

Observation of Contact-free 2D Micro Positioning using Diamagnetic Graphite

Haruhiko SUZUKI*, Chisato YOSHIDA*, Airi SUZUKI*, Shougo TANI*,
Manamu KASAI* and Atsushi ITO*

* Department of Electrical and Electronic System Engineering,
National Institute of Technology, Fukushima College
30 Nagao, Kami-arakawa, Taira, Iwaki, Fukushima, Japan

Abstract

The "non-contact magnetic suspended technology" utilizing the diamagnetism of materials in room temperature range was expected to be a new energy-saving elemental technology. This report aimed to clarify the characteristics of a model for non-contact two-dimensional micro actuation of full passive magnetic suspended octagonal diamagnetic graphite PG and HOPG plate samples above 2D Halbach PM array. It was important to observe the non-contact displacement characteristics and response characteristics by controlling the excitation current of the electromagnet to control the diamagnetic repulsive force acting on the edge of the octagonal graphite plate sample. However, to realize two-dimensional non-contact drive of the PG plate sample, it was necessary to place electromagnets at two edges of the octagonal graphite plate sample, and the characteristics depend on the anisotropy of the graphite sample and the characteristics of the two electromagnets. In this observation model, the displacement angle characteristics in the first quadrant were clarified by experimental measurements after understanding the influence of the sample characteristics and electromagnet characteristics. This experimental measurement confirmed the possibility of non-contact micro positioning and micro actuation in all quadrants.

Keywords : Diamagnetic, Pyrolytic Graphite, HOPG, 2D Halbach PM array, Contactless actuation, 2D micro positioning, Magnetic damping

1. Introduction

The purpose of this project is to develop a non-contact two-dimensional positioning actuator using magnetic suspended diamagnetic material on 2D Halbach PM array. The production of systems that integrate minute mechanical parts and electronic circuits using semiconductor microfabrication technology requires not only nano-order positioning accuracy, but also the elimination of the effects of dust and noise.

In 2009, we reported on non-contact micro-actuation of an octagonal PG (Pyrolytic Graphite) plate sample on 2D Halbach array permanent magnet, which is a two-dimensional arrangement of cubic Nd-based permanent magnet pieces (5 x 5 x 5 mm) as shown in Fig. 1 (Saito et al., 2010). After that, we placed an electromagnet above the edge of the octagonal PG plate sample and observed the non-contact displacement characteristics, response characteristics by controlling the magnetic field at an edge of the sample.

Improving the magnetic stiffness and vibration damping are the most important performance for non-contact positioning of the full passive magnetic suspended planer actuator using PG materials. In particular, the highly oriented pyrolytic graphite (HOPG) disk sample was found to have obvious vibration suppression effect and exhibit magnetic stiffness equivalent to that of the conventional PG sample.

In 2023, we reported on vibration suppression and improved response using an octagonal double layered sample of a HOPG plate sample and a PG plate sample, as shown in Fig. 2 (Suzuki et al. 2023). In order to apply a passive magnetic suspended HOPG plate to a 2D micro actuator, it is necessary to clarify the non-contact displacement characteristics in a two-dimensional plane. In this paper, we report that we have confirmed that an octagonal HOPG plate sample can be positioned at any displacement angle by controlling the excitation current of two electromagnets.

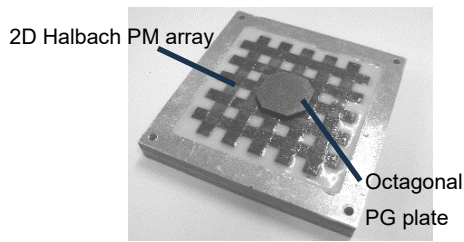


Fig. 1 Contact-free micro actuation model by using an octagonal PG plate above 2D Halbach PM array.

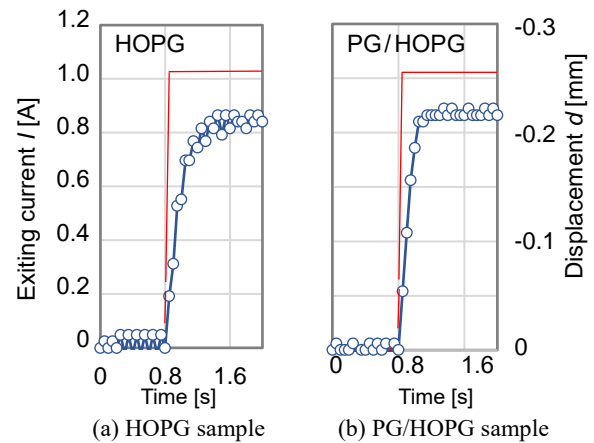


Fig. 2 Improvement of step response using double layer stacked sample PG/HOPG.

