A magnetically driven linear microactuator with new driving method

Paper

Member **Mochimitsu Komori** (Kyushu Institute of Technology)

Non-Member **Tsuyoshi Tachihara** (Kyushu Institute of Technology)

Summary

Recently, electromagnetically driven microactuators have attracted interest because of their availability. We have been studying magnetically driven actuators. This time, a magnetically driven linear microactuator using microsystem fabrication techniques has newly developed. The microactuator is composed of a mobile microplatform (mover) with some permanent magnets and a stator with a large number of planar coils. The planar coils of the stator are made by using photolithography technique and electroless plating technique. In this paper, static and dynamic characteristics of the magnetically driven linear microactuator are discussed. The mobile microplatform of the microactuator can move at speeds higher than 75 mm/s. The microplatform carries loads more than 0.1 g. As a result of the experiments, the magnetically driven microactuator is found to be useful for a new type positioning mechanism.

Key words: Magnetic drive, Micro actuator, Linear drive, Magnetic attractive force, Linear PM motor

1. INTRODUCTION

Various kinds of microactuators using electrostatic forces, electromagnetic forces, and other forces have been studied by many researchers [1]-[4]. Considering electrostatic forces and electromagnetic forces, it is said that electrostatic forces are superior to electromagnetic forces for micro-sized actuators. On the other hand, for millimeter/centimeter-sized actuators, magnetically driven method is regarded as useful and important, because millimeter/centimeter-sized motors are very useful for industrial field such as computer devices and audio-visual devices. Judging from the previous condition, magnetically driven type actuators are regarded as very promising for millimeter/centimeter sized microactuators. Thus, there are some reports on magnetically driven small-sized microactuators [5]-[8]. However, there are few reports on magnetically driven microactuators discussing dynamics of them quantitatively. Moreover, useful driving method for such microactuators has never been established.

This time, a magnetically driven linear microactuator has newly developed which has never been reported

elsewhere. The linear microactuator is composed of a microplatform with some permanent magnets and a stator with a lot of planar coils. The planar coils arrayed on a silicon substrate stator are made by using photolithography technique and electroless plating technique [7]. We propose a new driving method for the microactuator. Moreover, dynamic characteristics and performances are discussed and evaluated quantitatively.

Fig.1 Schematic illustration of the magnetically driven microactuator

2. MICROACTUATOR SYSTEM

2.1 System structure

The total system of the magnetically driven linear microactuator is shown in Fig. 1. The system is composed of the newly developed microactuator, amplifiers, a digital input and output (DIO) interface, a personal computer. Drive signals for the microactuator are generated by the personal computer using Basic programming language. The drive signals are applied to the actuator through the DIO interface and the amplifiers. The amplifiers with a gain of 0.2 A/V generate driving currents according to the drive signals.

2.2 Actuator

The newly developed magnetically driven linear microactuator is composed of a microplatform with some permanent magnets and a stator with a lot of planar coils. The microplatform consists of a Permalloy thin plate (8.5 mm × 8.5 mm × 0.1 mm) and four cylindrical permanent magnets. The magnets measure 1.5 mm in diameter and 1.5 mm in length. The microplatform with the permanent magnets measures 0.152 g in weight. Magnetic flux density on the surface of the permanent magnets is 0.16 Wb/m². The four magnets are placed just under the Permalloy plate at the four corners. The magnetic attractive force between the Permalloy plate and the magnets attaches the magnets to the Permalloy plate.

The stator is composed of arrays of planar coils for driving the microplatform. The stator consists of 36 (6 × 6) planar coils and measure 20 mm × 20 mm. Each coil is made of electroless plating copper with 10 turns. The cross section of electroless plating copper wire measures 0.1 mm in width and $\approx 3 \mu\text{m}$ in thickness. The pitch of the coils is 3.4 mm. Each coil has two copper pads to apply driving currents, and photosensitive polyimide layer (TORAY Corp) works as an insulator among copper wires.

