x_{act}) from linear scale. The drive current of the linear motor is sufficiently controlled by the speed and the current loop in the servo amplifier, and the driving force (F) is generated by the proportional gain (K_F) to the current. In under the force measuring experiments, F shown in Fig. 2 is measured as the driving force and these mentioned parameters are fixed through all experiments in this paper.

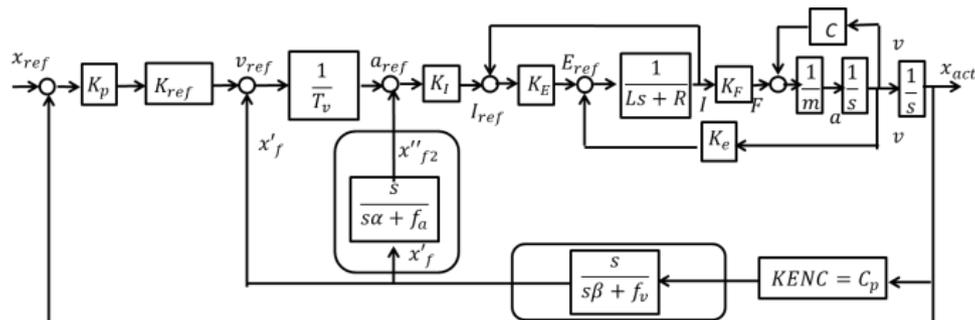


Fig. 2 Block diagram of feed drive system

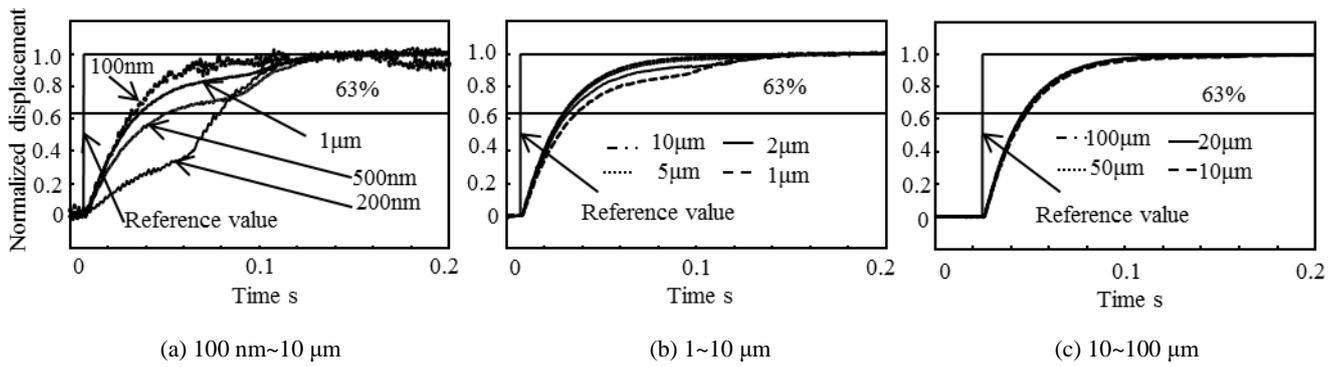


Fig. 3 Step responses for microscopic displacement

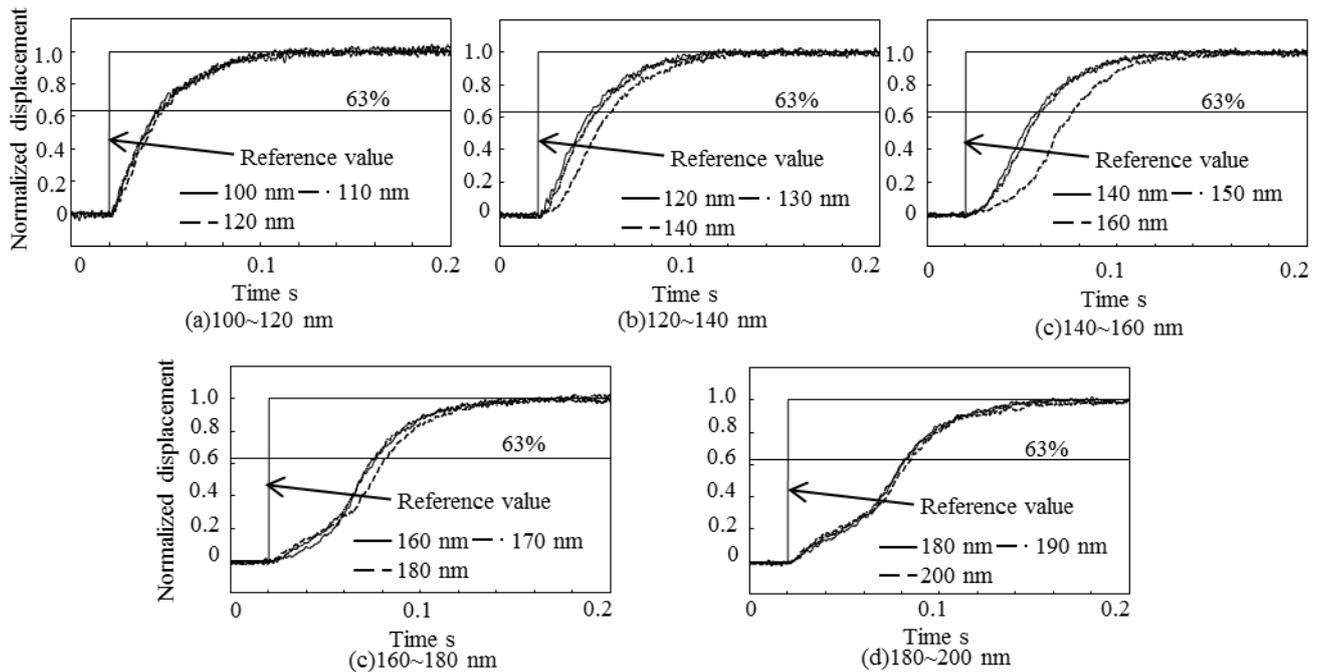


Fig. 4 Displacement and driving force

3. EXPERIMENTS AND DISCUSSION

3.1 Response for step inputs

In order to analyze the dynamic behavior in the fine motion for the feed drive system, the step responses were measured ranging from 10 nm to 100 μm . In the conditions that 2 seconds per step, 24 steps, the experiment were performed twice per single displacement.

The results of normalizing the measured step responses are shown in Fig. 3. Although it reached the reference position well from 50 nm to 100 μm , it does not reached 10 and 20 nm. It is thought that due to the resolution of linear scale and multiplier (1.25 nm) and increase of standing wave's ratio to response wave.

Considering the time constant (63% line), it is almost the same from 5 μm to 100 μm , but the time constant increases in the section from 200 nm to 2 μm . It is difficult to understand because it is normalized, but the stationary positions (the speed decreases) can be seen the point 150 nm from the reference positions. The cause of the stall is

considered that the amplifier reduces the driving force as it approached the reference position and it will be impossible to supply enough driving force against friction.

From the stationary position to the reference position, it is considered that the steel balls in the linear guide way is rest, and displaced by the elastic deformation⁽³⁾⁽⁴⁾. In this case, the steel balls are elastically deformed in resting state under the driving force and the frictional force, so the deforming force of the steel ball is smaller than the frictional force. The elastic deformation can be displaced with a smaller driving force than displacing against the friction. This condition is considered to be the reason why the time constant is decreased.

In Fig. 3(a), when the reference position is 100 nm or less, the time constant decreases and the stationary position is not observed. In this region, since the amount of displacement is less than 150 nm, it is considered that the dynamic characteristics of the rolling guide way not transit and can be displaced only by elastic deformation of the steel balls.

