



DESIGN OF OPEN SOURCE STRAIGHT PERMANENT MAGNET MOTOR

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ABSTRACT

This paper deals with the attraction and repulsion properties of the magnetic field of permanent magnets in order to produce reciprocating motion in a member of magnetizing material.

The essential idea of this work have started by putting a string of eight magnets type (Nd Fe 35) spaced by equal spaces placed on the axis between two series of same magnet type each string consists of nine magnets pieces spaced apart vacuum. Series of internal and external were organized with different opposite polarity north and south that created a series of free movement of internal series between the two external strings.

First of all, designed magnetic motor rectal movement consisting of two fixed (for external strings) and one moving part (Series Interior) analysis was done and its operation was analyzed. In addition, equations that describe the magnetic field arising from the moving part were modified by using two-dimensional computer model. The (femm) program was used for modeling the distribution of density, and DS Solid Works program to study and calculate the magnetic flux density, field strength and torque generated.

KEYWORDS

Attraction, Flux Density, Free Open Source, Permanent Magnet Motor and Repulsion

تصميم محرك مغناطيس دائم مستقيم الحركة بدون مصدر

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قسم الهندسة الالكترونية والاتصالات

مديرية انتاج الفرات الاوسط

كلية الهندسة/جامعة الكوفة

الشركة العامة لانتاج وتوزيع الطاقة الكهربائية

الخلاصة

يتعامل البحث مع خاصيتي التجاذب والتنافر للمجال المغناطيسي والذي ينتج عنه حركة الاجزاء المتمغنطة الحرة. فكرة العمل بدأت بوضع سلسلة تتكون من ثماني قطع مغناطيسية نوع (ND FE 35) متباعدة بفراغات متساوية وضعت على محور بين سلسلتين من ذات المغناطيس تتكون كل سلسلة من تسع قطع مغناطيسية متباعدة عن بعضها بفراغ. نظمت السلسلة الداخلية والسلسلتان الخارجيتان بقطبية شمالية وجنوبية متقابلة مختلفة ، مما خلق حركة حرة للسلسلة الداخلية بين السلسلتين الخارجيتين.

صمم المحرك المغناطيسي المستقيم الحركة المتكون من جزئين ثابتين (السلسلتين الخارجيتين) وجزء متحرك (السلسلة الداخلية) مع تحليل اداء المحرك. تم تعديل المعادلات التي تصف المجال المغناطيسي الناشيء من الجزء المتحرك بتصميم انموذج حاسوبي ثنائي الابعاد. استخدم برنامج (FEMM) لنمذجة توزيع كثافة الفيض و (DS SOLIDWORKS) لدراسة وحساب كثافة الفيض المغناطيسي وشدة المجال والعزم المتولد.

1. INTRODUCTION

Today when energy is so expensive, it is not hard to drum up interest for most any avenue that offers a breath of hope or way of escape. Magnets have enormous importance in the modern world. It would be hard to imagine life without their contributions in today's products. Automobiles have several hundred magnets from motor to sensor applications. Consumer electronics utilize them to generate video, sound and record; Computers wouldn't exist; and many high (RPM) instruments used in surgery and dentistry. The main purpose of magnets is to help in the conversion of energy: Mechanical to Electrical, such as in generators, sensors and microphones Electrical to Mechanical, such as in motors, actuators and loudspeakers Mechanical to Mechanical, such as for couplings, bearing and holding devices [1].

What exactly is a permanent magnet? what length time does the current need to be in the coil to make the magnet? how long can the resulting magnet support its own weight against gravity? How long human can support his own body weight against gravity before he get tired? if someone can't do it, how come the magnet can? These questions made the inventors interested with free permanent magnet motor since more than forty years ago. some of them made the first step of this field and others had shared with this work. some of the inventors are:

I- Charles J. Flynn, 1995 His work relates to a method of producing useful energy with magnets as the driving force and represents an important improvement over known constructions and it is one which is simpler to construct. can be self starting. Is easier to adjust, and is less likely to get out of adjustment, the present construction is also relatively easy to control, is relatively stable and produces an amazing amount of output energy considering the source of driving energy that is used. The present construction makes use permanent magnets as the source of driving energy but shows a novel means of controlling the magnetic interaction or coupling between the magnet members and in manner which is relatively rugged, produces a substantial amount of output energy and torque, and in a device capable of being used to generate substantial amounts of energy [2].

II- ShenHe Wang, 1997. He has designed and built an electrical generator of five kilowatt capacity. this generator is powered by permanent magnets and so uses no fuel to run. it uses magnetic particles suspended in a liquid. The motor consists of a rotor which has four arms and which sits in a shallow of liquid which has a colloidal suspension of magnetic particles in it. Outer fixed Cylinder has eight N pole Magnets. Inner rotating Cylinder has Six poles Magnets. Magnetic Shielding is used to create N pole only. By adjusting the alignment of the N pole magnet, slight rotation of the Inner cylinder will allow the magnetic repulsion to keep accelerating the inner cylinder –energy can then be extracted [3].

III- Harold E. Ewilgg, Chandler: Russell R. Chapman; David R. Porten both of Mesa, all of Ariz, 1997. A simple electrical generator powered by permanent magnets alone. this generator can also be used as a motor. The construction is not particularly complicated. it uses an arrangement where permanent magnets. Are associated with every second coil set around the rotor. operation is self-powered and the magnet arrangement is clearly defined. and the physical arrangement of the device is not particularly complicated [4].

IV- George Soukup, 2009 His a magnet motor has built on the "V" style of magnet placement which has two sets of permanent magnets. this style of magnet arrangement has a locking point where the switch from wide spacing to narrow spacing occurs and this causes the rotation to stop there. the taper is much less pronounced with an inner gap some four times greater than the gap to the outer ring. it also appears that the last inner magnet has a greater gap around the drum than the remaining ring of magnets. The housing has considerable clearance for the drum and magnets. The rear shaft bearing is just set into the back of the

housing. the positioning stator magnets allows the motor to overcome the normal sticking point of the typical V – motor arrangement [5].

