Extremely Energy-Saving Linear Drive Technique by using Diamagnetic Graphite Plate

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ABSTRACT: In this paper, we mainly describe about a performance of the successive acceleration motion of the asymmetrical shaped diamagnetic graphite (PG) plate in zero electrical power supply. The unique contact free motion of PG plate by using our novel technique was previously reported at the Maglev 2006 conference in Dresden, Germany. Since that time, some experiments revealed that the acceleration motion of PG plate was depend on the edge shape of PG plate sample. In the future planning, we would like to develop the continuous linear and rotation drive system by using this novel technique with edge shape effect of PG plate.

1 INTRODUCTION

In the recent years, there are some interesting reports about magnetic levitation using the diamagnetism of some substances in conjunction with strong magnetic fields at room temperature [3], [4]. Especially, passive magnetic levitation using diamagnetic graphite (Pyrolytic Graphite:PG) plates is a very important phenomenon. Moreover, the study of non-contacting rotors and linear conveyor using PG plate by the EPFL-LSRO group is very important in the field of micro mechatronic system and in the applications for industry [1], [2], [5].

Development of contact-free linear drive actuator and contact-free suspension are very important in the field of micro processing system. It seems that the energy-saving actuation technique is particularly required to using in the special condition such as clean room in vacuum.

In 2006, we reported that novel contact-free linear drive technique by using diamagnetic graphite (PG) plate on Halbach permanent magnet array [7]. PG plate, which levitated at room temperature, can move in a unique magnetic field gradient induced by interaction between Halbach PM array and an approached small PM. The prime advantage of our novel contact-free linear drive technique of PG plate is not to use electrical energy as shown Figure 1.

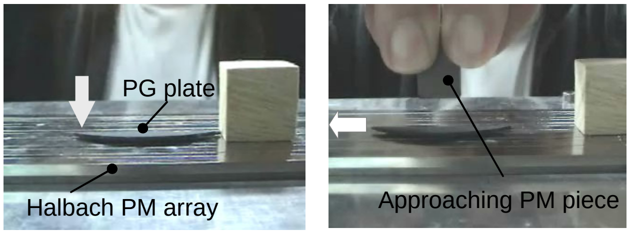

Figure 1. Contact-free magnetic levitation drive of PG plate by an approaching PM piece on Halbach PM array

Furthermore, in 2007, we explained that the acceleration motion of PG plate depends on the edge angle of PG plate by some experiment studies [8]. And, in case of the PG plate with asymmetrical edge angle (e.g. 45[deg] and 90[deg]), the acceleration motion is observed in only one direction [9].

Very recently, we were able to confirm a unique successive acceleration motion of PG plate on Halbach PM array which arranged several approaching PM pieces in series. By only using simple fixed approaching PM pieces without any other power supply, PG plate sample moved successively. If this successive motion is true, we may have found an important phenomenon as the energy-saving actuation technique.

In this paper, we mainly describe about a performance of the successive acceleration motion of the PG plate in zero electrical power supply.

2 NOVEL CONTACT-FREE DRIVE TECHNIQUE OF DIAMAGNETIC GRAPITE

2.1 Contact-free Motion of PG plate

We developed a novel technique for the driving on passive magnetic levitation of diamagnetic PG plate as follows. In case of the setting of PG plate on Halbach PM array as shown in Figure 2 and Figure 3. The acceleration motion(x direction on the PM rail) of PG plate is performed by the approaching of a small piece PM to the PG plate (see Figure 4).

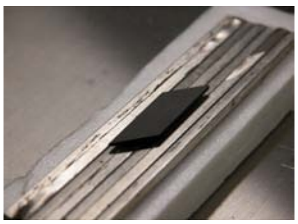

Figure 2. Stable passive magnetic levitation of PG plate on Halbach PM array.

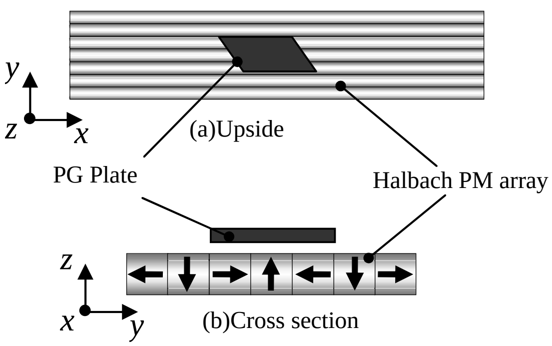

Figure 3. Layout of PG plate on Halbach PM array.
(PM rod: Nd-Fe-B, 3×3×100mm, B=0.4T on the surface)

