Friction Control Based on Ultrasonic Oscillation for Rolling Element Linear Guideway (7th Report)

Improvement of Position Tracking Accuracy in Sinusoidal Motion

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This research deals with a method of friction control for a linear guideway, which is based on ultrasonic oscillations. Experiments were conducted by driving a single-axis guideway in sinusoidal motion as a simulation to a circular motion. The sinusoidal motion was controlled with the installation of a PI controller. The ultrasonic oscillations were applied at the guideway's carriage with 6 different oscillation patterns. Subsequently, their influence for the frictional characteristics was investigated. The investigation is focused at the inverting moving direction, when the carriage starts from zero velocity. It is observed that when the carriage was oscillated with a gradually increasing intensity, the static frictional force and the maximum displacement error had been reduced approximately by 39% and 29%, respectively.

Key Words: friction, ultrasonic oscillation, linear guideway, positioning error

1. INTRODUCTION

In precision positioning, the system performances are greatly influenced by the characteristics of mechanism including actuators, power transmissions and bearings. In recent years, demand has accelerated for highly accurate guide elements such as those used in measurement instruments and precision machine tools. There are many researches undertaken to overcome this demand, including by using bearing comprises of non-contact elements such as linear motor and aerostatic bearing. However, the most significant problem with aerostatic bearings is their lack of stiffness and damping given the compressibility and very low viscosity of air [1].

This research is aiming at the investigation of a friction control method for a linear guideway, which is based on ultrasonic oscillations. The experiment was conducted by driving a single-axis carriage in sinusoidal motion as a simulation to a circular motion, and controlled with installation of PI controller. Tanaka et. al. reported an analysis of circular contouring error by driven a single-axis guideway in a sinusoidal motion as a realization of circular motion [2].

2. EXPERIMENTAL SETUP

2.1 Experimental Apparatus

Figure 1 shows the main apparatus of this research. Rail used for the experiment has a length of 160 mm. An ultrasonic actuator is bolted at the side surface of the carriage. It is oscillated using the signals sent from a computer (PC) and a function generator. These signals are modulated by an amplitude modulator before been sent to an amplifier. This amplified signal is subsequently high voltage by a transformer to activate the ultrasonic transducer. In making the carriage to move mechanically, the carriage is pushed or pulled by a Voice Coil Motor (VCM) which is operated using the current signal sent by PC and converted by a linear amplifier A shunt resistor is installed between the VCM and linear amplifier, and the potential difference between them is detected and recorded using a data recorder. Carriage position is measured by a linear encoder (Heidenhain MT2501) with 2 μm resolution, which is coaxially-mounted to the VCM. The position data is retrieved into the PC by a counter board. Measured displacement is used for the PI control and sent to the data recorder via D/A converter, simultaneously.

2.2 Experimental Condition

Towards consideration that the circular motion of XY table consists of sinusoidal motion, this experiment is conducted by driving a single-axis carriage in sinusoidal motion. The carriage is driven at 0.1 Hz with amplitude of 6 mm. The motion is completed for two cycles, which gives the total positioning time of 20 s. Proportional Gain and Integral Gain for the PI control are set to 1.0, respectively. Moreover, the carriage is oscillated with ultrasonic oscillation during the second cycle of the motion to give comparisons between non-oscillated conditions and oscillated conditions.

2.3 Oscillating Pattern

Experiment is conducted initially without oscillation applied. The experiment is repeated subsequently; this time with the carriage oscillated under ultrasonic frequency during the final 10 seconds of the experiment. The carriage is oscillated at frequency 49.27 kHz with the maximum oscillation amplitude is set to be 0.2 μm. Figure 2 shows six oscillation patterns from A to F. The starting time and stopping time of the oscillation is programmed to be responded with the percentage of the maximum reference displacement, which is 6 mm. For example, at Pattern B, the oscillation is begun at the instant which responded to 50% of the maximum reference displacement during
increasing velocity, and stopped at the decreasing velocity. Pattern A and C also follows the same setting, which is 100% and 10% of the maximum reference displacement, respectively.

2.4 Positioning Error

This experiment is focused on the static friction occurred during inverting moving direction, i.e., when the carriage starts from zero velocity. From preliminary experiment conducted under the same condition, the maximum displacement error is confirmed to occur within 0.5 s from inverting moving direction, as shown in Figure 3. Therefore, this experiment focuses on this time interval, which is decided to be between 12.5 s to 13 s.

3. RESULTS AND DISCUSSIONS

3.1 Maximum Displacement Error

The measurement was taken three times, and Figure 4 represents one of the three results of the maximum displacement error between 12.5 s to 13 s. It is found that Pattern D gives the most reduced maximum displacement error, i.e., approximately by 26% when compared to the error without ultrasonic application. It is also found that when the applied oscillation was a steep increasing intensity, the static friction becomes slightly larger due to the increased stiction effect. Figure 5 shows displacement error when the carriage was oscillated with Pattern D. Note that the error during oscillation period is reduced when compared to the error at the same position without the ultrasonic oscillation.

3.2 Frictional Force

Figure 6 shows the friction force when carriage is oscillated with Pattern D. It is obvious that during the oscillation period, static frictional force is became smaller; reduced from 8.7 N to 5.3 N resulted to approximately 39% reduction. Moreover, dynamics frictional force is also becomes smaller during the oscillation period. However, by referring to Figure 5 and Figure 6, ultrasonic oscillations had the maximum displacement error and frictional force fluctuating widely. Therefore, further investigation need to be done to clarify the phenomenon.

4. CONCLUSIONS

In order to improve the positioning error, experiments have been conducted under six ultrasonic oscillation patterns, which were applied to the carriage. The oscillation frequency and maximum oscillation amplitude was set to 49.27 kHz and 0.2 μm, respectively. It is found that when the carriage was oscillated with a gradually increasing intensity, the static frictional force and the maximum displacement error had been reduced. Pattern D shows the most successful result; the static frictional force and the maximum displacement error had been reduced approximately by 39% and 29%, respectively.

REFERENCES

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