2.3 Fabrication process of planar coils

The planar coils of the stator are fabricated by using photolithography technique and electroless plating technique. The fabrication process of the planar coils is shown in Fig. 2. First, we make preparations for a silicon substrate (Fig. 2(a)). A polyimide layer is deposited on the silicon substrate as an insulating layer as shown in Fig. 2(b). A seed layer of WSi is deposited on the

Fig.2 Fabrication process

polyimide layer by using sputtering technique as shown in Fig. 2(c). Thickness of WSi is an important factor for the coil fabrication process, because too much deposition of it leads to short circuits of themselves. Photolithography process delivers polyimide patterns for electroless plating coils as shown in Fig. 2(d). Finally, a coil layer is formed in the coil mould by electroless plating as shown in Fig. 2(e).

In order to study resistances of the coils, the relationship between applied voltage and the driving current were investigated. In the experiment, the driving current was applied to the coils up to 0.63 A (at 6.7 V). When the driving current was greater than 0.63 A, the coils were broken due to heating the coils. Fig. 3 shows the relationship between applied voltage and driving current. The result shows that the resistance of the coil is around 10.7 Ω . When the driving current is 0.63 A, magnetic flux density on the surface is 8.0×10^{-4} Wb/m².

2.4 Driving method

The stator coils are excited to produce attractive forces applied to the microplatform. A line of six coils is excited at a same time to drive the microplatform. Fig. 4 shows the driving method for the microactuator in the right direction. A microplatform is also illustrated on the stator. Fig. 4 shows an exciting pattern just before the

microplatform does a step motion in the right direction. Thus, the microplatform in each figure is attracted to the exciting coils.

In Fig. 4(a), the upper right hand magnet is attracted by two adjacent coils of S pole, and the lower right hand magnet is also attracted by a coil of N pole. That is, both upper right and lower right hand magnets are attracted by the three adjacent coils. As a result, the microplatform moves in the right direction at a distance of half the coils' pitch. Next, upper left and lower left hand magnets are attracted by two adjacent coils N and a coil S, respectively. Then, the microplatform does a step motion in the right direction as shown in Fig. 4(b). As a result, the microplatform moves a distance of half the coil's pitch. In the same manner, the microplatform moves in the right direction. Thus, the exciting patterns of the

Fig.3 Relationship between applied voltage and driving current

Fig.4 Driving method for the microactuator

stator for driving the microplatform are shown in Figs. 4(a), (b), ---, and (f). The microplatform can move in the left direction. The exciting patterns for the microplatform in the left direction are obtained in the same manner.

The movement of microplatform with up or down ward can be explained by the same manner as those shown in Fig 4. Thus, the microplatform can move in two-dimensional direction. However, in this paper, we discuss the dynamics in one direction. Dynamics in two-dimensional direction will be discussed in other paper.

3.DYNAMIC CHARACTERISTICS

3.1 Driving force

In order to investigate the driving force of the actuator, attractive force between a permanent magnet and a stator coil was measured for various driving currents. In the experiment, the attractive force and the displacement were measured by using an electronic balance and a micrometer, respectively.

The relationship between attractive force and displacement from coil center is shown in Fig. 5 for various driving currents of 0.05A ~ 0.40 A. The displacement zero means the center position of the coil. Each curve shows a maximum driving force at a displacement of ≈ 1 mm. The attractive force becomes large as the driving current increases. The largest driving force is 1.26×10^{-3} N at an driving current of 0.40 A. Since for our actuator two permanent magnets are excited at the same time, the attractive force is estimated at more than $\approx 2 \times 10^{-3}$ N.

Fig.5 Relationship between attractive force and displacement

3.2 Step response

In order to investigate dynamics of the microplatform, step responses were studied. In the experiment, the coils of stator were excited so that the microplatform does a step motion. The personal computer gives driving signals to the coils. Displacement was measured by using a laser displacement sensor with an accuracy of $\pm 10 \mu\text{m}$.

