

# A New Approach of Magnetic Field Interaction for Energy Harvesting: Concept and Principle

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## ABSTRACT

The global rise of energy consumption has highlighted the need to develop and implement novel methods of harvesting, conserving, and optimally utilizing energy. This paper analyzes a concept of using an array of magnetic fields of permanent magnets to produce mechanical energy. Its operating principle is based on the relative movement of the magnetic pole of the rotor magnet with respect to that of the stator magnet. A *Vizimag* simulator was used. Feasibility results have demonstrated potentials for such a system to produce rotational motion. Design optimization using this analysis will present alternative source for energy harvesting.

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## Introduction

For many years, permanent magnets have play a vital role in many devices, serving as essential components in various systems like electric motor, loudspeakers, computers, Instrumentation, compact disc players, microwave ovens, production machine and research devices. Their contribution is often overlooked because they are built-in devices that make them out of sight. Electrical machines (motors and generators) consist of permanent magnets and electromagnetic circuits build in stator and rotor. For it operation, it require power supply or fuel to run it, depending on the design of the machine. Recently, design of permanent magnet generators driven by micro turbines [1-3] has been developed, they totally depends on an external energy source. Permanent magnet machine which uses high energy magnets have been used in various applications [4-6]. Significant application of speed control of permanent magnet machine was presented by [7]. Electromechanical power conversion based on permanent magnet technology is inevitably when energy efficient solutions for generating and motoring are considered. Therefore, energy conversion technologies with permanent magnets also make it possible to create a new conversion system for competitive generation of energy. The objective of this paper is to analyze the concept of using magnetic field interaction between stator and rotor of a permanent magnet to produce mechanical energy.

Magnetic energy of an electromagnet is stored in the magnetic field generated around the inductor [8]. Consider two coils wound on top of one another and each is connected to its

own battery. The numeric derivation shows the total magnetic energy store in the two coils, conclusively arriving at an expression showing the energy density of a magnetic field. The circuit equations are given in Eqs. 1 and 2.

$$V_1 = R_1 I_1 + L \frac{dI_1}{dt} + M \frac{dI_2}{dt} \quad (1)$$

$$V_2 = R_2 I_2 + L \frac{dI_2}{dt} + M \frac{dI_1}{dt} \quad (2)$$

where  $V_1$  is the e.m.f of the battery in the circuits. The work done by the two batteries in increasing the currents in the two circuits, from zero at time 0, to  $I_1$  and  $I_2$  at time  $T$  respectively, is given by Eqs. 3 and 4.

$$W = \int_0^T (V_1 I_1 + V_2 I_2) dt \quad (3)$$

$$W = \int_0^T (R_1 I_1^2 + R_2 I_2^2) dt + \frac{1}{2} L_1 I_1^2 + \frac{1}{2} L_2 I_2^2 + M \int_0^T \left( I_1 \frac{dI_2}{dt} + I_2 \frac{dI_1}{dt} \right) dt$$

$$W = \int_0^T (R_1 I_1^2 + R_2 I_2^2) dt + \frac{1}{2} L_1 I_1^2 + \frac{1}{2} L_2 I_2^2 + M I_1 I_2 \quad (4)$$

Therefore, the total magnetic energy stored in the two coils is given by Eq. 5.

$$W_B = \frac{1}{2} L_1 I_1^2 + \frac{1}{2} L_2 I_2^2 + M I_1 I_2 \quad (5)$$

Considering an ideal solenoid, the energy stored in the solenoid when a current  $I$  flows through it is given by Eq. 6.

$$W = \frac{1}{2} L I^2 \quad (6)$$

where  $L = \mu_0 N^2 \pi r^2 l$  is the self-inductance and  $N$  is the number of turns per unit length of the solenoid, The field inside the

solenoid is uniform with magnitude is  $B = \mu_0 NI$ . Therefore, Eq. 6 can be written as shown in Eq. 7.

$$W = \frac{B^2}{2\mu_0} V \tag{7}$$

where  $V = \pi r^2 l$ , which is the volume of the solenoid. Conclusively, the energy density of a general magnetic field is given by Eq. 8.

$$U = \frac{B^2}{2\mu_0} \tag{8}$$

Magnets are classified based on their material composition of magnetic properties. General classification are; Neodymium Iron Boron, Samarium Cobalt, Ceramic and Alnico. Neodymium Iron Boron (NdFeB) and Samarium cobalt (SmCo) are Rare Earth magnets. At room temperature, NdFeB magnets exhibit the best properties of all the magnetic materials. NdFeB was selected as the best candidate as permanent magnets in the rotor [9] therefore, in selecting a proper material, shape, size and grade must be considered for a specific application.