3.2 Response for step input in the transitional section

In order to check the section where the dynamic behaviour of the feed drive system changes, the response wave to step input was measured in the section the change appeared: 100~200 nm. The conditions of experiments are same as the one mentioned before, fundamentally.

And the response wave of fifth step in measurement are shown in Fig. 4. It is clearly that there are no big changes in the section from 100 nm to 140 nm, and the responses slightly delay in the sections: 140 nm and 150 nm. In these two sections, the stationary points shown in Fig. 3 that locate in 150 nm from the reference point cannot be seen.

In the 160 nm step, the response obvious delays from 150 nm step. When the reference position is 170 nm or more, the stationary point appears at a position 150 nm before the reference, and the speed before the stationary point is later than that after the this point.

From those results, it is considered that the transition appeared in the section between 150 nm and 160 nm, and it is considerable that the changes are resulted from decrease of speed caused by stationary point. How the changes of dynamic behaviour are caused are considered as follows.

- 1) Driving force increases after the stationary point.
- 2) The main factor of displacement transitions from the rolling and slip of the steels balls to elastic deformation.

To Figure out which one can explain these dynamic behaviors, it is necessarily to measure driving force during step input.

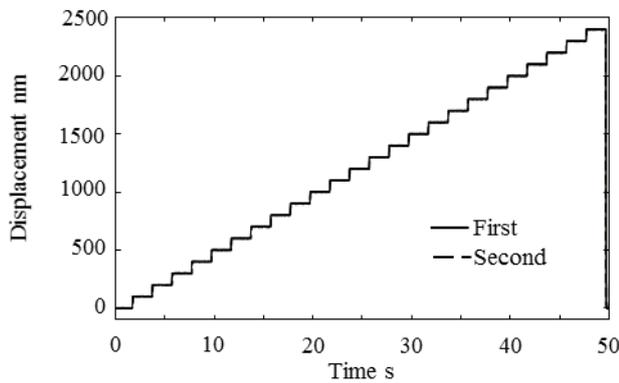
3.3 Verification for repeatability of response wave

In evaluating the driving force of the step response, It is necessary to clarify whether the experimental result is repeatable or not. It is mentioned above that response wave is measured twice, so the first and second experimental waveform were compared.

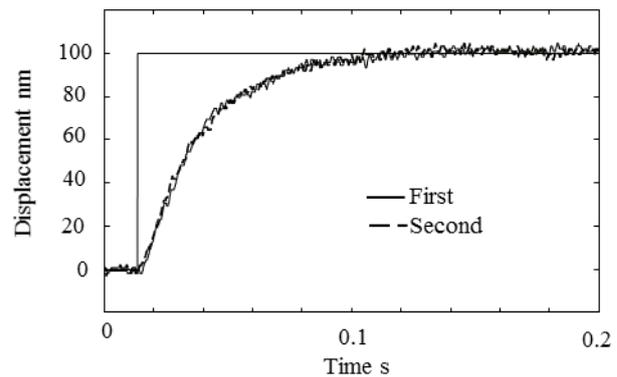
Fig. 5 is the graph overlaying the first and second waveform of 100 nm step. Fig. 5 (a) is 24 step, (b) is fifth step, It is clear that the first and second waveforms are almost same. Based on the above results, it can be said that the displacement waves have repeatability.

Refer to total driving force shown in Fig. 5 (c), they have almost same trajectory. Looking into single step shown in (d), they have similar trajectory at rising and settling of the driving force, however the vibration is caused in different timing.