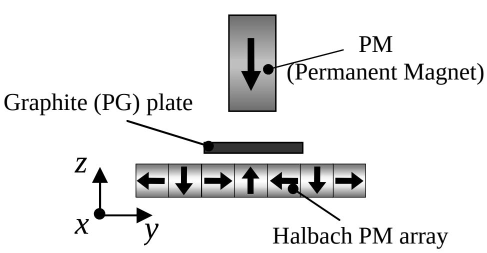

Figure 4. Layout of an approaching magnet for the drive of PG plate on Halbach PM array. (N-N magnetic polar arrangement)

About the move direction of a PG plate, it depends on the magnetic pole relation between the permanent magnet piece and Halbach PM array. For example, if the polarity of a permanent magnet as shown in Figure 4 (name the N-N magnetic polar arrangement) is given to the left end of the PG plate in Figure 3, the PG plate will carry out acceleration motion in the direction of left in Figure 3. On the other hand, if we have done the approaching to the left end of the PG plate by an opposite polar magnet, the acceleration motion rightward will be performed.

Figure 5 shows, in the present experimental set, an observational result of the magnetic flux density distribution on the Halbach PM array at 1mm from surface by an approaching PM (G=4mm). By approaching a PM piece toward plane of Halbach PM array, primitive magnetic flux density distribution is modified to the special magnetic gradient form as in Figure 5. It seems that the acceleration motion of PG plate is depending on the value of magnetic gradient formed in the space above Halbach PM array. Thus, we must do much attention to that an approaching PM is an important parameter to understand the acceleration motion of PG plate.

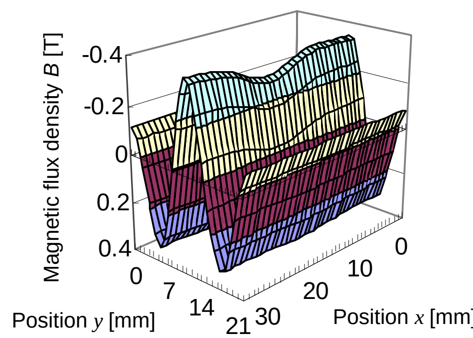

Figure 5. Distribution of magnetic flux density in 1mm from surface of Halbach PM array by an approaching PM (G=4mm).

2.2 Edge Shape Effect of PG Plate

When the variable of an approaching PM (Nd-Fe-B, W5.5×D10.5×H4.2mm, B=0.27T) is fixed, we are already obtaining an observation result that the acceleration power depends on the edge shape of a PG plate [8]. By the same volume PG plate samples as shown in Figure 6, (e.g. S=204mm2, thickness=1.0mm, m=0.47g), we revealed the acceleration motion of PG plate depends on its edge angle (α [deg]).

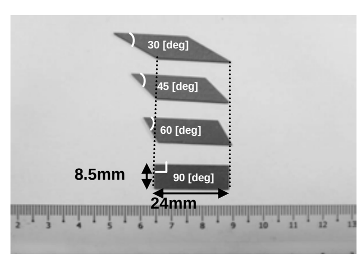

Figure 6. PG plate samples with different edge angle.

Figure 7 shows the relation of the setting position between the PG plate and an approaching PM on Halbach PM array in our present experiment. In the primal basic condition, a centerline of the approaching PM along y direction is crossing on the center point of right-side edge of PG plate.

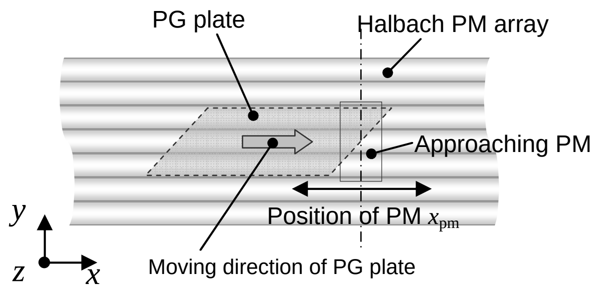

Figure 7. Relation of the setting position between the PG plate and an approaching PM on Halbach PM array.

