The study of the Electro Magnetic Acceleration and Deceleration system of the Ferromagnetic Ball using the Monopole Coil Structure

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Abstract— **The Electro Magnetic (EM) Acceleration and Deceleration (ACC/DCC) system of the Ferromagnetic Ball(FB) is the linear motor's final structural development which can be used for devices that conserve energy, gaming or rail gun. By accelerating the FB within the coil structure, it is difficult to utilize the FB's magnetizing feature via the ACC/DCC system. There is much monopole space inside the monopole coil. By using this particular feature of the FB, starting coil and Monopole Coil Structure (MCS) can be structurally separated and another simple electric related control system can be experimented for further development. For the purpose of development a review is needed of the control system of both basic stepper motor and BLDC motor.**

Index Terms— **Acceleration/Deceleration (ACC./DCC.), Electro Magnetic (EM), Ferromagnetic Ball(FB), Magnetizing, Monopole Coil Structure (MCS)**

I. INTRODUCTION

The FB used for the bearing is easy to obtain, but is unsuitable for the control device. By comparison to silicon iron or ferrite cores, there is uneven residual magnetism and is not a permanent magnetic material. By reason of low cost, if this material can be used for the control device, it would be economically beneficial. If this FB can be moved inside of the magnetic field, it can be used for devices such as games [1], energy conserving devices or even a rail gun. To know the activity of the FB inside the coil, magnetizing characteristic of the FB is analyzed. Further, the movement system of the FB is designed by the circuit. But firstly, to move a FB, a series of measures are undertaken that's similar to the Stepper Motor [2] circuit thereby developing a device and circuit that functions to accelerate. Once a particular device that can initiate the material is decided, it should be made to function anywhere. Although friction is the problem for the FBs movement, no special consideration is paid towards this. This paper studies the start and acceleration capabilities through researching basic developments based on qualitative analysis. This experiment focused on just one FB, but no consideration was paid towards having several FBs. However, when there are several FBs they are likely to be attracted to each other.

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II. MAGNETIZING CHARACTERISTIC FB INSIDE THE MONOPOLE COIL

As shown in Fig.1, when a FB is placed next to the coil, the FB is magnetized [3] and the N pole coil is attracted to the FB. S pole region is more affected than the N pole region. This is due to the closeness between the two coils and one coil being perpendicular. By having Fig.2 and MCS placed opposite to the FB, N region becomes narrower than the coil, but the magnetic flux density at the N region of the FB increases.

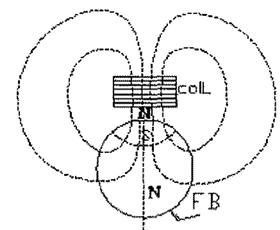

Fig. 1. FB in front of the coil.

There is no fixed direction of magnetization. In order to attain stable poles of the coils positioned at right angle, even though there is the factor of push and pulling due to magnetization, this will cease once equilibrium is established.

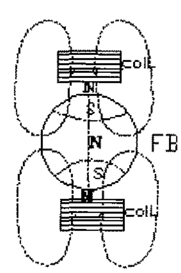

Fig. 2. FB in between two respective MCS.

However, after a moment of transient magnetization, the coil magnetizes causing the FB to instantly energize and becomes attracted to the coil. As shown in Fig.3 the FB moves along the direction from which it is being pulled.

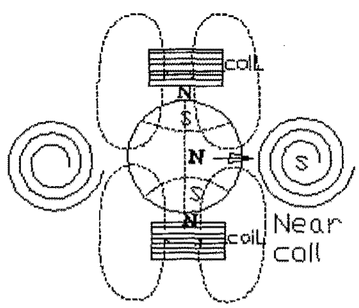

Fig. 3. FB attracted to its neighboring coil.

Using each FB's different quality, time of magnetization of the coil could not be measured, however the coil and FB spec. was determined. Experimental coil required more than 10 watts (Refer to spec. and quantity data in table (1)). This paper establishes mainly qualitative analysis.