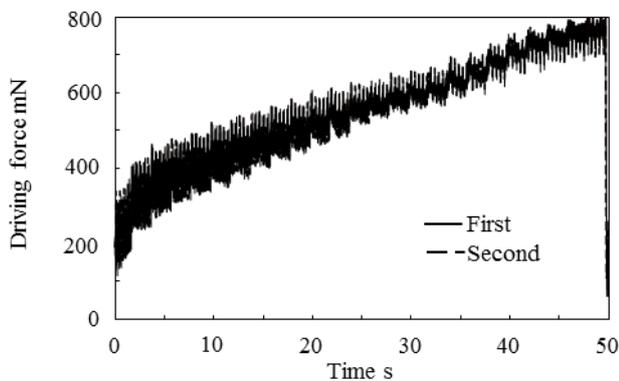
This vibration is thought not to be attenuated by 1 Hz filter enough and it appears because of elastic contact between guideway and steel ball⁽³⁾. From those results, it can be said that response wave has repeatability except for timing of driving force vibration.



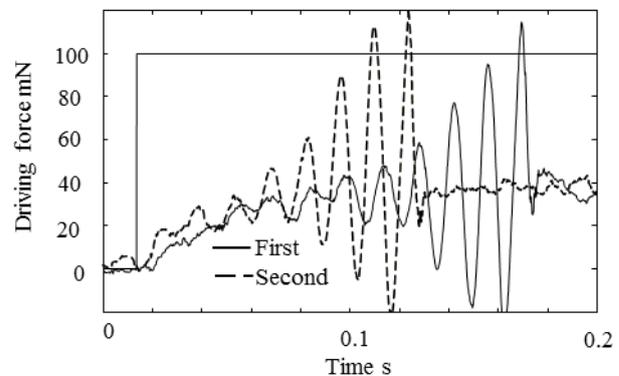
(a) Total Displacement: 100 nm



(b) Single step : 100 nm



(c) Total Driving force: 100 nm



(d) Single Driving force : 100 nm

Fig. 5 Comparison first wave and second wave

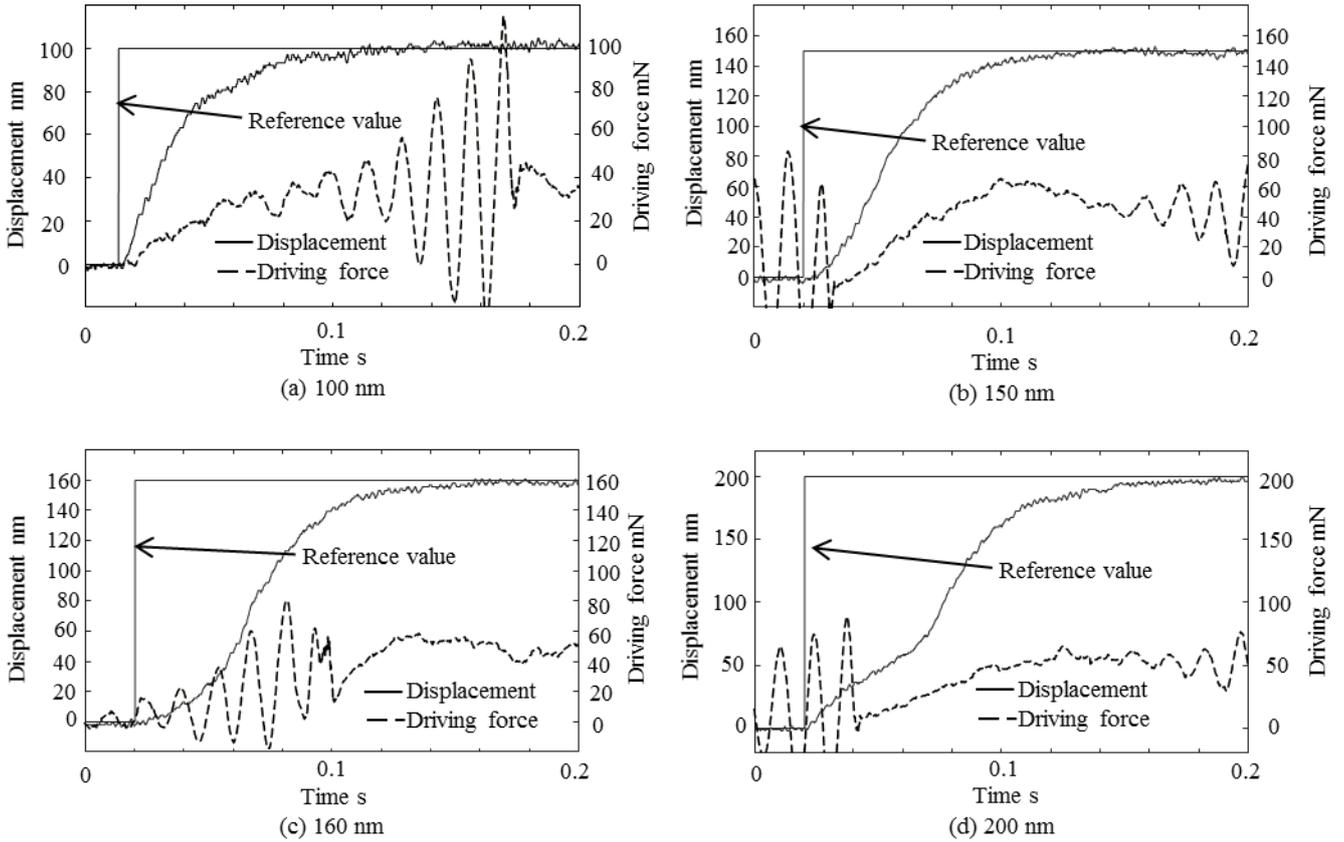


Fig. 6 Displacement-driving force diagram

3.4 Force measurement in the transitional sections

To consider relationship between driving force and time constant, the force measurements perform during the step response experiments that mentioned above. The reference position are changed in 100 nm, 150 nm, 160 nm, 200 nm. And the response waves of driving forces are output from servo amplifier and input to DSP board with 1 Hz filter.

The results of this experiment are shown on Fig. 6. In Fig. 6, the driving force is set zero at the value before reference position were input. Because the driving force cumulated every single step and it is clear on Fig. 6 that the driving forces does not go back to zero after displacement reach the reference value.

There are vibrations about 72 Hz in every measured driving force. Since these vibration are output despite passing through the 1 Hz filter, in order to keeping the displacement, it is considered that the driving force is actually output. Except for these vibration, peaks and the wave shapes of driving forces does not change dramatically in the transitional section 150 nm to 