Magnetic materials of neodymium magnet can be described by  $BH$  curve [10], second stage of this characteristic is called demagnetization curve which is vital for magnetic calculations. The position where this characteristic crosses the  $H$  axis is called coercivity,  $H_c$  which is the amount of external magnetic field needed to totally demagnetize the magnet and bring the value of  $B_r$  to zero. The higher  $H_c$  gets, the more difficult it is to demagnetize the magnet totally. Therefore, demagnetization curve  $BH$  is given as:

$$BH = \frac{B_r}{H_c} H + B_r$$

Magnet maximum energy product  $BH_{max}$  can be calculated from the equation  $BH_{max} = 0.25 B_r H_c$ .

The permanent magnet array presented in figure 1, shows configuration of the stator and rotor magnetic array, the relative motion caused by the interaction of magnetic poles (N and S). For this analysis, a linear arrangement of the permanent magnet rotor was used for simulation.

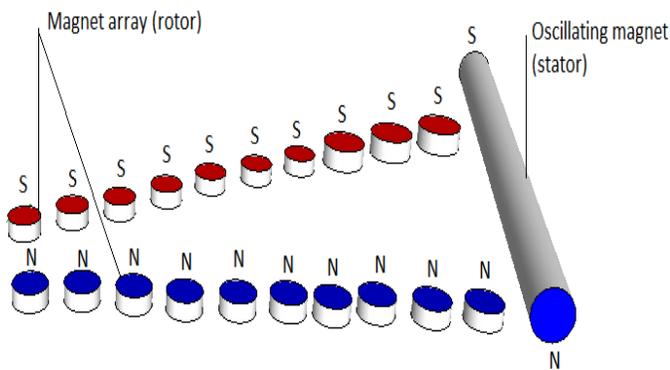


Figure 1. Configuration of Neodymium permanent magnets.

Magnetic lines of force seek the path of least resistance between opposite magnetic poles. In a single bar magnet it forms closed loops from pole to pole. The magnetic lines of force never cross one another. Their strength is the same and decrease in density when they move from an area of higher permeability to an area of lower permeability. They flow from the South Pole to the North Pole within a material and vice versa in air.

### Working Principle

Permanent magnets with one side aligned South Pole and the other aligned North Pole were arranged as shown in figure 1. These permanent magnets are configured in a V-shaped structure. This is necessary for unidirectional pattern of attraction for the rotation of the system for one complete circle (360°). At this point, it experiences resistance. An electromechanical pulse switch can be used to overcome the resistive point which will make the magnetic system to start a new rotation. For every new rotation, the phase of the magnet on the rotor advances to attract the corresponding magnet on the stator and the magnetic flux density increases which tend to attract the next magnet. In this manner, the magnets on the rotor sequentially approach each other, and magnetic attraction and repulsion occurs incessantly. As a result, the rotor will rotate continuously with the activeness of the electromechanical pulse switch. The magnetic field simulations analyzing the performance capability of the system are shown in figures 3 - 6.

### Simulation Results and Discussion

Magnetic fields can be described by Maxwell's equations [11], which are represented by "lines of flux". These lines of flux allow for the visualization of the magnetic field at each position of interaction even though they only represent invisible phenomena. The number of lines of flux varies from one magnetic field to another. The lines of flux are drawn with a direction indicated, since these lines and the magnetic field they represent are visualized as having a distinct movement from North to South Pole. Vizimag, a magnetic field simulation program has been used to simulate and analyze the magnetic field characteristic of the system, as shown in figure 2. Simulations of magnetic field were performed in three different positions of interaction between the rotor and stator.