2. Vibration damping properties of PG and HOPG

Figure 3 and 4 show the displacement d [mm] of octagonal graphite plates (PG, HOPG) depending on the stepped excitation current I [A], respectively. The step response of the PG plate sample reached the final stable point of about 0.3 mm after about 3.5 seconds, accompanied by an overshoot due to the sample's inertia. The step response of the octagonal HOPG (STM-1) plate sample was clearly different from PG sample, and no vibration phenomenon was observed.

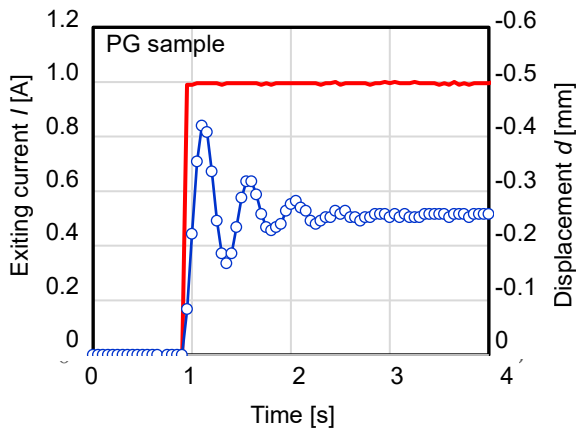


Fig. 3 Non-contact step response of octagonal PG plate sample.
(thickness :1.0mm, weight : 0.832g)

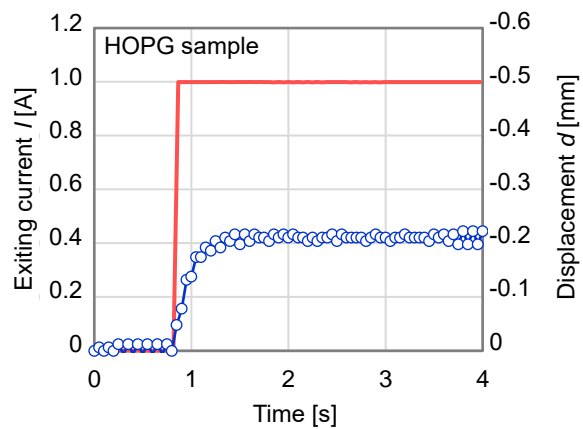


Fig. 4 Non-contact step response of octagonal HOPG plate sample.
(STM-1, thickness :1.0mm, weight : 0.760g)

3. Experimental methods

The octagonal HOPG plate sample was stably levitated with an air gap of approximately 1.0 mm due to the diamagnetic repulsive force (magnetic suspended force) from eight surrounding magnetic poles on the 2D Halbach PM array. In this state, when the electromagnets (EM1, EM2) placed above two magnetic poles were excited to change the magnetic field at the edge of the octagonal HOPG plate sample, the sample was displaced toward the magnetically stable point. Figure 5 shows the displacement direction of the octagonal PG plate sample when the electromagnets (EM1, EM2)

placed above points A and B (S magnetic poles) are excited at the S poles. The electromagnet was fixed at a position 3 mm above the 2D Halbach PM array using Z-axis stage. DC excitation current was applied to the electromagnet coil (500 turns), and the poles of the permanent magnet and the electromagnet were set to be the same polarity. Two laser displacement meters were used to measure the displacement as shown in Fig. 5 and Fig. 6. The displacement direction angle was calculated from the displacement in the x and y directions.

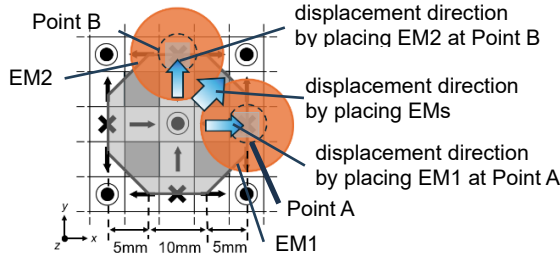


Fig. 5 Displacement of octagonal HOPG plate sample by excitation of two electromagnets [3].

