特　集
研 究 速 報

Precise Positioning of a Micro Conveyor based on Superconducting Magnetic Levitation

超電導磁気浮上を用いたマイクロ搬送アクチュエータの精密位置決め

Tetsuhiko IIZUKA* and Hiroyuki FUJITA*
飯 塚 哲 彦・藤 田 博 之

1. INTRODUCTION

A transportation system in vacuum is necessary for advanced semiconductor fabrication apparatus, such as in a cluster process. The system should be remote controllable, free from particle generation and small enough to be easily equipped in vacuum chambers. A micro magnetic actuator which levitates and carries an object is the most suitable for the purpose.

Furthermore, it is one of the most important problems to remove high friction and abrasion in the research of a micro actuator. The life time of the micro actuator depends on the high friction and the mechanical abrasion. One of the solution for this problem is to use the magnetic levitation.

We choose the levitation of the permanent magnet on the High Temperature Superconductor, because the levitation is stable by Pinning effect and Meissner effect. Pinning effect is the phenomenon that the superconductor holds the magnetic flux of the permanent magnet, and Meisnner effect is the diamagnetic phenomenon that the repulsive force works between the superconductor and the permanent magnet.

We have tried to move the levitated slider with the permanent magnets in the horizontal plane by the electrode film placed between the superconductor and the slider. The actuation principle is similar to a surface motor. We use the superconductor (Y-Ba-Cu-O) by the sintering fabrication, because it is more suitable than the superconductor by the melting fabrication for actuating the slider in the horizontal direction in the presence of Pinning force.

The advantages of this actuator are the following:

・This actuator can be used in the high clean environment. Because it is free from particle generation by the magnetic levitation.

・This actuator levitates stably by the restoring and damping force of Pinning effect. Thus we do not need the controller to adjust the height of the levitated slider.

In this paper, we have investigated the actuator for the quick conveyance and the precise positioning by combining the step actuation in the entire area and the micro-step actuation in the local area near the target position. We have obtained the conveyance speed of 280 μm/s over 2.8 mm and the fine accuracy of 40 μm. These values were achieved by using the rotary switch for the step actuation and by controlling the duty ratio of the square pulse current for the micro-step actuation.

2. MECHANISM

In this section, the experimental set up and the driving method are explained. Figure 1 shows the schematic configuration of the actuator.

The mechanism is the following. The liquid nitrogen (the temperature is 77 K) cools the superconductor through the cool-

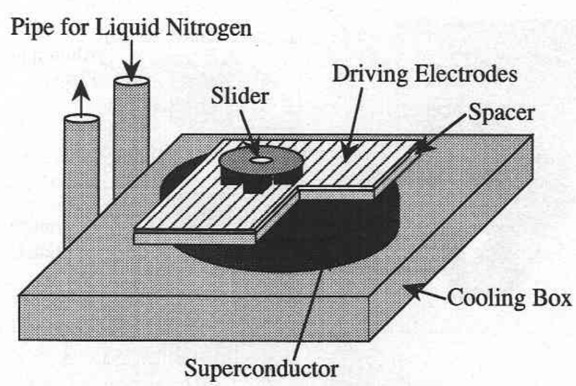


Figure 1　Main part of the actuator

*3 rd Department, Institute of Industrial Science, Univerity of Tokyo

ing box and the heat conductive paste. The slider with four permanent magnets levitates 1mm in height on the superconductor. The slider is driven in the horizontal plane by switching the current in the electrodes made of the flexible plate.

The materials and the dimensions of each part are shown in Table 1–3.

Figure 2 shows the slider with four permanent magnets. Figure 3 shows the stator (the electrodes film). The electrode film is a flexible plate. The copper electrodes were fabricated by wet etching on a poly-imide film.

Figure 4 shows the entire experimental set up. This set up consists of the cooling circuit of the liquid nitrogen, the glass vessel, the rotary pump and the driving circuit. The liquid nitrogen flows in the cooling box (the size is 30 × 50 × 5mm). The rotary pump produces vacuum down to 140 Pa in the glass vessel (diameter: 150mm, depth: 90mm) to avoid the deposition of the frost on the actuator. We observe the movement of the slider by a CCD microscopic camera.