TABLE 1.
PHYSICAL DIMENSIONS AND TEST DATA OF THE ITEMS

Items	Specifications.	Test Data	Description
FB	19 Ø mm,28gram	Residual magnetism 1gauss	
Bolt	4 Ø,12mm	Residual magnetism 2gauss	Bolt inside coil
Bottom &Top coils	0.3 Ø mm coil, 510 turns	90 gauss	Max 1Amp Dc12Ω
Out Side coil	0.3 Ø mm coil, 510 turns	40~60 gauss	Max 1Amp Dc12Ω
InSide coil	0.1 Ø mm coil, 540 turns	20 gauss	Max 0.5Amp Dc25 Ω
Control circuit	Used IC L297,SLA7024	2Amp Max	[4]

III. FB's monopole coil Acceleration and Deceleration device

A. FB's starting device

By applying magnetizing current onto the FB via the coil, both the coil and FB becomes attracted to each other thereby making movement difficult. Movement is made difficult because of the characteristic of the magnetization of the FB.

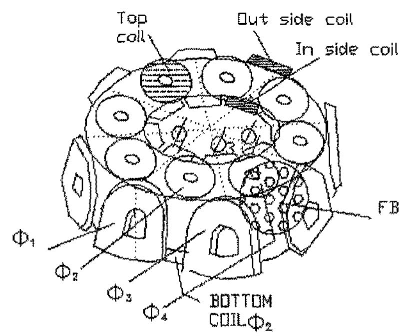

Fig. 4. MCS of the starting FB.

As shown in the research and Fig.4, 4Φ 1 phase energizer of the stepper motor [2] were made to adapt to the structure of the coil. Control circuits of the driving and accelerating structures were made differently in terms of physical structures. Inside of the driving structure, the FB should be made to move anywhere therefore driving structure is a much more complex design than the acceleration structure.

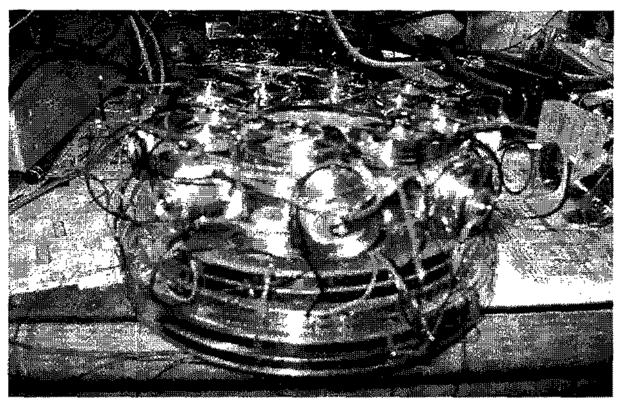

Fig. 5. Real device of the starting FB.

Shown on Fig.5, in certain phases inside the driving structure there are 2 respective coils facing each other, in between the coils there is the FB which represents the N pole thereby its neighboring coil must become S pole. The coil standing at perpendicular to its neighboring coil besides the FB attracts the FB by magnetization.

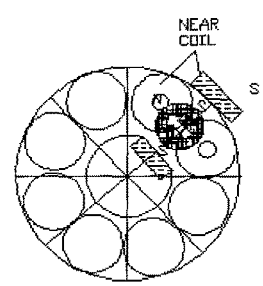

Fig. 6. Top view of the starting coil structure.

The attraction force [5] by magnetization of neighboring coil and FB can be expressed in equation (1).

$$F = I(L \times B) \tag{1}$$

The magnetic force is actually exerted on the electrons that make up the current I. Equation (2) is induced approximate force[6] from MCS.

$$\begin{aligned} F_{out} &= \frac{1}{2} i_1^2 \frac{dL(\theta)}{d\theta} u(t-\phi_1) + \frac{1}{2} i_2^2 \frac{dL(\theta)}{d\theta} u(t-\phi_2) \\ &+ \frac{1}{2} i_3^2 \frac{dL(\theta)}{d\theta} u(t-\phi_3) + \frac{1}{2} i_4^2 \frac{dL(\theta)}{d\theta} u(t-\phi_4). \end{aligned} \tag{2}$$

This device has a big magnetic gap consumer energy from equation (3).

$$\begin{aligned} &Power.Supply.Energy = Mechanical.Energy + \\ &Magnetic.Gap.Energy \end{aligned} \tag{3}$$

In Fig.6, it is shown as though there are 4 arrays of stepper motor coil, but in actuality there is not. The pulse sequence in conjunction with Fig.5 must be input into the coil in order of Φ_1=A, Φ_2=B, $\Phi_3=\bar{A}$, $\Phi_4=\bar{B}$.

