Proto-model of novel contact-free disk suspension system utilizing diamagnetic material

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Abstract – **Technology of passive magnetic levitation using diamagnetic materials at room temperature is very important in various industry fields. Recently, we have designed and manufactured a novel ring Halbach permanent magnet array. And contact-free suspension and rotation of a diamagnetic graphite (PG: pyrolytic graphite) disk was realized on this proto-model ring Halbach PM array. In this paper, we mainly describe the design of both the novel ring permanent magnetic array and the graphite disk, and we shall report preliminary experimental result about a novel contact-free disk suspension.**

Index Terms – **contact-free, passive magnetic levitation, diamagnetic, graphite, Halbach array.**

I. Introduction

Passive magnetic levitation is very important in various industrial fields. However, in the case of magnetic levitation using superconductive materials, it is necessary to use a big amount of electrical energy to cool down the system below 77[K].

In the recent year, some experimental studies on magnetic levitation using diamagnetic materials in conjunction with strong magnetic fields at room temperature have been reported. Eur. J. Phys. in 1997, magnetic levitation of a frog in stable zone of a 16T magnet was reported by the group of Univ. of Nijmegan, the Netherlands [1]. Also on the Nature in 2001, the experimental research on passive magnetic levitation of a permanent magnet piece in the special magnetic field gradient constituted with the bismuth cylinder or human finger was reported by the group of UCLA [2].

Particularly, the magnetic levitation using graphite plates is a very important phenomenon as shown in Fig.1. Moreover, the study of non-contacting rotors and linear conveyor using diamagnetic materials by the EPFL-LSRO group (co-authors) is very important technique in the field of micro factories and in the applications for industry [3,4].

Recently, we have designed a novel permanent magnet array made of concentric circles arranged in a Halbach structure [5-7]. We were able to realize the contact-free rotational driving of diamagnetic graphite disk on the surface of this novel ring permanent magnet array without mechanical support.

In this paper, we mainly describe the design of both the novel ring permanent magnetic array and the graphite disk, and we shall report preliminary experimental results of this system.

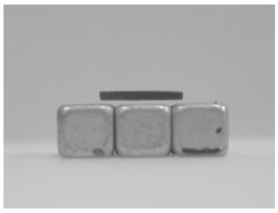


Fig. 1 Magnetic levitation of diamagnetic graphite(PG) plate at room temperature. (Photo by EPFL-LSRO1)

II. Novel Ring Halbach Array

A. Construction of Novel Ring Halbach Array

We have designed a novel permanent magnet array made of magnets disposed in concentric circles and arranged in a Halbach structure as shown in Fig.2, Fig.3 and Fig.4. When we make an ideal concentric circle type Halbach permanent magnet array, we have to prepare the permanent magnet of the shape of a cylinder. It is necessary to the magnetization of radial direction to the cylinder-type permanent magnet, and it is very difficult technically and is not economical. Therefore, this quasi-structure Halbach ring permanent magnets array is constructed with several arc-shaped permanent magnet pieces(Nd-Fe-B) with parallel magnetization(see Fig. 5).