Table 1　Superconductor

Material	Y-Ba-Cu-O
Fabrication	Sintering
Size	25mm in diameter 4mm in thickness
Critical temperature	90K

Table 2　Slider

Permanent magnet	Pr-Fe-B
Surface flux density	550$Gauss$
Total weight	38mg

Table 3　Stator (the electrode film)

Material	Copper	Poly-imide
Thickness	18μm	25μm
Line width	70μm	
Pitch	180μm	

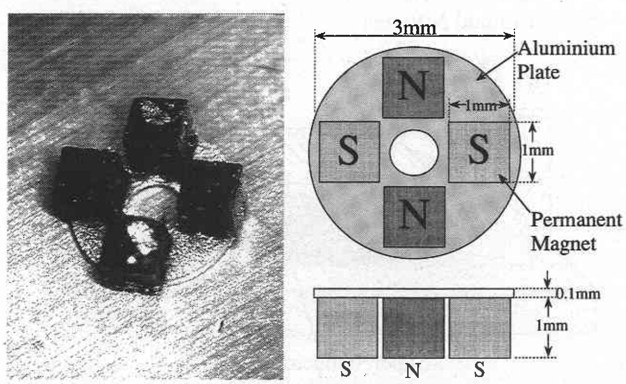


Figure 2　External view and the size of the slider

When the current in the electrodes flows, the slider is attracted to the electrodes. Thus we can actuate the slider in the lateral direction by switching the current in the electrodes (the step actuation).

Figure 5 shows the micro-step actuation method. The slider can be continuously moved by the micro-step actuation that is to change the duty ratio (T_1 / T_0 in Figure 5) of the square pulse current in two adjacent electrodes. The driving circuit consists of the non-inverted and the inverted buffer and the current amplifier. The driving circuit is connected to the function generator which can control the switching frequency and the duty ratio of the square pulse current. When the switching frequency is higher than 100Hz, the slider stands still at the middle position between two electrodes. Then, when we change the duty ratio, the slider continuously moves.

Figure 6 shows the stator electrodes and the driving circuit connection.The slider is conveyed in 17 steps by the rotary switch. Then we can position the slider with the micro-step actuation.