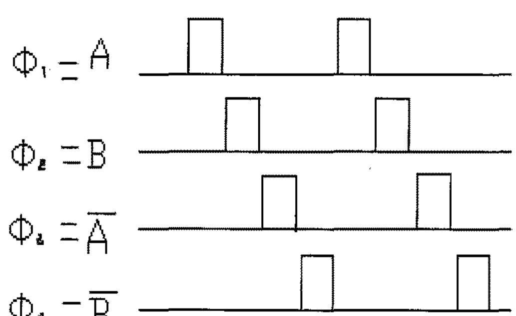

Fig. 7. 4 Φ_n - Single Phase Energizer.

Pulse is applied to 4 parts of the coil, from Φ_1 to Φ_4, by synchronization because same phases must have same actions. 4 Φ_n - single-phase energizer is accomplished by a simple Fig.7 in which coil is sequentially energized to accomplish an incremental motion. During this activity, the fastest speed the FMB can reach is 6Hz~10Hz. Experimental results showed FMB's average speed as 1rps. This may have been because of factors such as magnetizing response time and residual magnetism [8]. This is not for just one FB but for several FBs simultaneously working together. When there are numerous FBs, they should be separated because of the attraction they have for each other. This paper only aims to explain one FMB and its control structure.

B. FB acceleration and deceleration device

As the FB starts and is detected by a sensor, the coils surrounding the FB is energized. As this occurs, acceleration is initiated. As shown in Fig.8, when driving the acceleration device, starting circuit is ceased and acceleration device is activated.

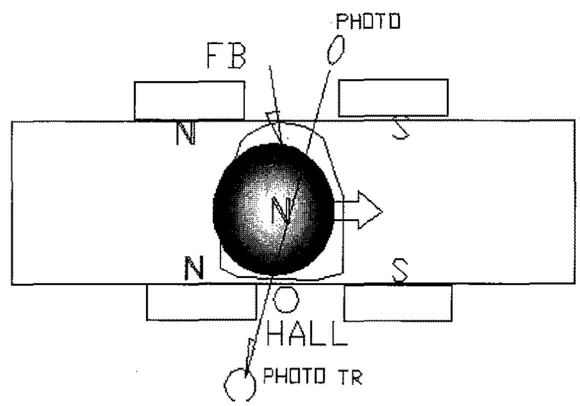

Fig. 8. Acceleration device.

The sensors should be able to detect the differential in level of magnetization of the FB, therefore the hall[9] element or photo element or resolver [10]should be utilized. When using the starting coil, the sensor and acceleration coil must be made the same way as shown in Fig.9.

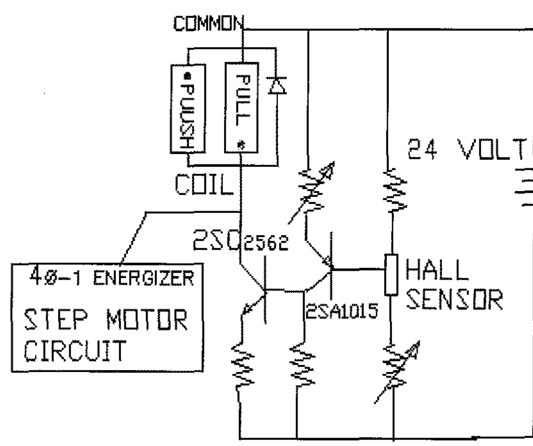

Fig. 9. Circuit of the accelerating device.

The speed of the FB is determined by coil response time, magnetization response time and residual magnetism. These variables [11] affect the speed equation. Therefore, the control circuit must have sufficient energy and the response time should be as short as possible. Generally, the acceleration of the FB works in three ways. First is by push, second is by pull and thirdly, by push and pull. To initiate deceleration only requires the opposite of acceleration, therefore energizing the coil requires the opposite of acceleration as shown in Fig.10.

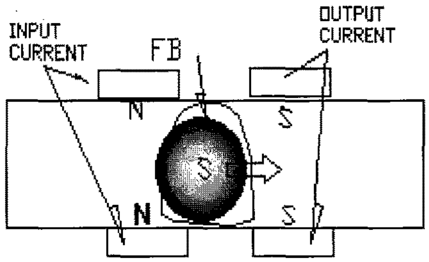

Fig. 10. Deceleration device.