V- Dietmar Hohl, 2010. He uses 20 mm diameter round neodymium magnets 10 mm thick, stacked in pairs in the stator. a magnetic gate arrangement built on a flat piece of Medium-Density fibreboard 30 mm thick. The holes drilled in it are 20.1 mm in diameter and positioned so as to take two of the 10 mm thick magnets stacked together. the holes are drilled at an angle of 63° to the horizontal or 27° to the vertical. on one side of the board, the inserted magnets have their North poles facing upwards, while on the other side of the board, the magnets are inserted with their south poles facing upwards. his design using angles magnet pairs, the number of magnets needed is quite high. for single V, There are 58 magnets. for a 2-V version, 116 magnets. the motor power is likely to increase as the diameter increases as the lever arm that the magnet has to turn drum, increases – double the diameter to double the power [6].

1.1. Permanent Magnet

Two basic types of magnetic materials are soft magnetic materials and hard magnetic materials. Hard magnetic materials are referred to as permanent magnets because once magnetized they tend to remain magnetized. Permanent magnets are used as field source components in a wide range of products including consumer electronic equipment, computers, data storage devices, electromechanical devices, telecommunications equipment and biomedical apparatus [7].

The resource crisis of rare earth materials has broken out in motor industry in the world. The resource of rare earth material is uneven distributed in the globe. The price of these materials is raising high and high strategically. Nowadays, many of electric motors use rare earth permanent magnet for the source of magnetic field [8].

In order to configure the magnetic circuit, an operating point has to be set that will determine the energy transferred from the magnet to the gap. Consider an idealized magnetic circuit where the magnetic permeability's μ_r of the soft magnetic materials are infinite so that their reluctances can be ignored. Since the sum of MMF's in the circuit equals zero, the line integral of the magnetic field along the path of the circuit becomes [9]:

$$H_m L_m = - H_g L_g \quad (1)$$

Where : H_m is the magnetic field of the magnet in $A m^{-1}$,
 - L_m is the length of the magnet in m,
 - H_g is the magnetic field of the gap, in $A m^{-1}$,
 - L_g is the length of the gap in m.

Also, as stated by Maxwell's equation $\nabla \cdot B = 0$, flux is continuous as it does not have a source or sink, therefore the total flux in the magnet can be equated to the flux in external space:

$$B_m A_m = B_g A_g \quad (2)$$

Since in the air gap

$$B_g = \mu_0 H_g \quad (3)$$

Then (2) becomes

$$H_m B_m V_m = - \frac{1}{\mu_0} \frac{B_g^2 L_g}{V_g} \quad (4)$$

$$\text{Then } B_m/H_m = -\mu_0 \frac{l_m A_g}{l_g A_m} \quad (5)$$

The quantity $P_g = \mu_0 A_g / l_g$ is termed the permanence of the air gap.

As seen in the previous derivation, the ratio B_m / H_m is only dependent on the geometry of the magnetic circuit.

Fig. 1 illustrates the second quadrant of a permanent magnet's BH curve.

Directly identifiable are the aforementioned quantities B_r and H_c . However, once the geometry of the magnetic circuit has been established and the reluctances calculated, a load line needs to be drawn, to identify the operating point of the device. The load line typically intersects the BH curve and has a slope $B_d=H_d$, as previously mentioned.

As seen from the equation, the slope of the load line is only dependent on the geometry of the magnetic circuit. However, since the air gap in linear motors and actuators is of variable dimensions, the load line will also vary, unlike with other magnetic circuits, such as that of a loudspeaker. Bearing that in mind, the engineer needs to design the circuit in such a way that the load line is steep enough, so that the magnet is not prone to demagnetization effects; in the latter case, the operating point of the circuit is not close enough to H_c as needed for a large sinusoidal signal to demagnetize the magnet.

At the same time, to make good use of the magnet's capabilities, the operating point has to be close to the point where $BH = (BH)_{\max}$, in order to extract maximum energy from it.

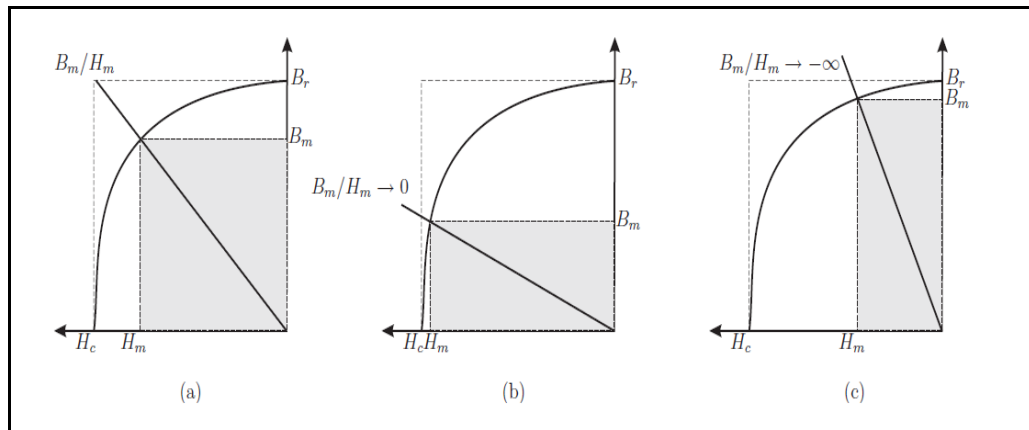


Fig. 1. The load line in (a) is intersecting the demagnetization curve at $BH_{\max}$. The load line in (b) is essentially an open circuit, where $B_m/H_m \rightarrow 0$ and l_g approaches infinity. The load line at (c) is essentially a short circuit, where $B_m/H_m \rightarrow -\infty$ and l_g approaches zero.

In a practical situation, however, it is safe practice to account for the magnetic flux leakages and the finite magnetic permeability. Two new quantities are introduced, namely the leakage coefficient K_1 and the loss factor K_2 [10]:-

$$K_1 = \frac{\text{Total flux in circuit}}{\text{Useful flux}} = \frac{\text{Useful flux} + \text{Leakage flux}}{\text{Useful flux}} \quad (6)$$

$$K_2 = \frac{\text{Magnet MMF}}{\text{Useful MMF}} \quad (7)$$

2. OPEN SOURCE DESIGN

Before advancing into practical aspects of this design, the underlying theory has to be addressed first. In this section, the mathematics underlying will be derived in the design of the open source motor.

2.1. Mathematical Description of the open source

Suppose a bar sample is magnetized by a field applied from left to right and subsequently removed. Then a north pole is formed at the right end, and a south pole at the left, as shown in Fig. 2-a, the H lines, radiating out from the north pole and ending at the south pole, constitute a field both outside and inside the magnet which acts from north to south and which therefore tends to demagnetize the magnet. This self-demagnetizing action of a magnetized body is important, not only because of its bearing.