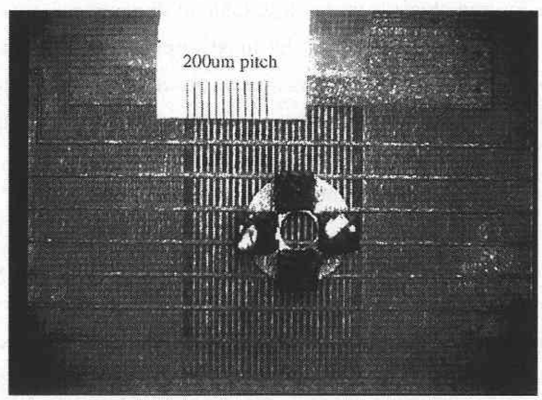


Figure 3　Stator (the electrodes film) and slider which is placed upside down

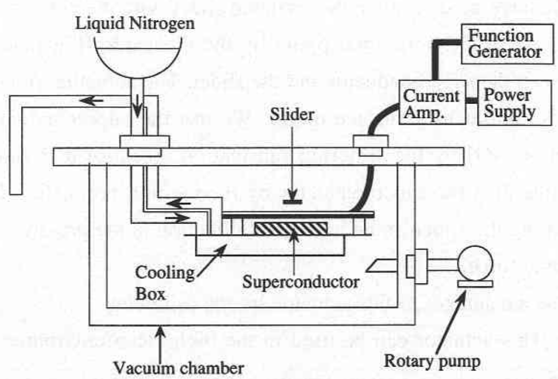


Figure 4　Experimental set up

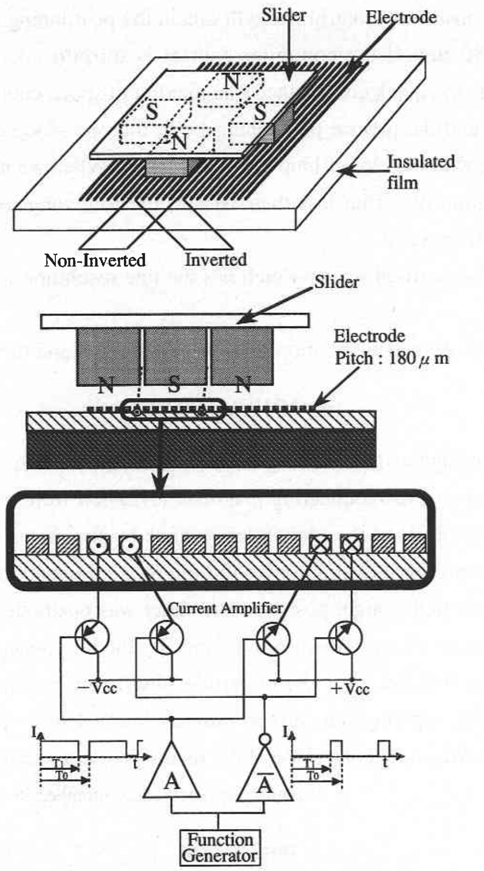


Figure 5　Micro-step actuation

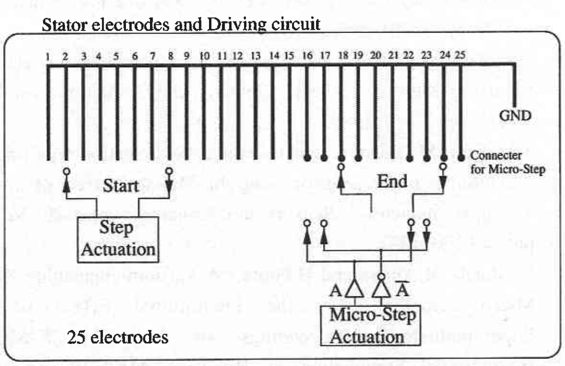


Figure 6　Stator electrodes and the driving circuit connection

3. RESULTS

In this section, we explain the experimental procedure, show the results and discuss them. The experimental procedure is the following:

・Set the spacer (the thickness is 0.5 mm), the stator and the slider on the superconductor.

・Pour the liquid nitrogen to the cooling box.

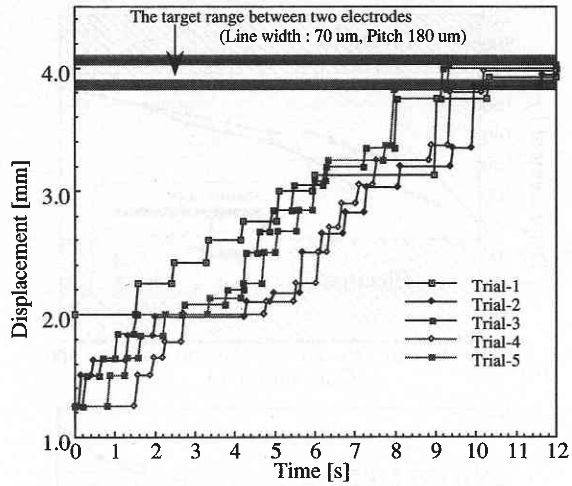


Figure 7　Displacement of the slider in the step actuation

・The slider levitates in the height of 1mm on the superconductor.

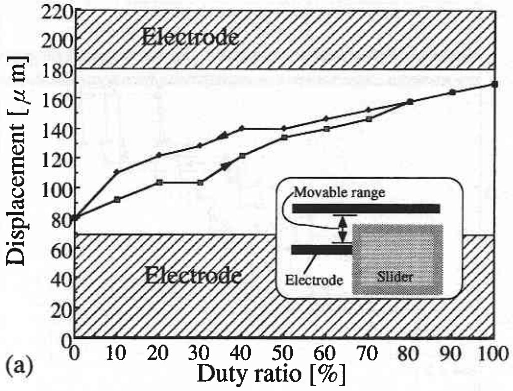
・Drive the slider by the rotary switch (the current is 400mA) and the duty ratio (the switching frequency is 200 Hz).

・The movement of the slider is observed by the CCD microscopic camera (20–100 zoom magnification) and the TV monitor.