160 nm. In the area from the stationary point to reference position the speed of feed drive system increases on Fig. 6(d), however there is no big increase of driving force. It means the change of speed is not caused by driving force but decreasing of the force needed for moving of linear guide.

3.5 Responses for sinusoidal inputs

To consider the how decrease of moving force is caused, it is necessary to investigate correlations between Driving

force and displacement without cumulation of driving force. Thus, the measurement of responsive waves to sinusoidal inputs were run. The frequency of the input wave was fixed in 0.1 Hz, and amplitudes are variated between 10 nm and 100 μm . And the waves of driving forces are output from servo amplifier and input to dsp board with 1 Hz filter.

The displacement and driving forces are shown on Fig. 7 (Displacement: grey, driving force: black), and the displacement-driving force diagrams (hysteresis loops) are shown on Fig. 8.

In the sections between 100 nm and 100 μm , responsive waves followed well, but in the sections between 10 nm and 50 nm, the responsive waves were vibrating with about 10 nm amplitude. This vibration is inferable to be caused by increasing of the ratios of standing wave.

Referring to the waves of driving forces, in the sections between 200 nm and 100 μm , the reference the more amplitudes get smaller, the wave follow the displacement waves better.

The more amplitudes get shallow, shapes of hysteresis loops get shallower and in the sections between 50 nm and 100 nm, the wave shapes become linear to displacements like a spring. It means that something included in the feed drive system caused elastic deformation.