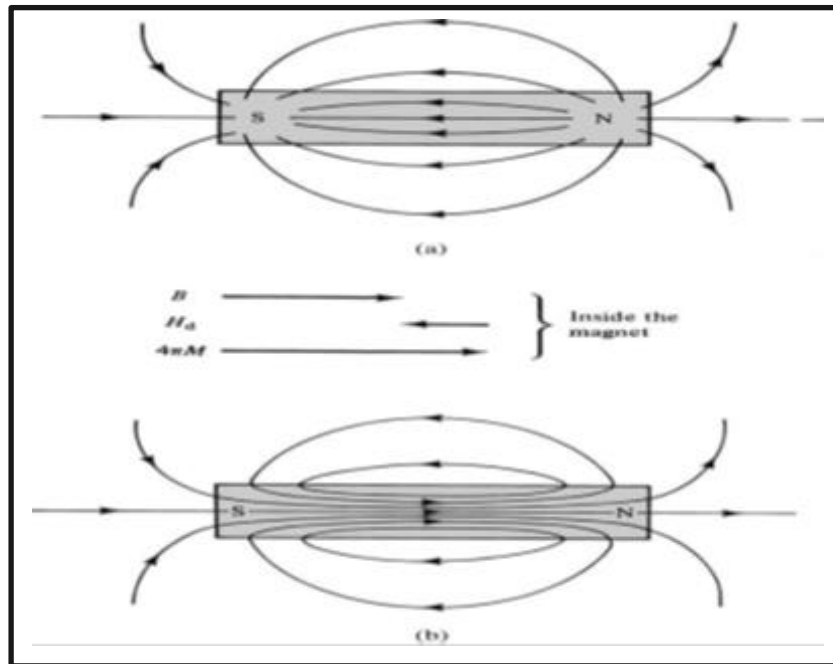


Fig. 2. (a) closed magnetic circuit (b) an open magnetic circuit

The demagnetizing field H_d acts in the opposite direction to the magnetization M which creates it. In Fig.(2-a) H_d is the only field acting, and the relation $B = \mu_0 H$. The flux density B inside the magnet is therefore less than $(\mu_0 M)$ but in the same direction, because H_d ($\mu_0 H_d$) can never exceed $(\mu_0 M)$ in magnitude. These vectors are indicated in Fig. 2, along with a sketch of the B field of the magnet. Note that lines of B -are continuous and are directed from south to north inside the magnet. Outside the magnet, $B = \mu_0 H$ and the external fields in Fig. 2-a & 2-b are therefore identical. The magnet of Fig. 2-b is in an open magnetic circuit, because part of the flux is in the magnet and part is in air [11].

3. PRACTICAL ASPECTS OF THE MOTOR DESIGN

3.1. The idea of Open Source Permanent Magnet Motor

Initially, the idea was to permanently mount the magnets on a straight parallel shaped base. However, it then became apparent that there is a necessity of making the prototype as flexible as possible.

First In this work we have used parallelogram magnets with arrangement by putting twelve magnets in two rows with length with different polarity to create a magnetic track by sending pieces of magnets sliding with length of (20cm) moves between the two rows of straight magnets. The magnets had got very satisfactory movement. Fig 3-a and 3-b illustrating: (The idea of straight open source permanent magnet motor) with top views of the prototype which consists of : twelve ceramic magnets placed on two wooden axis with

different polarity and sending straight magnets sliding between them). Fig 3-c shows Isometric of the permanent magnet.