Figure 7 shows the displacement of the slider in the step actuation. We could convey the slider to the target range between two electrodes every time by the rotary switch. The positioning accuracy was 100 μm in the step actuation. The motion of the slider was influenced by the magnetic flux fixed at the initial position (when the temperature of the superconductor became 90 K). The Pinning flux distribution was not always uniform on the surface of the superconductor.

Figure 8 (a) shows the micro-step actuation by using two adjacent electrodes. The movable range was 90 μm (the distance between the duty ratio of 0 % and 100 %). To cover outside of the movable range, we chose the electrodes with the interval of 2 electrode pitches (the distance is 360 μm) (see Figure 8 (b)). The movable range was 170 μm. These movable ranges in Figure 8 (a) and (b) overlapped each other in the end of the movable range. Thus, we could control the slider to any position precisely.

Figure 9 shows the positioning of the slider in the step and the micro-step actuation at 5 trials. The stationary position of the slider was scattered in the range of 100 μm between two electrodes only by the step actuation as shown in the left part of Figure 9. We tried to position the slider precisely by the micro-step actuation. The slider moved stepwise and reached near the



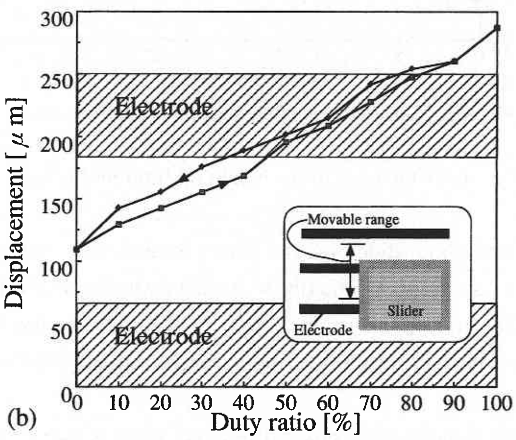


Figure 8　Displacement in the micro-step actuation

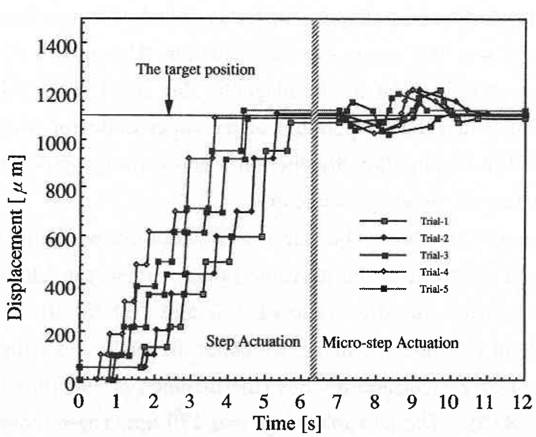


Figure 9　Positioning of the slider in the step and the micro-step actuation

target position. Then we switched to the micro-step actuation circuit. We could control the position of the slider in the range of 40μm. The operation was to adjust the duty ratio manually with monitoring the position of the slider through the 60 magnification lens. If we use the lens higher than 60 magnification, we can obtain more precise positioning. This time, we observe the scatter of the duty ratio in the range of 30 % at 5 trials. So if we try the open-loop control, we will obtain the positioning accuracy of 80 μm. If the computer control is introduced, we can estimate the quick conveyance (the maximum speed could be 10 mm/s) and the precise positioning (with the open-loop control: 80 μm, with the closed-loop control: 40 μm). When we need the positioning precision less than 10 μm, the following improvements are needed.

・The position sensor which has the fine resolution less than 1 μm.

・The precise fabrication of the electrode film and the slider.

4. CONCLUSION

The design and the driving characteristics of a micro conveyor based on superconducting magnetic levitation were reported. We have obtained the global conveyance by the step actuation and the precise positioning by the micro-step actuation in the local area to the target position. The slider was positioned in the accuracy of 40 μm. The movable range by the micro-step actuation was smaller than the electrode pitch; this problem was solved by applying the current with the interval of 2 electrode pitches. We could control the slider to any position precisely.

(Manuscript received, September 29, 1997)

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