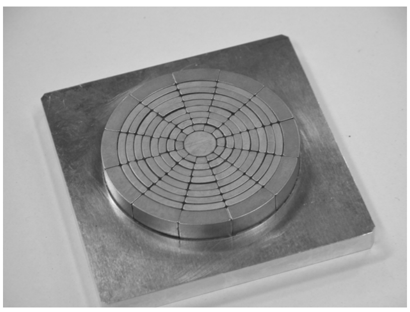


Fig. 2 Proto-model of novel ring Halbach PM array

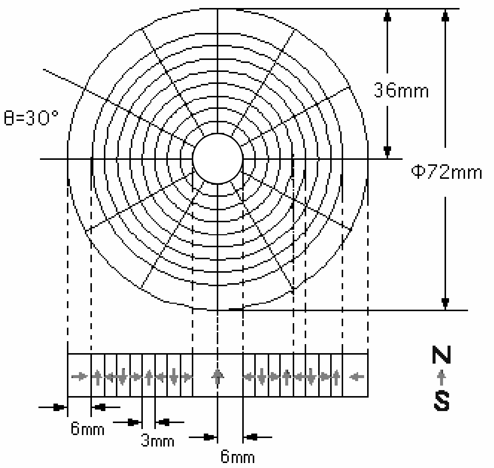
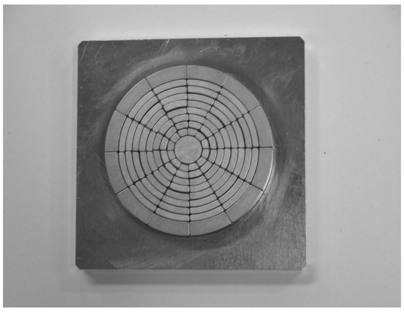
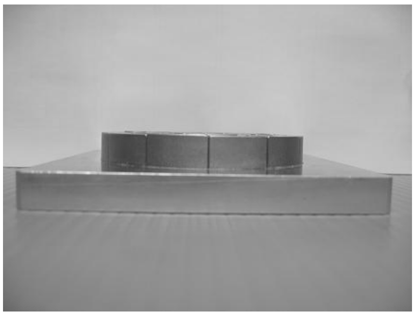


Fig. 3 Design of novel ring Halbach PM array



(a)Upside view



(b) Side view

Fig. 4 Proto-model ring Halbach PM array

(a) parallel (present) (b) radial (ideal)

Fig. 5 Magnetization direction of arc-shaped PM piece

B. *Magnetic Flux Density Distribution*

In order to check the usefulness of a proto-model of novel ring Halbach PM array, the observation of magnetic flux density distribution was performed in an area of surface of the ring magnet as shown in Fig.6. The result of the observation of magnetic flux density is shown in Fig.7.

We can see that the unique magnetic field distribution with big amount of magnetic flux density caused by the novel Halbach array. The three-fold wave of strong magnetic flux density appears in the radius direction, and at the center PM and perimeter PM, the maximum flux density is about 0.4[T]. This is the result of increasing the thickness of the magnetization direction of the center and the perimeter PM pieces. Moreover, this is an important treatment to use the magnetic support effect to realizing the contact-free magnetic levitation of a graphite (PG) disk. And, we can not observe the undulation of magnetic field intensity along the circle direction caused by a lot of small arc-shaped PM pieces.

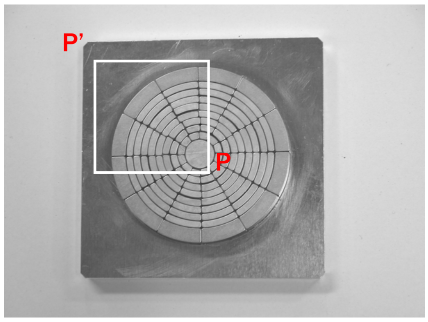


Fig. 6 Observation area of magnetic flux density

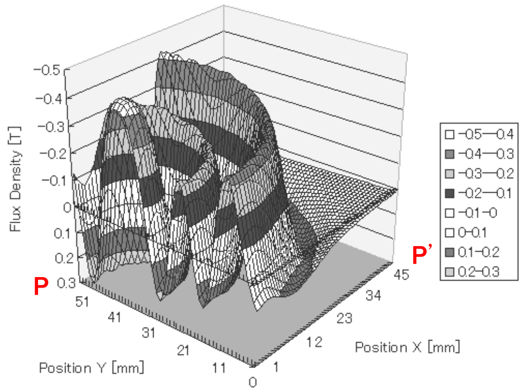


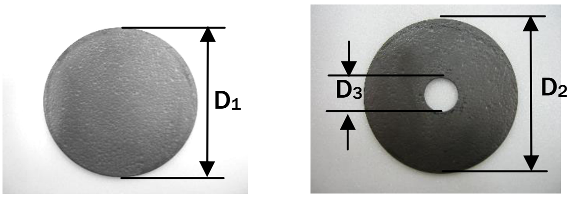
Fig. 7 Magnetic flux density distribution on a surface of proto-model of novel ring Halbach PM array. (air gap : 2mm)

III. Levitation of Graphite Disk

A. *Diamagnetic Graphite (Pyrolitic Graphite:PG)*

Figure 8 shows two kinds of diamagnetic graphite (pyrolytic graphite:PG) disk plates used by the present system. The PG disk in Fig.8(a) is called "normal-type disk", and Fig.8(b) is called "hole-type disk", respectively. In the both disk sample, the diameter is about 54mm, and thickness is 1.3mm. Weight is 5.01g(normal-type disk) and 4.85g(hole-type disk), respectively.