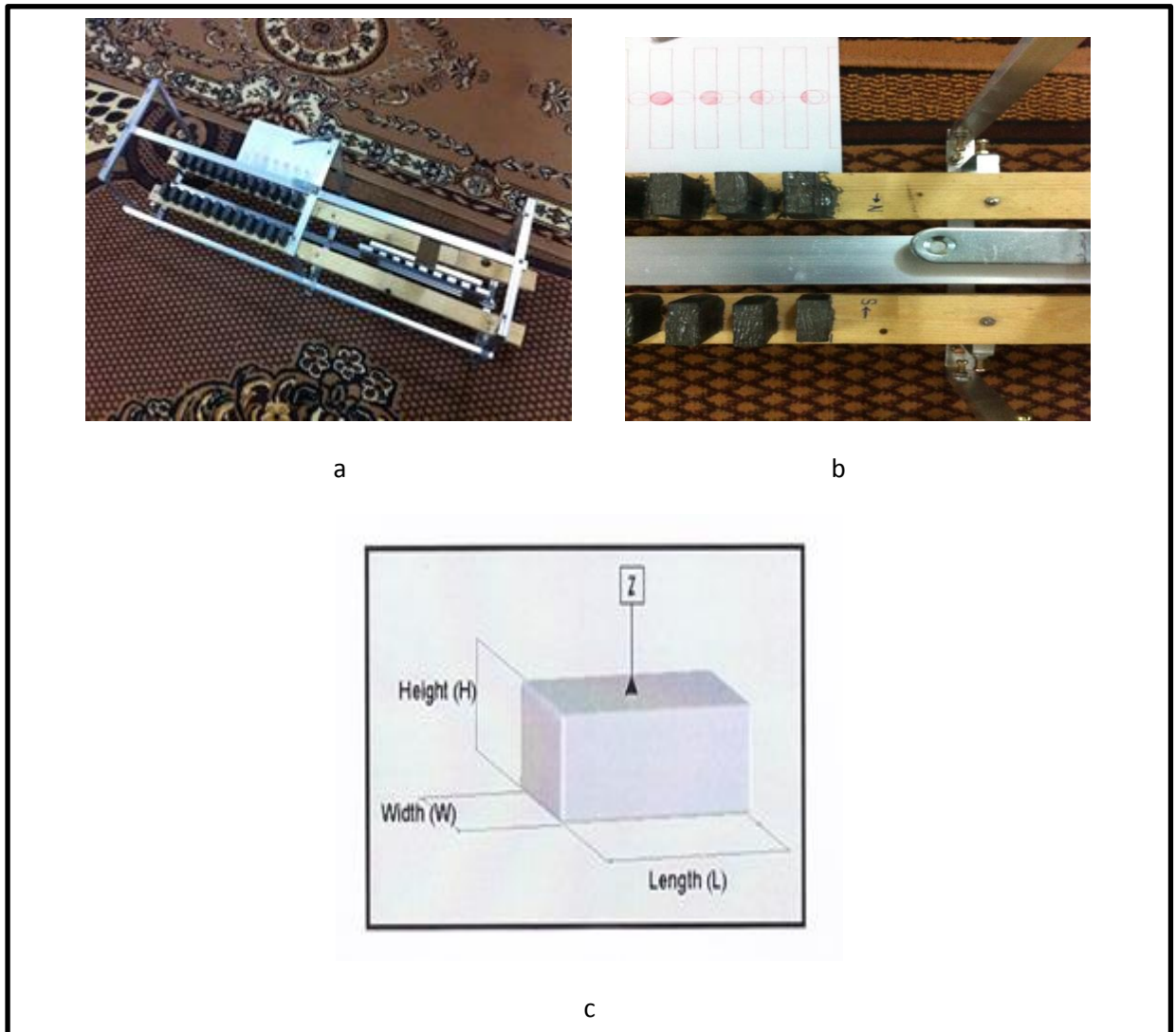


Fig. 3. (a) the top views of the prototype , (b) top views of the outer strings and (c) Isometric of the permanent magnet.

Secondly, it was began by taking each **two** parallelogram magnets in **two** rows and arranged by changing the distance between them and sending a slide of **two** parallelogram magnets between them. Notice the North and the South Poles are reversed on the magnets, then observe the magnetic flux lines between them with (Vizimag) package, as illustrating in Fig. 4.

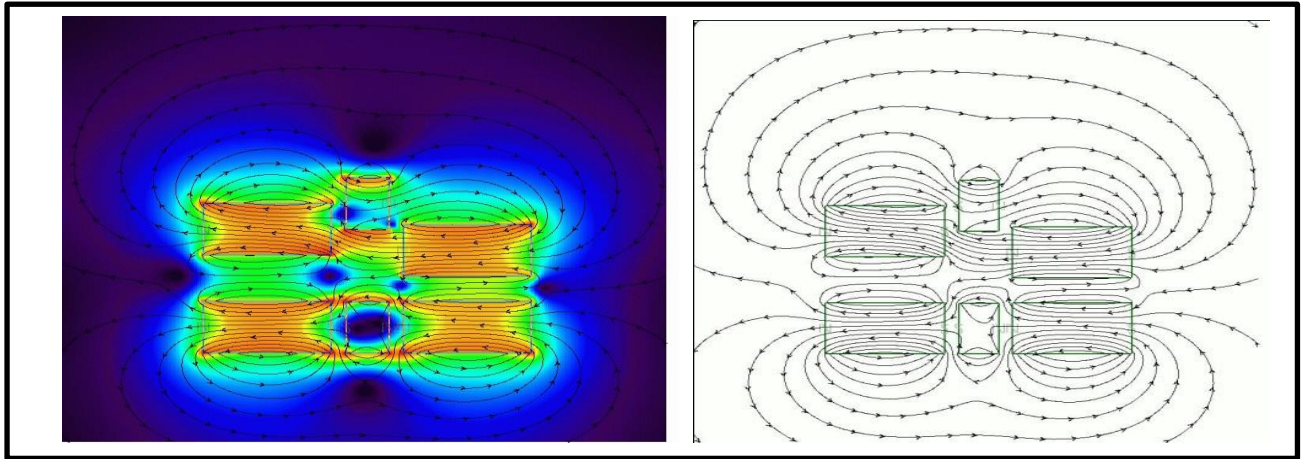


Fig. 4. The flux lines distribution of straight open source

Notice the lines between them begin from and go back into the same magnet. These are the lines of magnetic repulsion. When moving a slide of magnets through the fixed magnets, so that the north and south poles face each other, the lines which pass from bottom of one magnet to the bottom of the other are the lines of magnetic attraction.

Then stack up **sixteen** magnets on one side and **twelve** magnets on other sides of stationary part with (30 cm) length, the distance between the **sixteen** magnets on the right side less than the distance between the **twelve** magnets on the left side (that means there is an angle between the edge of any magnet on the right side and the another one on the left side, then passing a slide of **six** magnets with (15cm) length between them. There are flux lines passing from the top magnet to the bottom magnet on each side. Fig. 5 illustrate The equivalent magnetic circuit of straight open source.

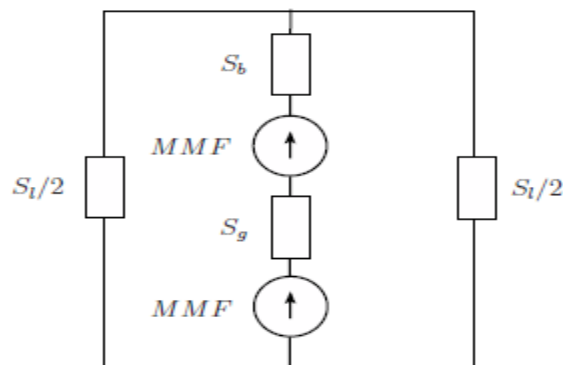


Fig. 5. Illustrate The equivalent magnetic circuit of straight open source.

This will not happen when we arrange the magnets in a circle, the circle does not have a first and last magnet. If we look closely at the middle magnet, we can see what will happen inside the circle. If the magnets on the right and the left are stationary and the magnets on the middle are allowed to rotate, the magnets on the right will begin to push the magnets on the middle away. the magnets on the middle will begin to attract to the magnets on the left. then the magnets on the left will begin to push the magnets on the middle away. the magnets on the middle will begin to attract to the magnets on the right. Fig. 6 illustrate **two** layers of stationary and moving magnets, each magnet on the middle is moving through different positions.

Notice that there was never occur any lines of attraction between the two layers. This is because the lines of repulsion are always greater than the lines of attraction. The moving of free magnets will be easy and smooth and fast.

