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PRECISE OPEN-LOOP POSITIONING USING LPM WITH ERROR CORRECTION

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Abstract A precise open-loop positioning system using linear pulse motor has been developed. The system is operated in a microstepping mode by controlling the electric current. One step of 508 μm (tooth pitch of the linear pulse motor) is divided into 508 micro-steps equally. The displacement is measured with a system using a Fiezeau-type interferometer. Periodical positioning error with a period of the tooth pitch was observed in this system. Therefore, the position is corrected using the error. The error is stored into computer in advance, and the micro-step current is corrected on basis of the stored data. Although the positioning error of the system without the correction was ±4.5 μm, that with the correction was decreased to ±1.0 μm.

Keywords Positioning system, Linear pulse motor, Error correction, Precise positioning, Micro-step

1. INTRODUCTION

Precise and high speed positioning systems are required for wafer probes, machine tools, etc. Since conventional electric rotary motors include gears and screws to convert rotary motion to linear motion, they have several drawbacks for high speed operation, reliability, etc. On the other hand, since linear pulse motors (LPM) require no complicated moving parts such as gears or screws, they are suitable for high speed operation and extremely reliable.

The resolution of the LPM is limited by the mechanical resolution (tooth pitch). Therefore, we have reported an open-loop positioning system using LPM operated in a microstepping mode by controlling the electric current. The positioning error of about ±4.5 μm was obtained [1,2]. However, the expected error is about ±1 μm (one micro-step), because one pitch of 508 μm was divided into 508 steps.

In this paper, we will discuss the periodical error of the positioning system using LPM operated in a microstepping mode. Furthermore, we will propose a precise positioning system with correction of the periodical error, and report improvement of the positioning accuracy.

2. EXPERIMENTAL

A motor used in this experiment is a hybrid linear pulse motor. The motor is based on the Sawyer principle. Figure 1 shows the cross sectional view of the forcer and stator. The forcer can be moved in an X and Y direction by driving units for X and Y motions arranged at right angles to each other. Since the magnetic flux generated by the excitation current is nonlinear, two driving units are used to decrease the effect of the nonlinearity. The effect is compensate each other, when the units are driven 180 degree out of phase each other.

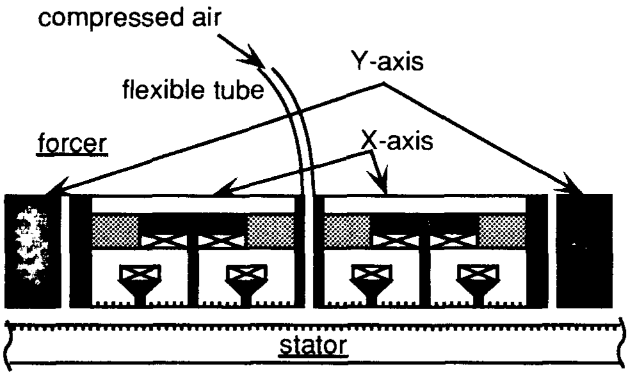

Fig. 1 Cross sectional view of the forcer and stator.

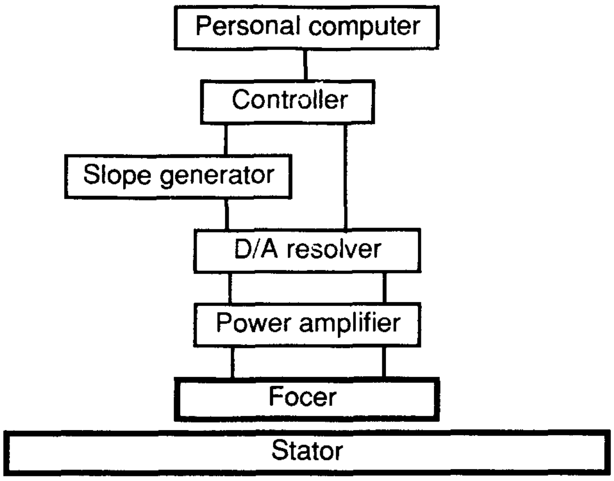

Fig. 2 Electronic control system.

