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A Control System for Dual-Axis Linear Motor

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Abstract

Fundamental positioning characteristics of a dual-axis Sawyer linear motor are described. The Sawyer motor is capable of high positional accuracy. An electronic control unit of the motor whose velocity is proportional to the frequency of the electric current was produced in our laboratory. The positioning system was constructed using two Sawyer motors, an air bearings suspension unit and an electronic control unit. The stable motion of the motor was confirmed on the open loop operation. The adjustable operating conditions were the live load of 1kg, the maximum acceleration of 1.2G and the maximum velocity of 350mm/s. Absolute positioning accuracy was improved within $\pm 5\mu m$, on microstep operating conditions of dividing one pitch of $508\mu m$ into 508 steps. The following two conclusions were obtained. An accelerating-cruising-decelerating control is effective for reduction in the travel time required. Also, microstep operation is effective for improving the resolution of position.

1. Introduction

The demand for high velocity and high resolution in accurate positioning systems of wafer probes, machine tools, etc. is increasing. In the case of conventional electric rotary motors, gears and screws are used to convert rotary motion to linear motion. So these systems have several drawbacks for high speed operation, reliability, etc. Linear pulse motors require no complicated moving parts such as gears or screws, so they are suitable for high speed operation and extremely reliable. However, the resolution of the linear pulse motors is limited by the mechanical resolution. One way to eliminate the limited resolution is to use microstep operation by controlling the electric current.

In this paper, we will report the development of an electronic control system for a dual-axis Sawyer linear motor, and discuss the improvement of the resolution of position by using microstep operation and the characteristics of high speed operation by using this system. A displacement measuring system using a Fizeau-type interferometer was developed, and the positioning errors were measured. The positioning accuracy will be also discussed.

2. Experimental

2.1 Structure of Linear Pulse Motor

Figure 1 shows the structure of the linear pulse motor used in this experiment. The forcer and stator made by precision manufacturing techniques are products of Xynetics corporation. This hybrid linear pulse motor has eight teeth on each pole, so a large force is obtained in spite of the small tooth pitch. The motor is based on the Sawyer principle. The forcer is composed of

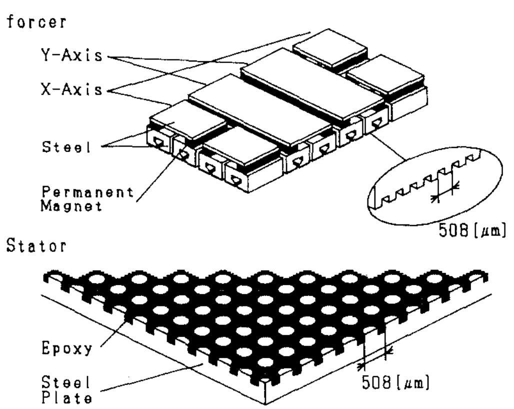


Fig. 1. Structure of linear pulse motor

driving units for X and Y motions arranged at right angles to each other, and can be moved in an X and Y direction. For each direction, two driving units are arranged with the phase shift of 180°. The periodical errors for each unit, which appears periodically with the frequency of the electric current of sine wave, are balanced out owing to the phase shift, and the positioning errors are decreased. The stator is a flat plate and grooves are etched in the upper surface for X-Y motion. The tooth pitch is 508μm, and the area of the X-Y motion is 250x150[mm]. The forcer is supported by an air bearing suspension. The surfaces of the forcer and stator are stiffened with epoxy and finished flat by a grinding or lapping operation. 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 and stable air gap of 10μm in the air pressure of 5.5kg/cm^2.

2.2 Electronic Control System

Figure 2 shows the block diagram of the electronic control system

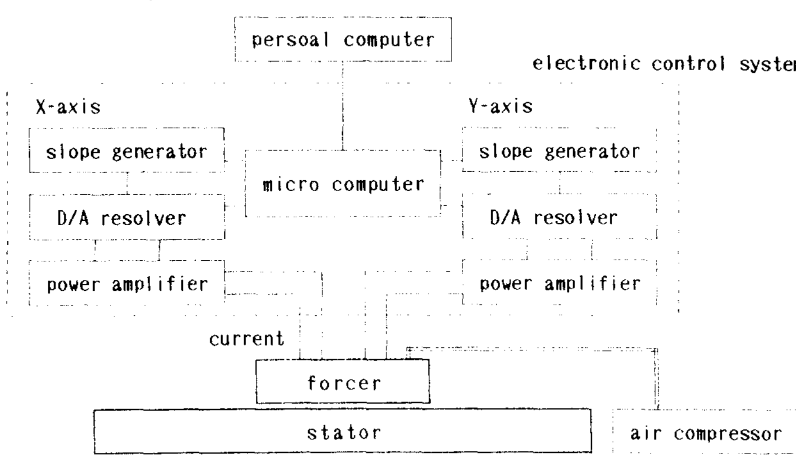


Fig. 2. Electronic control system

electronic control system. A mass of load and positioning instructions are entered to a personal computer from a keyboard. The frequencies of the electric current, according to the desired conditions previously input into the computer are automatically supplied to the coils with slope generators and the D/A resolvers. The motor is operated on an accelerating-cruising-decelerating mode by the changing frequencies. The frequency of the electric current through the two coils is determined by the D/A resolvers. Two sets of these driving units are used to control the forcer for X and Y motion independently. The motor is operated in a microstepping mode to obtain higher resolution. One pitch of 508μm is divided into 508 steps, thus the positional resolution is 1μm. Figure 3 shows the waveform of the electric current.