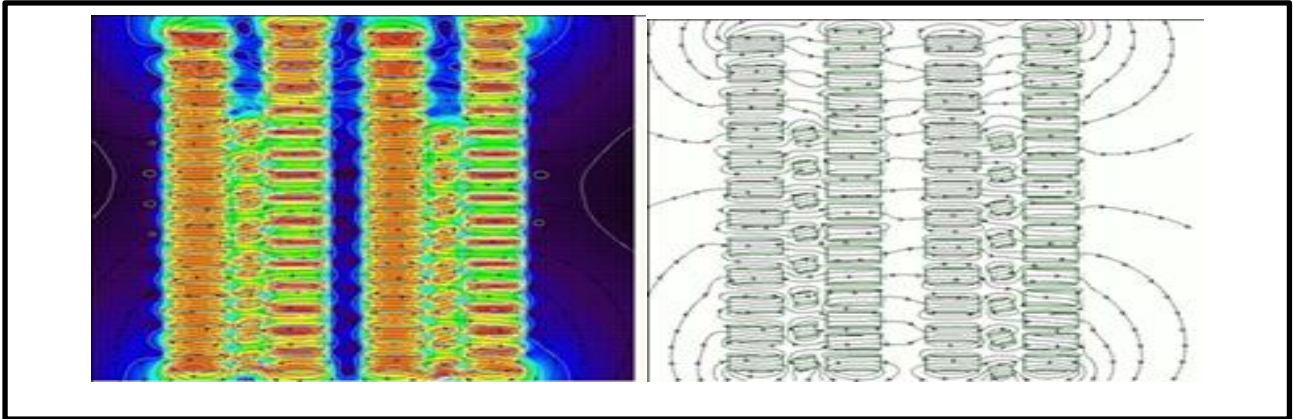


Fig. 6. Illustrate two layers of stationary and rotary magnets

3.2. Geometry

The purpose of the **open source motor** is to induce a torque on the rotor, via a magnetic field gradient. In practice, a continuous gradient as implied by the expression $dB=d\theta$, is possible only with a circle permanent magnet. The flux density seen from the rotor magnets as the rotor rotates 2π radians would then resemble very closely to the trend of circular ship, in the case of an Archimedean circular. The aforementioned magnetization pattern, however, is not cost effective.

Instead, it was decided that the magnetic field gradient could be assumed continuous by placing permanent magnets of two sizes in a circular stator and rotor arrangement as follow. It was decided that the magnetic field gradient could be assumed continuous by placing numerous permanent magnets of small enough size in a straight arrangement as desired in Fig. 7. However this would inevitably lead to a B versus θ . The only workaround to get a good approximation to continuous gradient was to increase the number of density of magnets and therefore reduce the spacing between adjacent magnets, in order to get a higher spatial resolution.

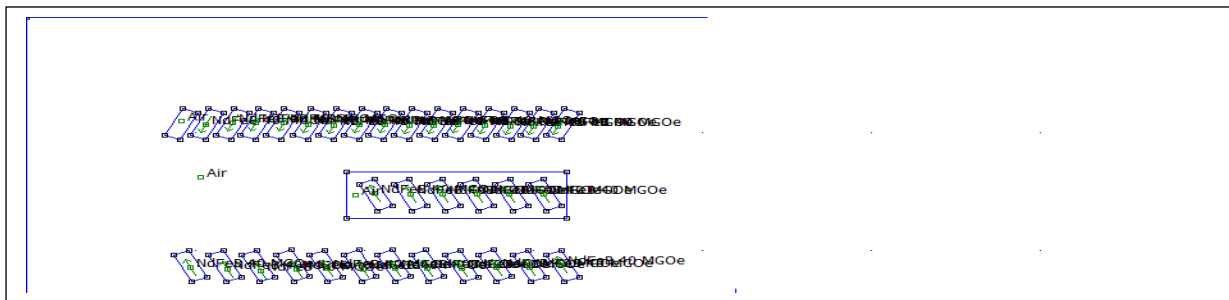


Fig. 7. arrangement of permanent magnets

3.3. Permanent Magnet Material Selection

A specific grade of Neodymium Iron Boron (NdFeB Goe) material was used to provide the magneto motive force of the inner and outer stages, namely N35. Initially, it was considered wise to employ NdFeBGoe magnets in the outer and inner structure. The wide commercial availability of NdFeB Goe magnets made it possible to purchase magnets of decent

dimensions and BH_{max} at a relatively low cost. Appendix (A) lists the magnetic properties specific to that grade (NdFeB Goe) which was made by (OeMag) company in china. Appendix (B) shows the sample of N35 magnets with two sizes (14*30)mm & (12*30)mm.

The belts of outer and inner parts of a straight base made of steel on which the permanent magnets can be attached. Also, the core consists of plastic rod which magnets can be placed. The magnetic properties of the steel were unknown, therefore measurements had to be carried out. The material was available in two sizes namely outer (stator) and inner (rotor).

The magnetic measurements for the magnetic materials were carried out using a permeameter. The purpose of a magnetic measurements is to extract the magnetic properties of a material, such as coercivity H_c , remanence B_r , point of saturation B , and maximum permeability μ_r (max). This information can be extracted the B-H loop of the measured material. In addition to the sample the permeameter involves an induction coil for the measurement of the flux density B inside the sample. And a Hall prob for measuring H produced by the electromagnet at the point where B is picked up by the induction coil as shown in Fig. 8 below.