The stator is a flat plate and grooves are etched in the upper surface. The tooth pitch is 508 μm and the length of the x motion is 250 mm. The forcer is supported by an air bearing suspension. The surface of the forcer and stator are stiffened with epoxy and finished flat by a grinding or lapping operation. The forcer and stator are commercially available, and are products of Xynetics corporation. Compressed air is supplied through a flexible tube, and injected through small orifices. The magnetic attraction force and the air suspension force are balanced between the forcer and the stator, and the forcer is maintained on a small gap of 10μm in the air pressure of 5.5 kg/cm^2. The operating conditions are the live load of 1Kg, the maximum acceleration of 1.2 G and the maximum velocity of 350 mm/s. Only X motion was used in this experiment.

Figure 2 shows a block diagram of the electronic control system. The frequencies of the electric current are automatically supplied to the motor with slope generator and the D/A resolver. The motor is operated on an accelerating-cruising-decelrating mode by changing the frequencies. The frequency of the electric current is determined by the D/A resolver.

The motor is operated in a microstepping mode. One pitch of 508μm is divided into 508 steps at equal intervals, thus the positional resolution is about 1 μm.

A displacement measuring system using a Fizeau-type interferometer [3] was used to measure the displacement of the forcer precisely. It was operated with a 780 nm semiconductor laser and the effect of the temperature was calibrated by a computer. The resolution of the measuring system is about 0.2 μm, and smaller than the positional resolution of 1 μm.

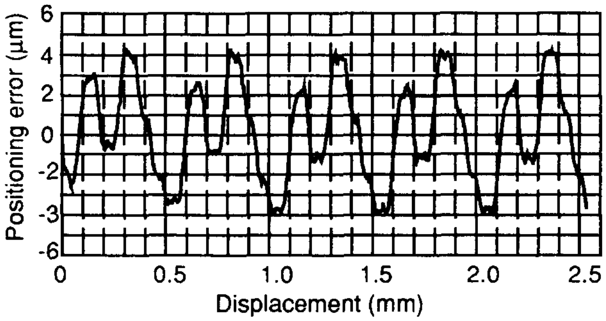

Fig. 3 Positioning error of a system operated in a microstepping mode.

3. RESULTS AND DISCUSSIONS

3.1 Microstep Operation

Figure 3 shows the positioning error. Periodical error with a period of the tooth pitch 508 μm is observed. The measurement was carried out in a range of 2.54 mm (5 pitches). The maximum positioning error is about ±4.5μm. The error is due to the nonlinearity of the magnetic force to the exciting current. As a result, one micro-step is not a constant. Although this error is decreased by using two driving

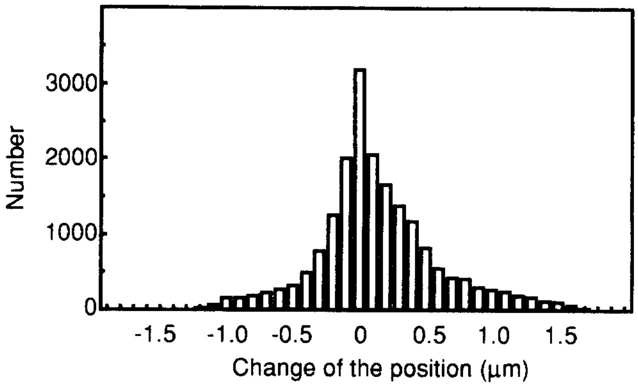

Fig. 4 Reproducibility of the positioning.

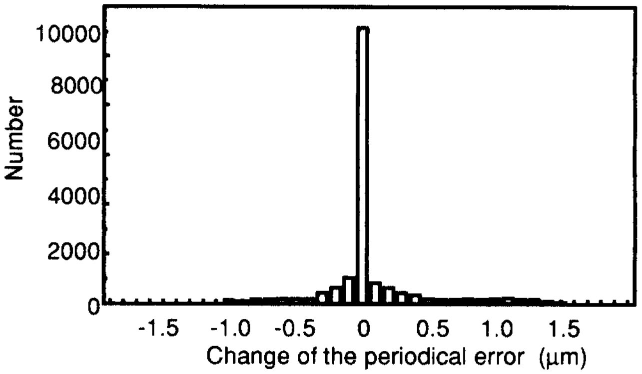

Fig. 5 Periodicity of the positioning error.