These sizes are determined by using the result of magnetic field analysis of the ring Halbach array, the result of magnetic flux density observation, and the result of the preliminary experiment with small PG piece.



(a) PG disk plate (normal-type disk) (b) PG disk plate (hole-type disk)

Fig. 8 Pyrolitic Graphite (PG) disk

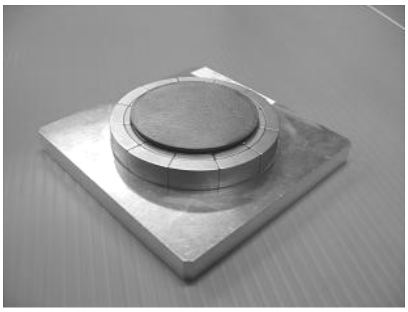
B. Stable Levitation and Rotation

As shown in Fig.9 (normal-type disk) and Fig.10 (hole-type disk), stable magnetic levitation of the graphite (PG) disk is realized by the unique magnetic field of the novel ring Halbach PM array.

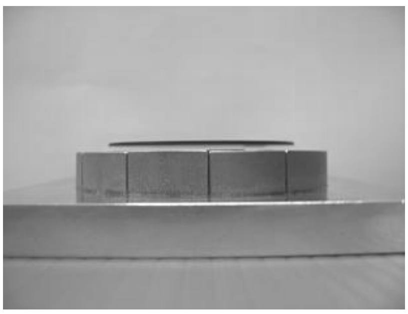
Stable passive magnetic levitation of the normal-type disk and the hole-type disk are carried out holding an air gap about 1.3mm and about 1.2mm, respectively. Then, there is a peculiar stability to the radius direction respectively. The hole-type disk has the clearly strong stability against external stress by magnetic support compared with the normal-type disk, and its restoration cycle is shorter.

Moreover, contact-free rotation of the PG disk can be carried out without any mechanical support. You can see that the upper surface of this system is full opened. Therefore, it is clear that contact-free rotating PG disk surface can be used freely.

And, it seems that the magnetic friction in the rotation direction of this system by using diamagnetic graphite PG is very small. That is, if it is true, it will be thought that it is possible to rotate PG disk for a long time only by giving very small energy.

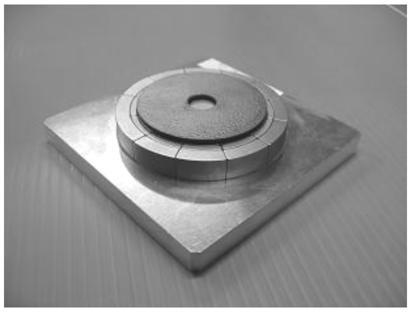


(a)

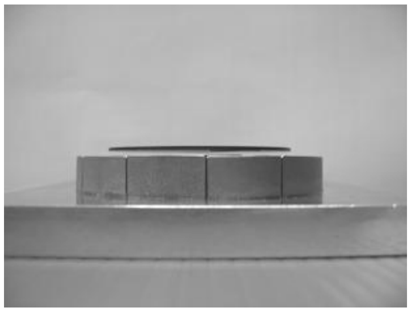


(b)

Fig. 9 Magnetic levitation of graphite (PG) disk (normal-type) on proto-model ring Halbach PM array.



(a)



(b)

Fig. 10 Magnetic levitation of graphite (PG) disk (hole-type) on proto-model ring Halbach PM array.

IV. Experimental Results

In order to determine the levitation characteristics of this novel contact-free disk drive system, a static load test was carried out. The normal-type PG disk had been loaded with about 10g maximum and performed a stable rotation without any contact. Also, the hole-type PG disk supported about 9g maximum loads. Figure 11 shows stable magnetic levitation and rotation of normal PG disk with 3g payloads.