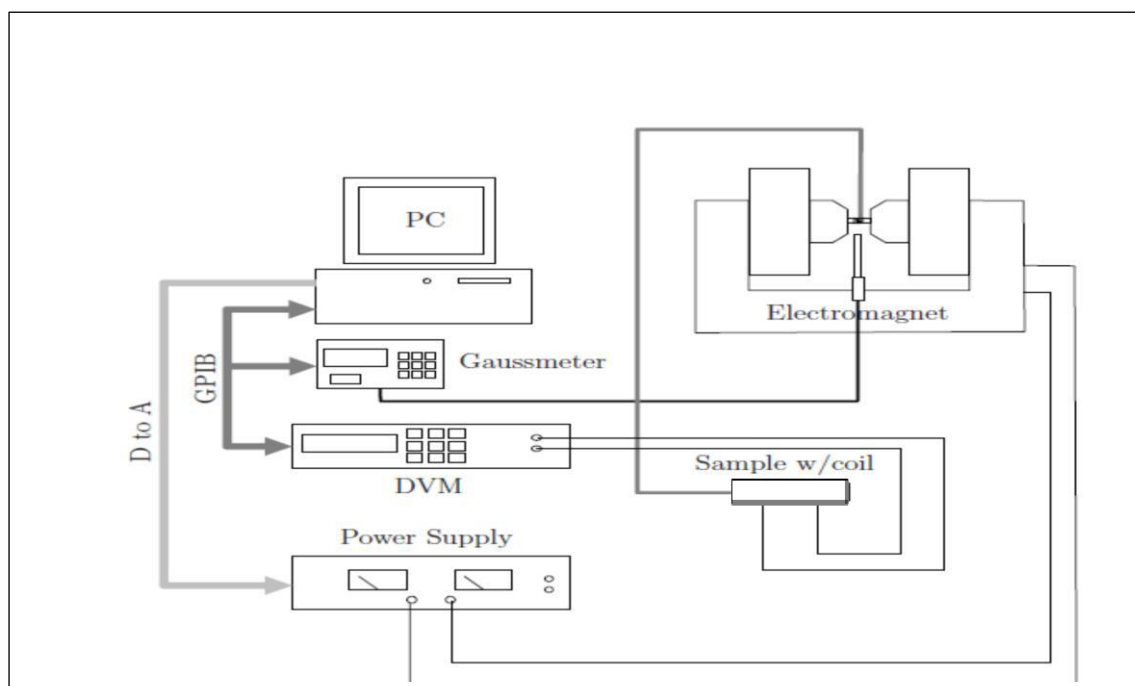


Fig. 8. Schematic of measurement system

The DVM records the voltage across the coil wound around the sample, and feed it to the PC, which will in turn calculate B . The gaussmeter directly measures H at the point where B is measured. A digital to analog (D to A) converter is used to connect the PC to the power supply. A General Purpose Interface Bus (GPIB) is used to connect the gaussmeter and DVM to the PC. Fig. 9 shows the permeameter for induction coil and the magnet. Appendix (C) illustrate the experimental setup.

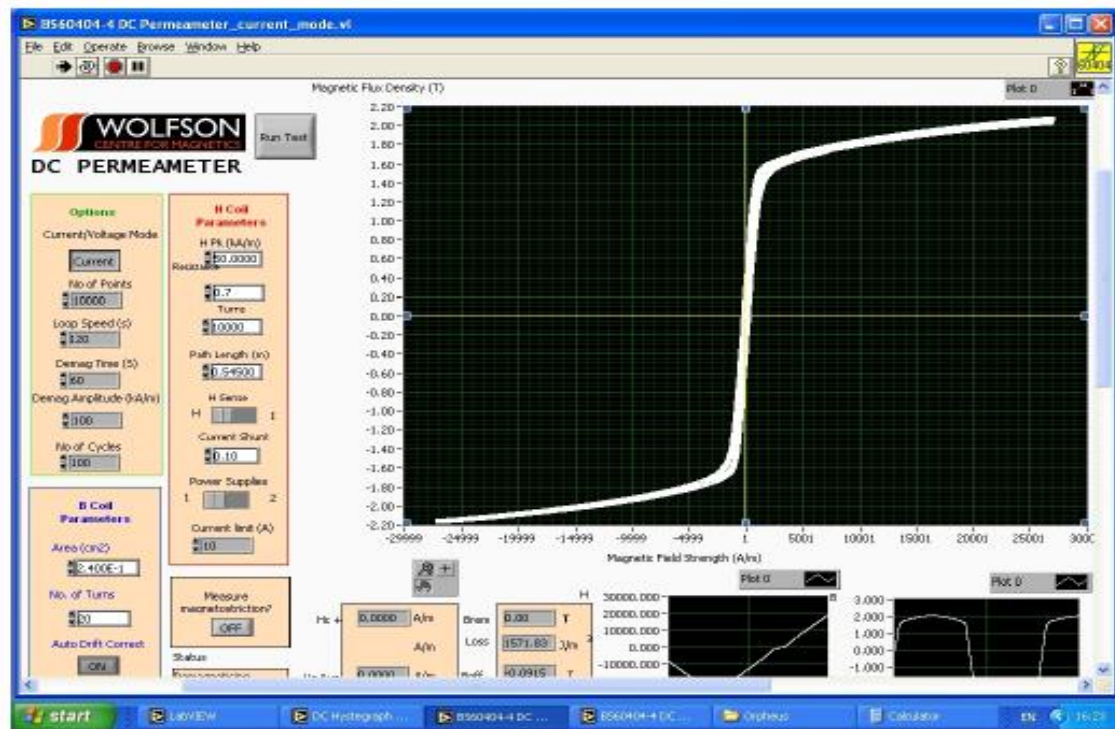


Fig. 9. The parameter for induction coil and the sample(14*30)mm

The modeling of the flux lines for the suggest design which used (Vizimag) package can be represented by the Fig. 10-a represents the movement of free magnets on the straight slides with number of magnets steps when open source was a straight and Fig. 10-b represents the steps of free magnets on the free rotor with number of magnets steps when open source was a ring (cycle) shape.

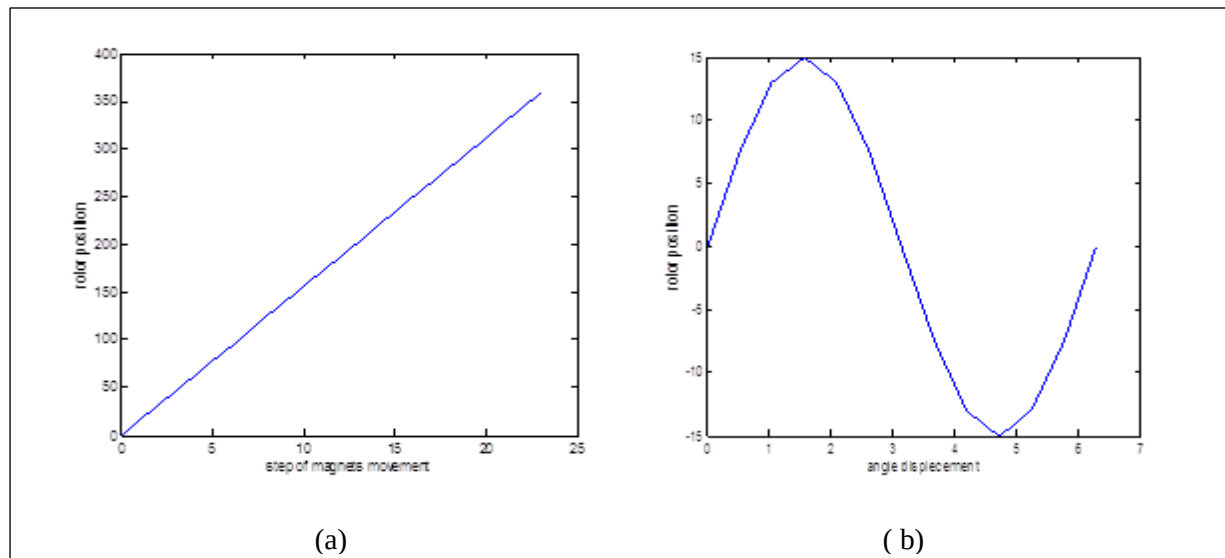


Fig. 10. The movement of free magnets. (a) when open source was a straight and (b) when open source was a ring(circular) shape.