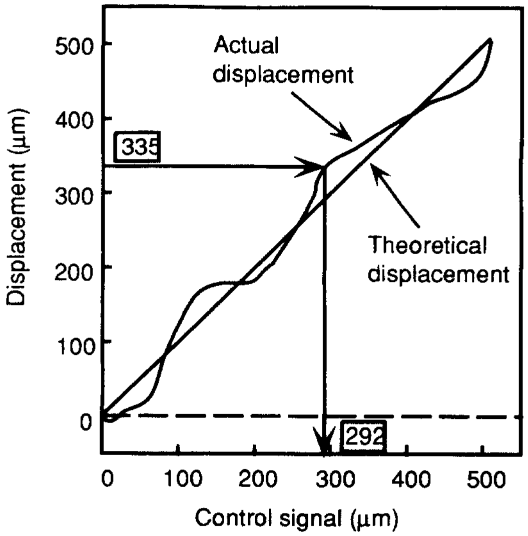

Fig. 6 Dependence of the theoretical displacement and the actual displacement on the control signal. (Schematic draw)

units 180 degree out of phase each other, error owing to the unsymmetry of these units appears.

The reproducibility of the positioning was examined. The positioning error was measured in the moving range of 2.0 mm. The measurements were carried out 10 times at the same place, and the data were stored into the personal computer. The average values of the 10 measurements were calculated at each position, and the differences between the average values and the values of each measurement were calculated at each position. Figure 4 shows the reproducibility of the positioning obtained from such measurements. It is a histogram of the differences. The standard deviation is σ = 0.4 μm, and smaller than the positional resolution of 1 μm. The system has good reproducibility of the positioning.

The periodicity of the error was examined by using the data obtained by the above experiment. Each data of the 10 measurements was divided into data of each period, and the data were averaged at each position. The differences between the average values and the values of periodical error measured experimentally were calculated at each position. Figure 5 shows the periodicity of the error obtained from such calculation. It is a histogram of the differences. The standard deviation is σ = 0.04 μm, and smaller than the positional resolution of 1 μm. The system has good periodicity of the positioning error.

3.2 Error Correction

The position of the LPM positioning system was corrected by using the data of the periodical error. The actual displacement is calculated by adding the periodical error to the theoretical displacement, and corrected displacement data are made. Figure 6 shows a dependence of the theoretical displacement and the corrected displacement on the control signal for a period schematically. The error is magnified for convenience. For example, to move the forcer to the position of 335 μm, the personal computer sends a control signal for the position of 292 μm.

Figure 7 shows the periodical error signal obtained by average of 5 periods. Figure 8 shows the positioning errors observed by the system with error correction using this periodical error signal. The measurement was carried out in a range of 2.54 mm (5 pitches). The maximum positioning error is about ±1.0 μm, and smaller than the system without

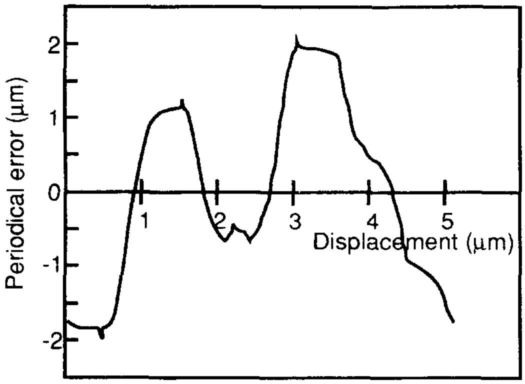

Fig. 7 Periodical error signal obtained by average of 5 periods.

error correction.

4. CONCLUSIONS

A precise open-loop positioning system using linear pulse motor has been developed. The system was operated in a microstepping mode by controlling the electric current. The reproducibility of the positioning and the periodicity of the positioning error were measured. The positioning error of the system was ±4.5 µm. The position of the positioning system was corrected by using the periodical error signal. The error is stored into a computer in advance, and the micro-step current is corrected on basis of the stored data. The positional accuracy was improved within the positioning error of ±1.0 µm with the error correction.

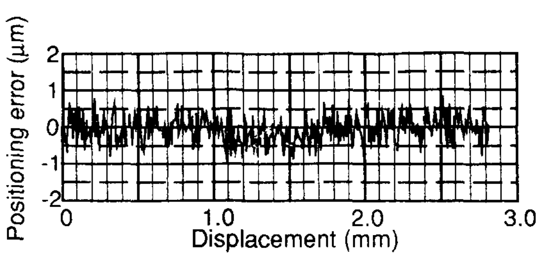

Fig. 8 Positioning error of a positioning system with error correction.

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