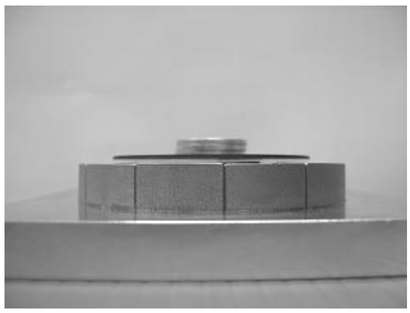


Fig. 11 Magnetic levitation & rotation of normal PG disk on proto-model ring Halbach PM array (load: 3g)

Figure 12 shows the result of measurement of the static payload test (payload weight vs. air gap) of two kinds of PG disk on the surface of proto-model of novel ring Halbach PM array. The nonlinear characteristic is very similar although the difference of the value of the air gap for the payload appeared among both of samples. It seems that the decreasing of magnetic repulsion force of the hole-type disk is caused by reduction in an effective area of the PG disk surface simply.

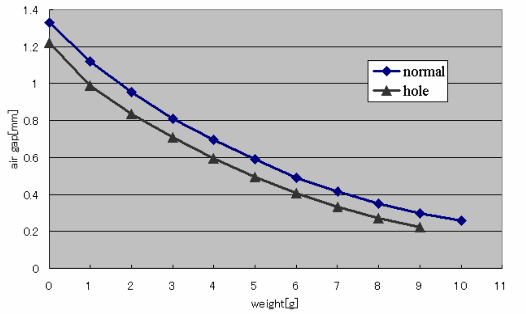


Fig. 12 Load performance of PG disk on the surface of proto-model of novel ring Halbach PM array

In magnetic levitation of PG disk on the surface of novel ring Halbach PM array, the preliminary observation of stability of radius direction was performed. Compared with normal-type PG disk, hole-type PG disk was clearly stable, and the magnetic guide effect of the radius direction was stronger.

On the other hand, we also made the concentric circle magnet array which structured with an opposite magnetic poler arrangement(N-S-N) as shown in Fig. 13, in order to reveal the advantage of novel ring Halbach array and the magnetic characteristic of PG disk. Magnetic levitation of PG disk on the surface of this concentric circle magnet array called "Oppositte ring PM array" was not performed so much stably and the air gap was very slight. However, it was shown that the payload characteristic of this Oppositte ring PM array was not so bad to the perpendicular direction.

The detailed observation of the stability of magnetic levitation and rotation in both ring PM arrays are now being performed.

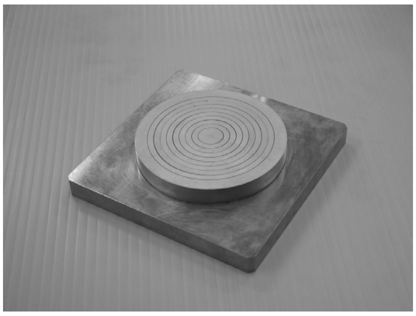


Fig. 13 Opposite ring PM array

V. Conclusions

We developed the proto-model of novel ring Halbach PM array, and revealed the characteristic magnetic field distribution on the surface of the PM array. In this novel ring Halbach PM array, stable non-contacting levitation and rotation of two kinds of diamagnetic graphite (PG) disk was realized, and the preliminary result of a payload characteristic was clarified.

By having performed the observation of magnetic levitation of PG disk on the surface of an Opposite ring PM array, it became clearer that stable magnetic suspension and rotation of PG disk are realized by the unique magnetic field of novel ring Halbach PM array. Moreover, it also became clear that the electromagnetic characteristic depends by the design of PG disk.

In our present system, the stable contact-free suspension and rotation of PG disk can be carried out without any mechanical support. Therefore, you can see that the upside of PG disk in this system is free perfectly. This fact is great advantage for the development of various application devices with contact-free suspension system for using at the clean room, the micro-factory, and another micro-technique.

It seems that the magnetic friction of the levitated PG disk on the surface of ring Halbach array is very weak. In special condition in vacuum, it will be thought that it is possible to rotate PG disk by giving extremely small energy. In the future, we would like to develop several contact-free suspensions and drive systems using this novel disk drive in the field of micro-factory.

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