3.4 Straight Permanent Magnet Motor Simulation

At first, the initial mesh was designed in (DS Solidworks package) consistent with the straight parameters chosen previously as shown in Fig. 11.

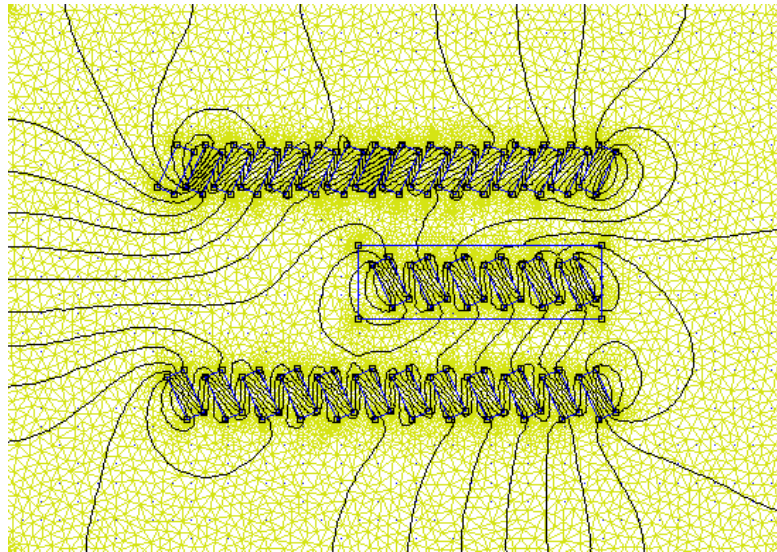


Fig. 11. Straight permanent magnet motor initial mesh

The mesh with 23705 nodes was then imported into (Infolytica Magnet) and a static 2D simulation was performed on both outer (stator) and inner (rotor) the distribution of flux lines is sketching with (femm), so that the magnetic field gradient can be computed. Fig. 12 shows the simulation of straight permanent magnet.

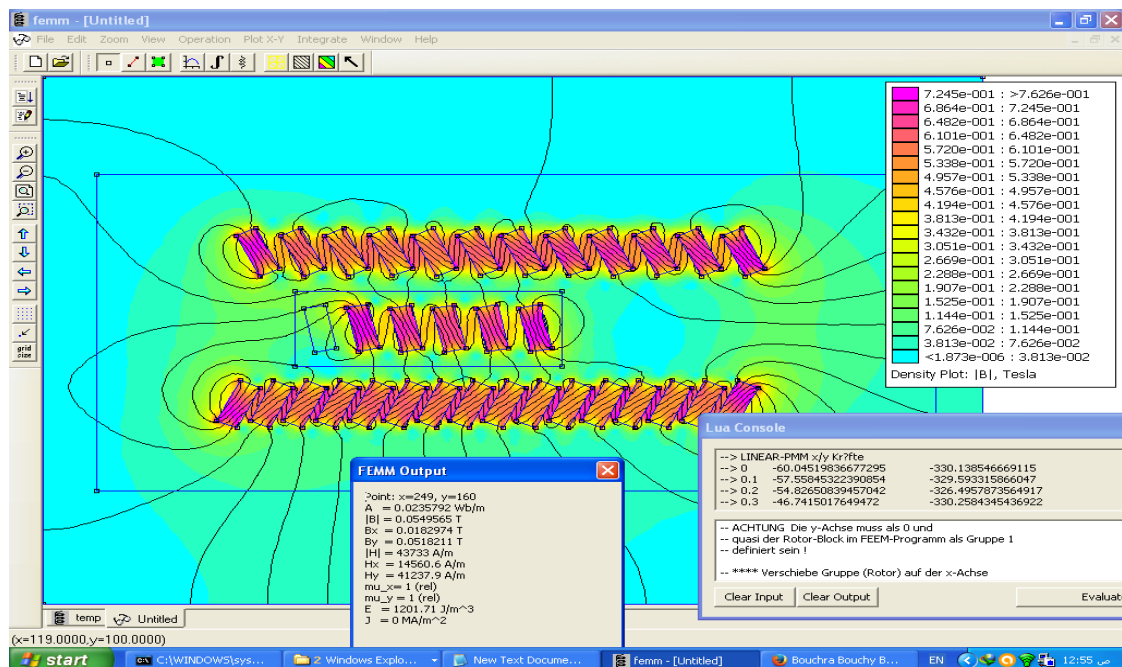


Fig. 12. Straight permanent magnet motor simulation result

The steps of inner (rotor) movement inside two outer (stator) are illustrated in Appendix (D). One of these results is the distribution of flux density as shown in Fig. 13.

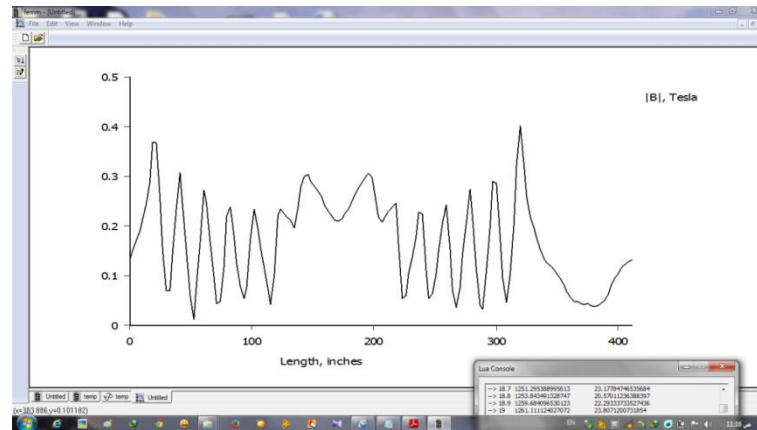


Fig. 13. The distribution of flux density

4. CONCLUSION

The magnet of (N35) is made with low cost therefore the energy is between 263 -287 that mean it easy to broken ,so the magnets must be fixed on core with glue to prevent its damaged.

The core of stator and rotor are made from non-magnetizing and insulator material to reduce remanance of magnetism or generating the eddy currents.