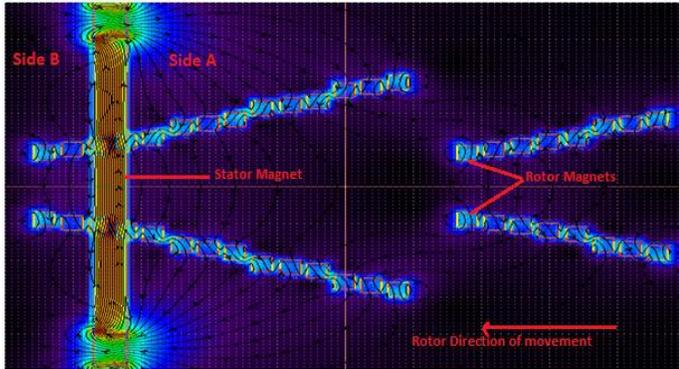


Figure 2. Rotor and Stator magnets.

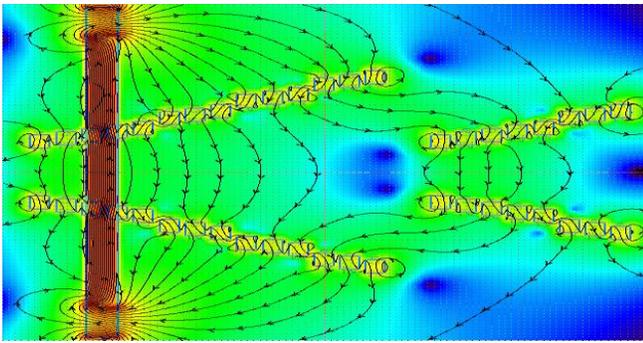


Figure 3. Rotor and Stator magnetic field in position one

In view of the high levels of flux-density of NdFeB magnets, the magnetic field visualizations in figures 2 and 3 shows that at side A, the flux density is very high compared to side B where the flux density is almost zero. Due to the v-shaped arrangement of the magnets on the rotor, which at every position the magnets has different phase, the stator magnet tends to get attracted to the next available rotor magnet. This action will continue to occur for the system to rotate until it gets to the last magnet on the v-shaped configuration.

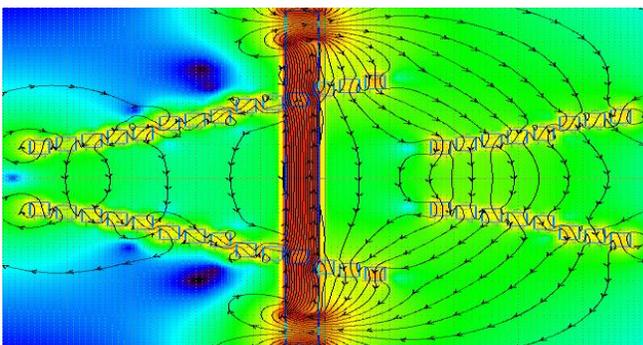


Figure 4. Rotor and Stator magnetic field in position two.

Visualizing the system at position two in figure 4, we see that at side B there is no attraction between the rotor and stator, rather it is repulsion. As usual, the attraction occurs at side A and push to side B creating rotational motion. The blue color is a region of no magnetic strength; green is magnetic field region, yellow is flux density and red is high magnetic strength.

Rotational resistance was clearly observed by the feedback magnetic field line in figure 5. At this position, the system will not rotate, so the idea of using an electromechanical pulse switch is important. It is very clear that with this configuration and electromechanical pulse switch, a new energy harvesting system can be designed.

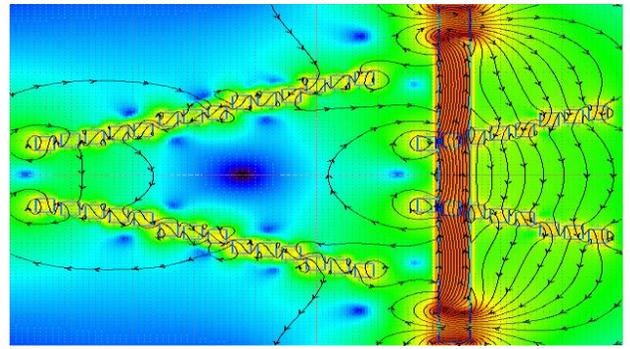


Figure 5. Rotor and Stator magnetic field in position three.

To test the capability of the system as a low power motor (LPM), an experimental prototype for testing was developed. A battery source voltage ( $v$ ) shown in figure 6, was utilized to supply power to the system. Figure 7 shows the picture of the motion translator used.