In above setting condition, we already obtained an observation result that the displacement by the motion of PG plate depends on the edge angle of PG plate. In case of the air gap (G=10mm) of an approaching PM to the surface of Halbach PM array, we obtained a result as shown in Figure 8 [8]. Gradient ($\Delta d/\Delta t$) of the d-t curve is clearly an average speed ($v_{ave.}$). About average speed between 0.2s and 0.3s of four PG samples, 90 deg. sample's speed is the slowest ($v_{ave.}$=20[mm/s]) in them. Other three curves are similar gradient each other. Above all, a curve of 45 degrees shows a slightly sharp slope, ($v_{ave.}$=35[mm/s]), within above measurement range.

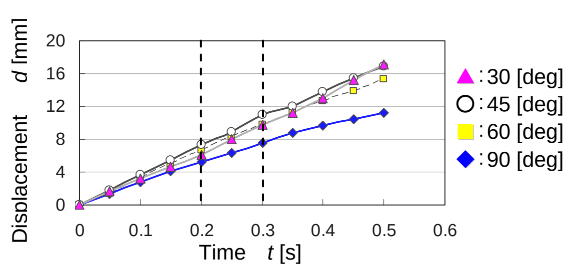

Figure 8. d-t curve on the motion of PG plate sample.

3 SUCCESSIVE ACCELERATION MOTION OF PG PLATE

3.1 One-way Motion of PG plate

In case of the PG plate with asymmetrical edge angle (e.g. 45[deg] and 90[deg]) in Figure 9, the acceleration motion is observed in one direction. It is because that one-way motion of an asymmetrical PG plate sample can be performed by the difference of magneto-dynamics acting on both edges resulted from Figure 8, as shown in Figure 10(a) and Figure 10(b). In addition, we confirmed this fact of one-way motion of asymmetrical PG plate sample by an experiment as shown in Figure 11.

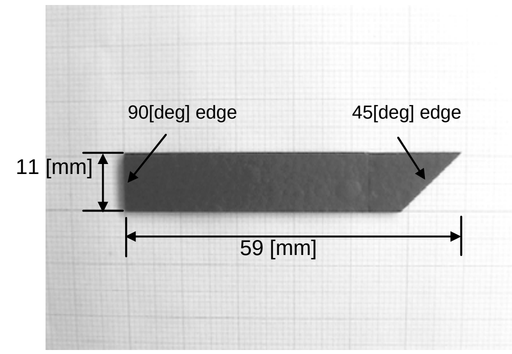

Figure 9. Asymmetrical shaped PG plate sample with 45[deg] and 90[deg] edge.

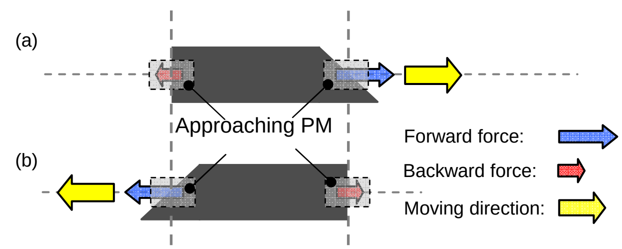

Figure 10. One-way motion caused by unbalanced magneto-dynamics in both edge of PG plate.

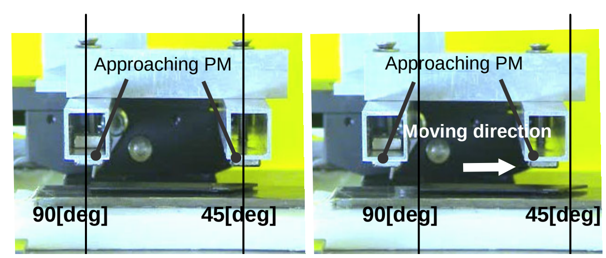

Figure 11. One-way motion by an asymmetrical shaped PG plate sample.

3.2 Successive acceleration Motion of PG plate

Figure 12 shows the principle of successive acceleration motion by an asymmetrical shaped PG plate sample under the arranged approaching PM pieces in series. In case of this illustration, the magnetic pole pitch of approaching PM (L_{PM}) is equal to the edge length on center of PG plate sample (L_{PG}). We can see that the principle of successive motion in one direction of single PG plate is caused by the case shown in Figure 10 and Figure 11.

On the other hand, Figure 13 shows the principle of successive acceleration motion by a coupled asymmetrical PG plate sample under the arranged approaching PM pieces in series. Twin PG plate (PG1 and PG2) are stuck on a non-conductive thin film as keeping space and balance. In case of coupled PG plate sample, the magnetic pole pitch of approaching PM (L_{PM}) is equal to the edge length (L_{PG}) and the space between two samples (D_{PG}). Therefore, four magnetic poles operate to all edge of coupled PG plate sample at one time. Then, one-way motion of coupled PG plate sample actually performs by total difference of magneto-dynamics.