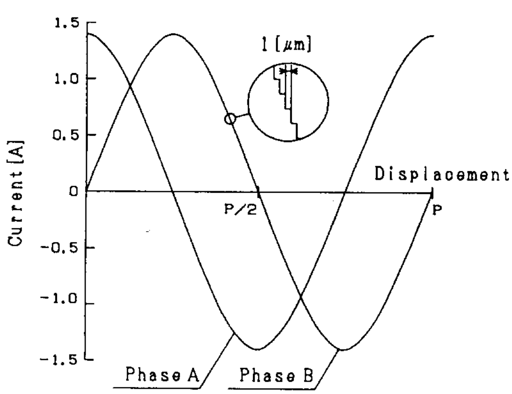


Fig. 3. Current of microstep

2.3 Displacement Measuring System

A displacement measuring system using a Fizeau-type interferometer was developed to measure the displacement of the forcer precisely. Figure 4 shows the fundamentals of the system. The

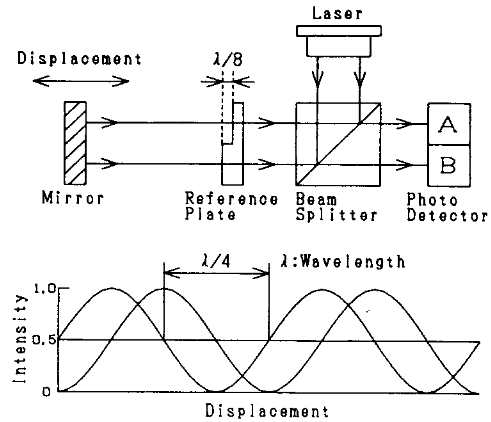


Fig. 4. Fizeau-type interferometer

intensities of the interference signals between the reflected waves from a reference plate and a mirror are detected by a photo detector. The displacement is measured by counting the changes of the dark and light signals. The displacement is calculated on the basis of the wavelength of the laser. Since the wavelength of the semiconductor lasers depends on the temperature, it was calculated with a computer by measuring the temperature of the package with a thermometer and using a calibration curve. A 780nm semiconductor laser was used, thus the resolution of this system is about 0.2μm - a quarter of a wavelength. The direction of the displacement is determined by measuring the phase shift between the two interference signals of A and B. Since the interferometer is a Fizeau type, it is little affected by fluctuation of air, disturbance, etc.

3. Results

3.1 Positioning Time

Figure 5 shows the dependence of the position of the forcer on the time for various live loads. An accelerating-cruising-decelerating control was

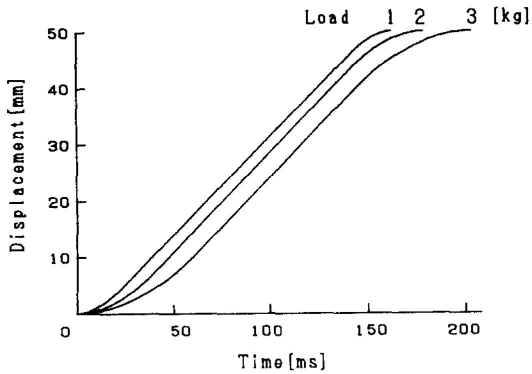
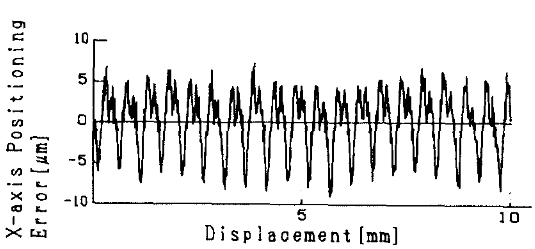


Fig. 5. Positioning time

used with maximum acceleration of 1.2G and maximum velocity of 350mm/s. When the motor is operated at speeds higher than this, represented by the area to the left of the curve, it loses control and becomes jammed.

3.2 Positioning Accuracy

Figures 6 show the positioning errors for X and Y directions at various points. Periodical positioning error with a period of the tooth pitch 508μm appears. The maximum positioning error is



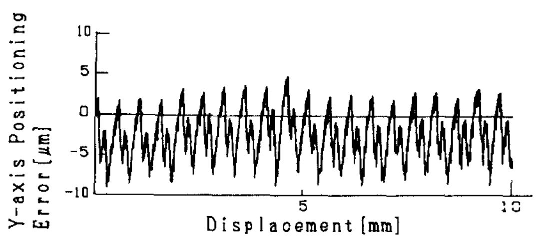


Fig. 6. Positioning error

about $\pm 5 \mu m$. These characteristics were also observed at any point on the X-Y surface. Therefore, the positioning accuracy of this motor is within the periodical positioning error of $\pm 5 \mu m$.

4. Conclusion

An electronic control system for a dual-axis Sawyer linear motor has been developed, and the fundamental characteristics of the motor has been described. By using an accelerating-cruising-decelerating control and microstep operation, the travel time required has been reduced, and the resolution of the position has been improved. A displacement measuring system using a Fizeau-type interferometer has been developed to measure the positional accuracy of the forcer. By using the electronic control system, the positional accuracy has been improved within the periodical positioning error of $\pm 5 \mu m$.

Acknowledgments

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Reference

[1] H.Shingu, J.Zhang, S.Nohira, Y.Uchida and T.Sumi, "A positional system of dual-axis linear motor", Bulletin of Aichi Institute of Technology, vol.27B, pp.217-222, 1992 [in Japanese].