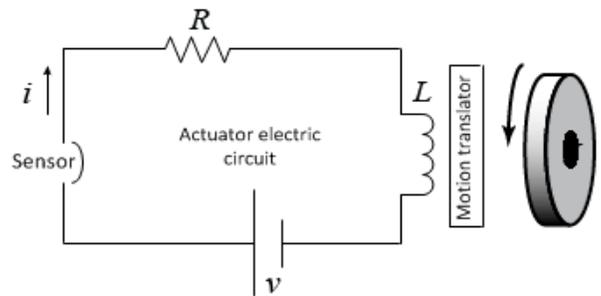


Figure 6. System circuit diagram

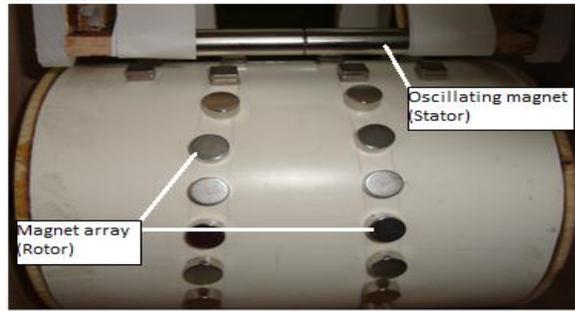


Figure 7. Photograph of motion translator.

Figure 8 shows the voltage waveform. When the system starts operating, it reach the nominal voltage level of 11V and suddenly drop to the off position (reference level). It can be seen from figure 9, the current suddenly goes to a nominal current level of 1.2A, and suddenly back to the reference level. The period at which the system draws current when it is at nominal current level is far less than when it stays at off position (reference level). The peak input power was divided by 3 (three positions per cycle of rotation), in which the average power consumption using position controller was calculated using Eq. 9.

$$P_{IN} = \frac{13.2}{3} = 4.4 W \quad (9)$$

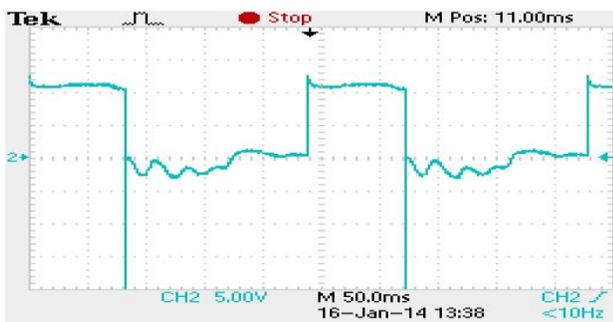


Figure 8. Voltage waveform (ch.2: Voltage)

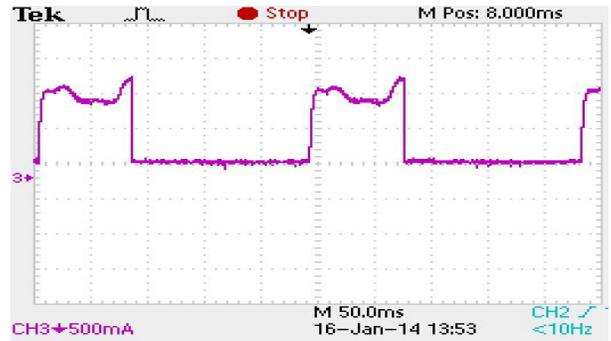


Figure 9. Input Current waveform (ch.3: Current).

Observing the simulation results of the system at different positions of interaction between stator and rotor, figure 4 shows that the magnetic flux density increases at side 'A'. As the v-shaped rotor magnet passes the stator, the magnetic flux density decreases as shown in figure 4. Conclusively, the magnetic flux increase at side A and decrease at side B simultaneously. This shows the rotational potentials of the system which tends to stop at the end of the v-shaped rotor magnet and with the timing pulse switch action of the electromechanical switch which can be connected to the system to enable the magnetic system to work effectively.

### Conclusion

A permanent magnet machine whose operating principle is based on the relative movement of a stator and rotor magnet has been analyzed. It provides a revolutionary new concept concerning the utilization of the natural resource phenomenon of magnetic field. The feasibility studies of the simulation results have shown the potential of such a device for energy harvesting. This analysis can be used for improvement and optimization of magnetic system designs.

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