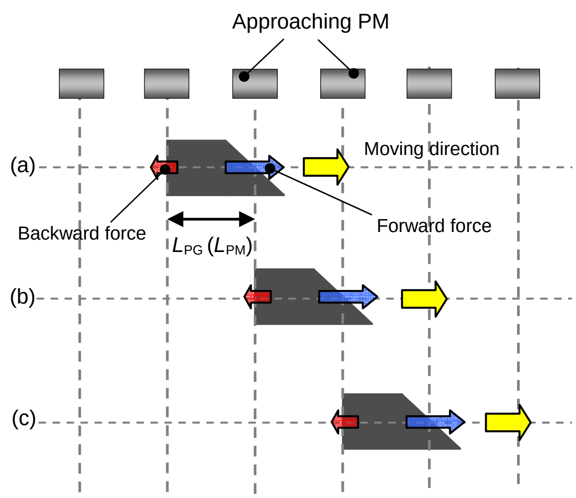

Figure 12. Principle of successive acceleration motion by single PG plate with asymmetrical shaped edge.

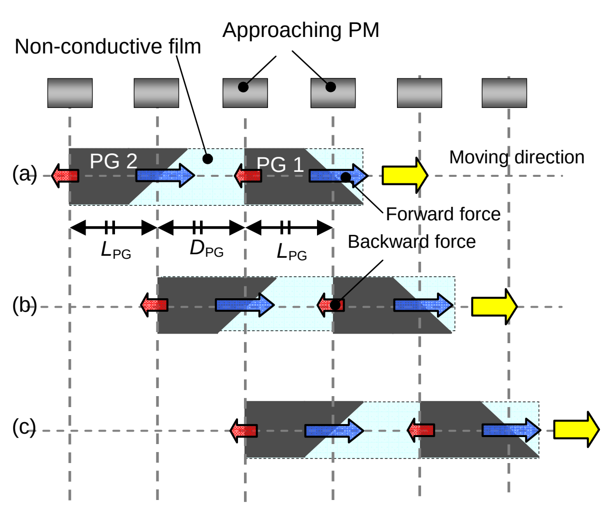

Figure 13. Principle of successive acceleration motion by coupled PG plate with asymmetrical shaped edge.

3.3 *Observation of Successive acceleration Motion of PG plate*

We present an observational result of successive acceleration motion by PG plate as follows. Figure 14 shows an experimental set with the arranged eight approaching PM (Nd-Fe-B, 10.5×5.5×4.2 [mm], B=0.27[T]) pieces in series on Hybrid-type PM array. Brand-new Hybrid-type PM array is constructed by composite structure that sandwiched an iron plate in PM plate of same magnetic pole as shown in Figure 15. Moreover, magnetic flux distribution on Hybrid-type PM array is quite similar to Halbach PM array's one. Maximum magnetic flux density at 1mm from surface of Hybrid-type PM array is about 0.53T. In approaching PM gap G=8mm, magnetic flux density distribution close to arranged some approaching PM piece on Hybrid-type PM array was observed as shown in Figure 16.

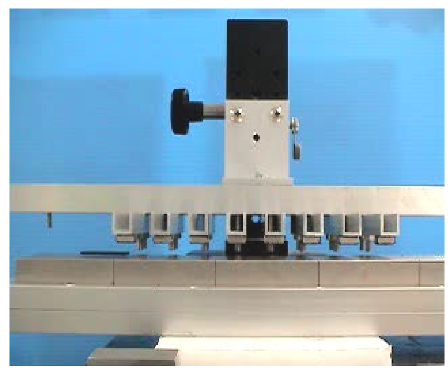

Figure 14. Experimental set for successive acceleration motion by PG plate on Hybrid- type PM array.

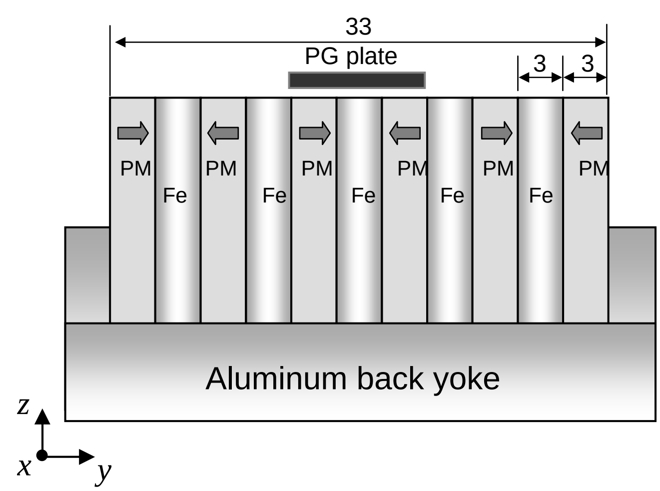

Figure 15. Close-up illustration for the cross sectional view of brand-new Hybrid- type PM array.