Figure 6 shows step responses for various driving currents of (b) 0.26 A, (c) 0.30 A, and (d) 0.35 A. Upper step curve in Fig. 6(a) is a drive signal by the computer. Each response has the same starting time. As shown in the figure, step responses without overshoots are observed. It is found that the microplatform moves smoothly on the stator. The step responses have different final values and rise times. As the driving current increases, the final values and the rise time become large and short, respectively.

In order to study step responses quantitatively, the final value (displacement) and the rise time were evaluated using Fig. 6. The relationship between final displacement and driving current is shown in Fig. 7. The final value (displacement) increases with increasing current in the current range up to 0.35 A. The maximum displacement is around 2.0 mm in the current range

Fig.6 Step responses of the microplatform

greater than 0.35 A. To move the microplatform through the distance 1.7 mm corresponding to half the coil width, the driving current 0.32 A should be applied to the stator coils.

The relationship between rise time and driving current for the microplatform is shown in Fig. 8. The rise time is defined as the time required for the response to rise 10 to 90 percent of its final value. The figure has proved that the rise time decreases with increasing driving current. The minimum rise time is 21 ms at a current of 0.43 A. The minimum rise time corresponds to a speed of $\approx 75 \text{ mm/s}$, which is high speed for such microactuators.

In order to investigate carrying capacity, step responses of the microplatform with carrying loads were studied. In the experiment, final displacements of the microplatform with loads of 0.07 g and 0.123 g were

Fig.7 Relationship between displacement and driving current

Fig.8 Relationship between rise time and driving current

Fig.9 Relationship between displacement and driving current

measured. The experimental setup is the same as that used in Fig. 6.

The relationship between final displacement and driving current is shown in Fig. 9. The final displacement increases with increasing driving current. The displacement increases with decreasing carrying loads. The result shows that the microplatform carries around the same load as itself (0.152 g).

3.3 Continuous driving performance

Continuous driving characteristics of the microplatform were studied. The displacement is measured by using the laser displacement sensor. The drive signals by the personal computer were also recorded. The experimental procedure is almost equal to that used in Fig. 6. The step number is restricted at three because of the stator dimensions.

Figure 10 shows the experimental result for the microplatform. The upper three curves show the computer signals to the microactuator. The lower curve shows the displacement of microplatform. As shown in Fig. 10, the microplatform shows the step motion. One step corresponds to ≈ 1.7 mm. It is found that the microplatform moves accurately according to the computer signals.

4. CONCLUSIONS

In this study, the magnetically driven linear microactuator using microsystem fabrication techniques is successfully developed. The microactuator is

Fig.10 Continuous motion of the microplatform.

composed of a mobile microplatform with some permanent magnets and a stator with a large number of planar coils. The planar coils of stator are fabricated by using photolithography technique and electroless plating technique. From the results, the driving method is found to be available for driving the microplatform. The step responses without overshoots are observed. The final values and rise times of the step responses depend on the driving currents. The minimum rise time corresponds to a speed of ≈ 75 mm/s, which is high speed for such microactuators. From the study on carrying capacity, it is found that the microplatform carries about the same load as itself. The microplatform shows the continuous motion according to the computer signals.

As a result, the microactuator mentioned above is found to be useful for some kinds of applications such as microconveyer and micropositioner.

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Mochimitsu Komori (Member)

He was born in Hyogo prefecture in 1958. He received M.S. degree from Osaka University, and Ph.D degree from Kyushu University. He is an associate professor at the Department of Mechanical System Engineering, Kyushu Institute of Technology.

Tsuyoshi Tachihara (Non-member)

He was born in Fukuoka prefecture in 1973. He received B.S. degree and M.S. degree from Kyushu Institute of Technology in 1997 and 1999, respectively. He is now working in Meitec Corp. His main research interests are in the micro systems.