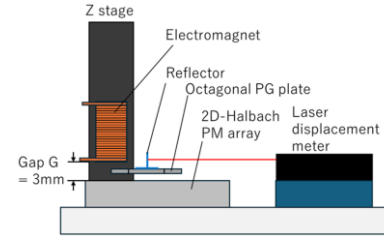


Fig. 6 Measurement system displacement of octagonal HOPG plate sample with laser displacement meter.

4. Experimental results

Figure 7 shows the combination of excitation currents (I_{EM1} , I_{EM2}) when measuring the displacement characteristics. Figure 8 shows the displacement characteristics of the octagonal HOPG plate sample when the excitation current shown in Fig. 7 is applied. As a result, it was found that by determining the ratio of the current values, it is possible to control the position of the octagonal HOPG plate sample while maintaining the displacement direction angle.

Table 1 shows that the displacement from the initial position (IP) and the displacement direction angle (θ_d : about 45 degrees) can be controlled in all quadrants by combining the polarities of the excitation currents of EM1 and EM2.

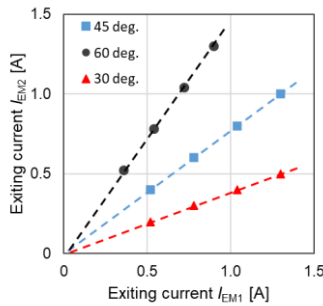


Fig. 7 Exciting current of EM1 and EM2 vs. displacement direction of octagonal HOPG plate sample.

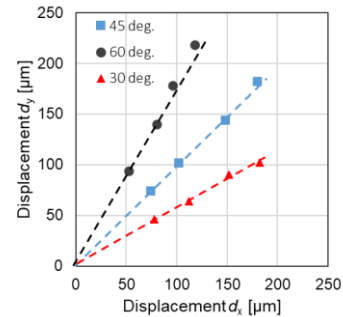


Fig. 8 Displacement characteristics of octagonal HOPG plate sample.

Table 1 Position control of 45-degree direction angle in each quadrant

Measurement position and quadrant	I_{EM1} [A]	I_{EM2} [A]	d_x [μm]	d_y [μm]	θ_d [deg]	
IP	0	0	0.00	0.00	0.00	
quadrant	1st	1.00	1.22	158.46	158.46	45.00
	2nd	-1.00	1.31	175.27	178.87	134.42
	3rd	-1.00	-0.94	136.85	140.46	225.74
	4th	1.00	-1.51	252.10	250.90	315.14

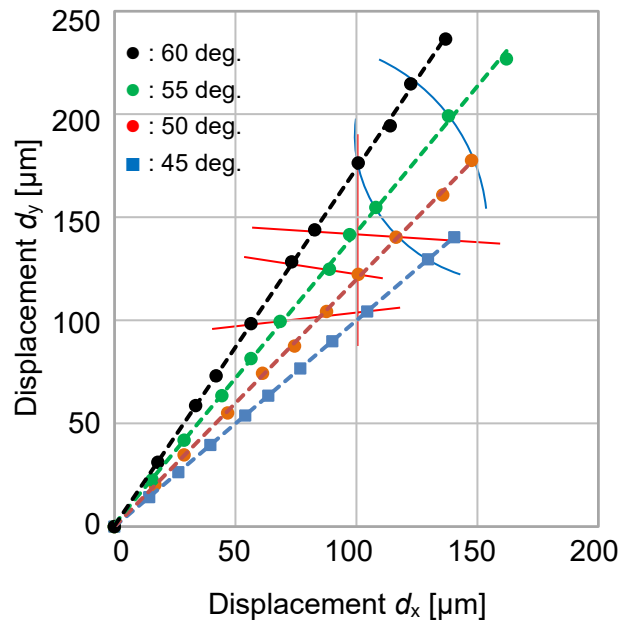


Fig. 9 Possible transition of displacement direction angle in the first quadrant.

5. Conclusions

In order to clarify the micro positioning characteristics of the HOPG plate on the 2D Halbach PM array, we controlled the magnetic fields at the two edges of the HOPG plate sample and focused on the displacement direction characteristics in the first quadrant. Although the observational data is still preliminary, it has been confirmed that non-contact micro positioning and actuation are possible in all quadrants. We are currently researching the linear displacement characteristics of the octagonal HOPG plate sample, but in order to further expand it to non-contact two-dimensional actuation, it is also essential to have turning response as shown by the blue solid line in Fig. 9 and change in displacement direction as shown by the red solid line in Fig. 9. We are also considering methods to improve the instability of the excitation current caused by heat generation from the two electromagnets installed above the octagonal HOPG sample.

References

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