From this result, it is inferable that the changes of feed drive's responsive characteristics shown on above referenced responses to step inputs caused by the changes of conditions of balls included in linear guides between rolling, slipping and deforming⁽⁵⁾⁽⁶⁾.

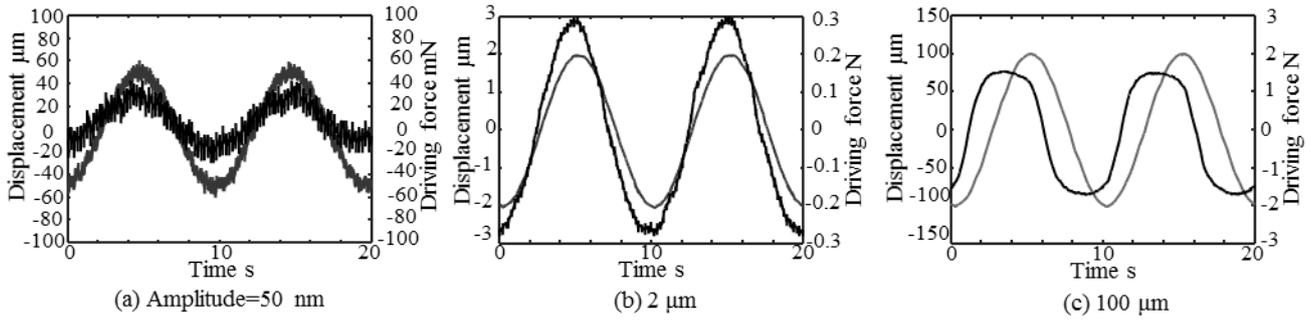


Fig. 7 Displacement and driving force

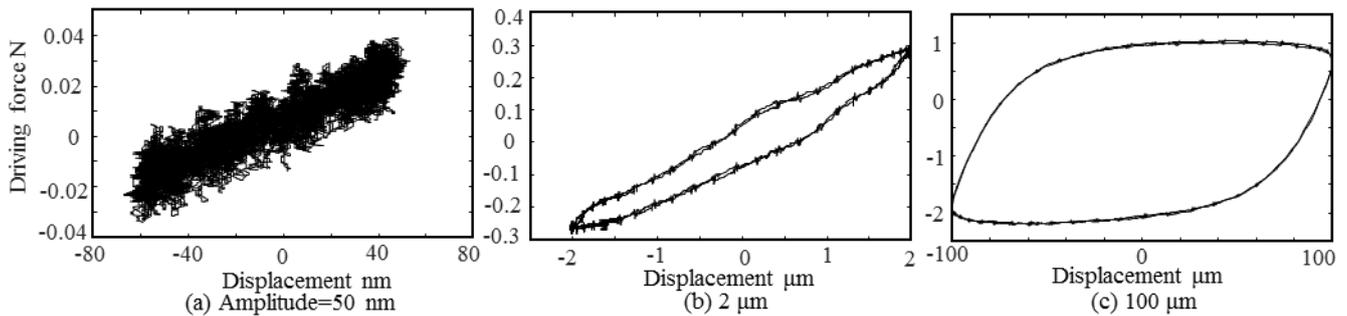


Fig. 8 Displacement-driving force diagram

4. CONCLUSION

In this paper, we mentioned about the change of the characteristics of feed drive's dynamic behaviour from non-linear to linear. In order to Figure out the changing points, we measured the responsive waves to step inputs. As a result, we find out that there are two points changing behaviours.

And in order to find out the relationships between displacement and Driving force, we measured responsive waves to step and sinusoidal inputs. In those measuring, it is clear that increase of response speed is not caused by the change of Driving force, and Driving force increase directly proportional to displacement in the sections smaller than 100 nm. It means that feed drive behaves like a linear spring in those sections.

From those experiments, it can be said that the change of dynamic behaviours of feed drive are clarified by measuring of Driving forces.

5. REFERENCES

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