If FB runs at a high speed, only one coil is activated as PM and another coil receives energy from the FB. Mechanical energy is received and conserved by the moving FB. But the material of the FB must be endurable against heat of up to curie temperature. This experiment only used attractive forces by starting device and the push and pull forces of the accelerating device. Theoretically, if the speed of the FB is faster than the coil response time, there is a problem with the attraction forces. Furthermore, the pushing force by the coil against the FB causes no movement if the response time of the coil is slow. Therefore, coil must respond quickly as well as the FB.

IV. CONCLUSIONS

The acceleration of the general FB was activated by a special frequency of the coil and FB's magnetizing characteristic. Qualitative observance is required and many measuring devices are needed for this experiment. The starting device is made by 4 Φ_n - single-phase energizing circuit of the stepper motor. Moreover, 2-3 Φ_n phase energizing circuit is possible and will be researched in the future. In the past, acceleration of metallic objects was used in weapons by use of electronic field[12]. Similarly, this experiment was based on basic coil structures using magnetic field. Practical application requires maintenance of high speed of the FB. The FB must move in open spaces without any physical contact (including friction) because of its high speed. This research is useful for engineering applications of dynamically moving objects. Furthermore, when several FBs are in use, there are cases of FBs been attracted to each other, therefore further research on how to avert this problem is needed. In close system, when separated FBs are in rotation, nutation[13]-[14], procession[15], spin and coriolis forces[16]-[17] are observed adding effectiveness to the experiment.

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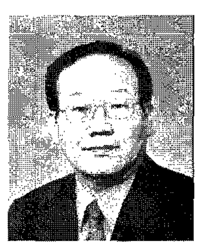
REFERENCES

[1] Kisul Publishing Editor, "Application Techniques for a Precision Micro Motor," Kisul Publishing ,pp161,1989.
[2] Se Won Publishing Editor,"Stepping Motor Control Circuits Design,"Se Won Publish Company, pp34,1998.
[3] Barret,Nix,Tetelman, "Scientific Materials Principles," Korean Translation(c) 1995 by Hayung Kim, Su Jeong Seo through Ji Sung Publishing Company. pp458,1995.
[4] Jong Rak Lee,"Motor Application Circuits 101 for Mekatronics,"Korean Edition Copyright ,1994 by SEWHA,PP50
[5] Joseph A. Edminster, "Schaum's outline of Theory and Problems of Electromagnetics 2/ed'" McGraw-Hill,INC.,Pp155-165,1993.
[6] Jin woo An,"Swithed Reluctance Motor",Osung Media, pp17,47-50, 2004 .
[7] Takashi Kenjo,Akira Sugawara, "Stepping Motors and Their Microproccessor Controls,"Oxford University Press.,Korean Translation (c)1997 by IL-JIN Publishing Company, pp69-101,1997.
[8] Robert c. o'handley, "Modern Magnetic Materials Principles and Applications,"John Wiley & Sons, pp6,17-20, 2000.
[9] Sang Jin Kim,"Small Motor Control,"Seong An Dang Publishing company,,pp91-92,1991.
[10] Jong Su Won,"Ac Servo Motor and Microprocessor Contro,"Korean Language Edition by Dong-ill Publishing company,pp29,1994.
[11] B.T. Chung, "A study on the computer simulation function model and application system of the vertical force by the vertical current using the half coil configuration,"Journal of the Korea Computer Industry Education Society, AUG.2008
[12] Se Hwa Publishing editor, "Linear Motor Application Hndbook," Se Hwa Publishing, pp224,1988.
[13] B.T.Chung , "The Principle of the Actuator the Using the Nutation Force in the Closed System," Proceedings of ISCIT-2003, Vol.II,BP Samila Beach Hotel and Resort, Songkhla,Thailand,pp685-687, September3-5,2003.
[14] B.T.Chung , "A study on the computer simulation model of the closed moving system using the nutation force," Journal of the Korea Computer Industry Education Society. Vol.6, No. 2, pp331-336, June 2005.
[15] Jae Gul Go, "Dynamic," Chung Mon Gag, pp214,1993.
[16] B.T. Chung, "A study on the computer simulation of the closed system using the coriolis force," Journal of the Korea Computer Industry Education Society. Vol.5, No. 6, pp679-684, June 2004.
[17] B.T. Chung,"The Effect of Non-conserved Movement at the Relation between ICM and Coriolis Force of Rigid Body in the Closed System," Proceedings of the KSAS Spring Annual Meeting 2002, The Korean Society for Aeronautical & Space Science pp568-57,14.12 .2002.



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