The sixteen outer magnets are placed with skewing angle $=15^\circ$ between the two magnet's ends, that mean different poles. This angle was chosen to prevent the loss attraction which represented by negative sign. while the eight inner magnets are placed with skewing angle ($\theta=30^\circ$) between each two ends or different poles. This angle was chosen to prevent the loss attraction which represented by negative sign, that means the angles less them will reduce the force to zero and the rotor tends to return to its previous position where it will experience equilibrium. Therefore, at the end the result of simulation was positive for all reading from 1-19. This angle depends on the result of simulation that shown in Figs. 11 and 12. in addition to the position angle the direction of inner magnets is opposite to the outer magnets direction. In this work, a Straight Permanent Magnetic Motor was designed and its operation was analyzed. Equations described the magnetic field gradient seen by the inner part (rotor) were developed.

Parallelogram shape had been replaced with Cylindrical shape of magnets because the affect of edge of parallelogram was appeared on the movement of free magnets, this conclusion explained at **Dietmar Hohl, 2010** because the result torque of his motor had changed from negative to positive then return to renegative values. his problem was the flux density of the edges.

A two dimensional computer model of the motor was designed in order to perform a magnetic analysis.

The magnets (N35) were examined practically with pereameter to calculate the B-H values and with (DS Solidworks) package to calculate the torque and speed.

5. FUTURE WORK

After completing the computer simulations to determine the torque and speed, a control system can be set up. The reason for that is to be controlled the starting and braking of the Straight Permanent Magnetic Motor and speed controlling at all time.

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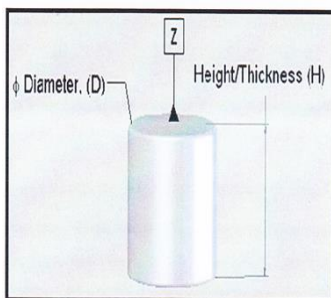
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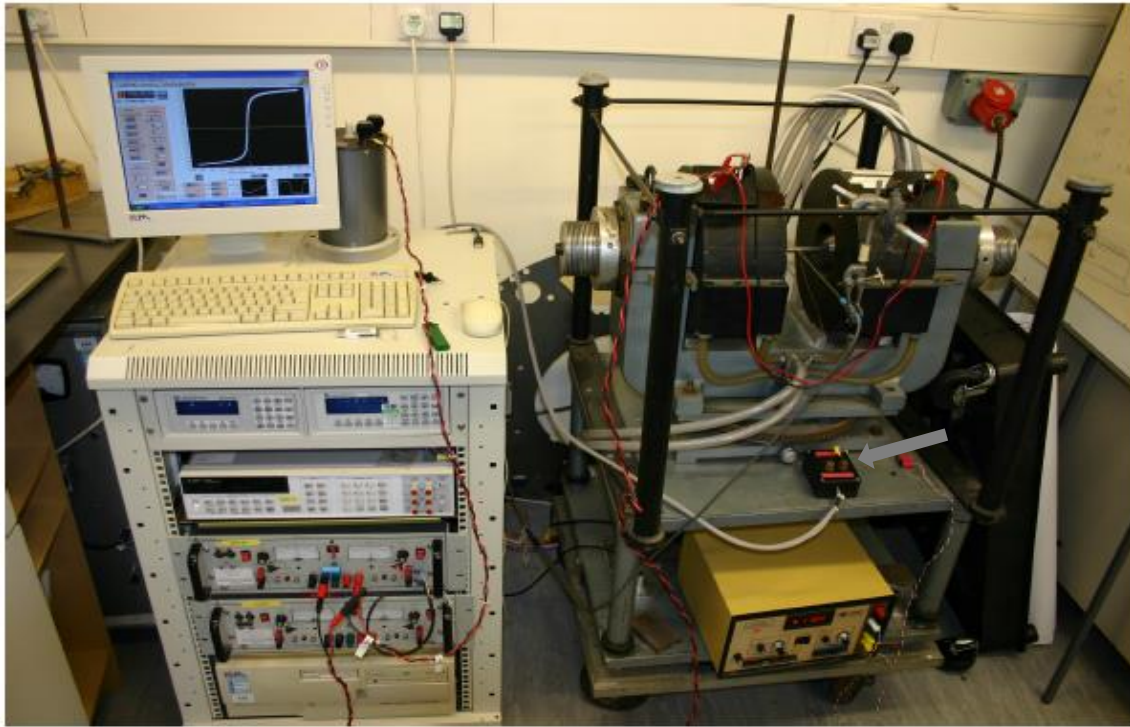
APPENDIX (A) :TABLE (1) (NDFEB GOE) MATERIAL PROPERTIES

DATASHEET

Material	N35	
Remanence Br	1'160-1'210	mT
Coercivity HcB	836	KA/m
Coercitivity HcJ	955	KA/m
Energy Product(BH)max	263-287	kJ/m ³
Operating Temperature	80	°C
Curie Temperature Tc	310-380	°C

APPENDIX (B) : THE SAMPLES OF N35 MAGNETS WITH TWO SIZES (14*30)MM & (12*30)MM.



APPENDIX (C) : THE EXPERIMENTAL SETUP**APPENDIX (D) : SCHEDULE OF THE STEPS OF INNER (ROTOR) MOVEMENT INSIDE TWO OUTER(STATOR)**

steps	Stationary South magnets(RS)	Free (FR)	magnets	Stationary North magnets(LS)	Air gap	The distance by angles (degree)
1	→1	1	1	1	0	0
2	1	1	1	1	1.3	15
3	1	1	1	1	2.6	30
4	1	2	2	2	4	45
5	2	2	2	2	5.2	60
6	2	2	2	2	6.5	75
7	2→3	3	3	3	7.8	90
8	3	3	3	3	9.1	105
9	3	3	3	3	10.5	120
10	4	4	4	4	11.7	135
11	4	4	4	4	13	150
12	4→5	4	4	4	14.4	165
13	5	5	5	5	15.7	180
14	5	5	5	5	17	195
15	6	5	5	5	18.3	210
16	6	6	6	6	19.6	225
17	6→7	6	6	6	21	240
18	7	6	6	6	22.2	255
19	7	7	7	7	23.5	270
20	8	7	7	7	24.8	285
21	8	7	7	7	26	300
22	8→9	8	8	8	27.5	315
23	9	8	8	8	28.7	330
24	9	8	8	8	30	345