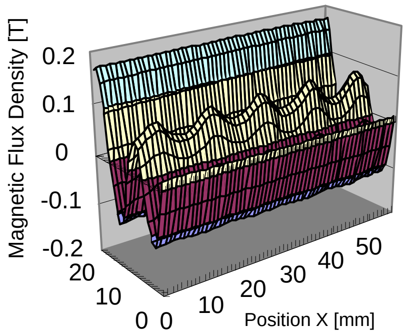

Figure 16. Magnetic flux density distribution close to arranged approaching PM pieces on Hybrid-type PM array.(Approaching PM gap G_{PM}=8mm, Observe point gap G_{OB}=3mm)

Figure 17 shows example layout of arranged approaching PM pieces on Hybrid-type PM array. In condition for successive acceleration motion by this experimental set, the relation of a magnetic pole pitch of the arranged eight approaching PM pieces and a length of PG plate edge is approximately L_{PM} : L_{PG}=1 : 0.5-2.0.

Table 1 shows preliminary observational data for the average speed of four asymmetrical PG plate samples. Although it is not good condition, successive acceleration motion of all PG samples was observed. Then, it seems that it is not so difficult to confirm the best condition for the relation between L_{PG} , L_{PM} and air gap of approaching PM piece.

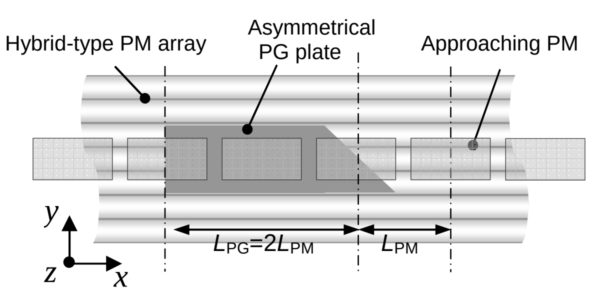

Figure 17. Example layout of arranged approaching PM piece on Hybrid-type PM array.

Table 1. Example data for the average speed of asymmetrical PG plate samples.

Sample No.	90/45-24	90/45-18	90/45-12	90/45-8
L_{PG} [mm]	24.45	18.35	12.25	8.25
$v_{ave.}$[mm/s]	27.34	30.57	33.04	33.17

L_{PM}=16mm, G=14mm

4 CONCLUSIONS

We have observed preliminary a successive contact-free acceleration motion of some PG plate samples by using our novel technique. This observation result suggests that realizing of an extremely energy-saving actuation device. However, by linear PM array of limited length, we cannot confirm the truth of successive acceleration motion of PG plate. Therefore, we will also try to confirm the successive acceleration motion of arc-shaped PG plate with asymmetry edge which passively levitated on ring Halbach PM arrayed [6] in concentric circle and endless as shown in Fig.18 [9].

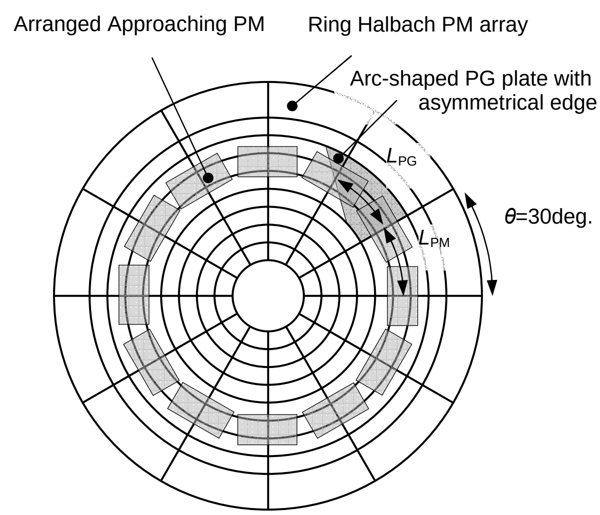

Figure 18. Layout of arranged approaching PM pieces and arc-shaped PG plate on ring Halbach PM array.

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