Design and Analysis of Electromagnetic Propulsion System

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Abstract

In the first part of this project, different methods for electromagnetic propulsion such as Maglev, Electrodynamic, Inductrack Project, Rail guns, Propulsion using Halbach Arrays, Electromagnetic Thrusters are studied. These concepts are studied and analysed for better understanding of electromagnetic systems. On the basis of literature Review a simple mathematical model to determine the magnetic field components in an axially magnetized PM will be presented. MATLAB codes are written to evaluate the magnetic field components. Based on the results electromagnetic analysis is done using a commercial FEA software. The forces acting on the permanent magnet is obtained by the analysis. Further study is made on different parameters to establish a relation between parameters, and to obtain maximum propulsion. Theoretical analysis has helped to obtain optimized configuration for greater propulsive force. Based on the analysis and study a simple model is fabricated to evaluate the design. Magnetic propulsion has been demonstrated successfully in this experimental setup.

Keywords: Electromagnetic Propulsion, Electromagnetic Vehicles, Propulsion Theory

1. INTRODUCTION

The late 20th century was truly magnificent for the field of electromagnetism. With the development of maglev vehicles, electromagnetic rail guns, electromagnetic cannons, and much more, many scientist and researchers are now looking towards electromagnetism for more reliable solutions. The same initiative has been extended towards propulsion systems as well. Though, the concept of electromagnetic propulsion was first discovered in 1889 by Professor Elihu Thomson when working with electromagnetic waves and alternating current, not much of a thought was given to it until 1966 when James R. Powell and Gordon Danby successfully developed and patented superconducting maglev vehicle. With the development of electric propulsion [1-3] and extension to electromagnetic propulsion with more powerful magnetic materials [4] Electromagnetic propulsion is no longer a dream. Researchers like John C. Mankins [5] presented some of the early models for launching of rockets using EMP. Presently there are lot of research activities going on into making electromagnetic propulsion for conventional vehicles into reality such as super conducting levitation vehicle model [6] and Advanced electromagnetic propulsion vehicles studies done by NASA [7]. Since the conventional propulsion system utilizes different kind of propellants in obtaining the thrust force required to drive a body, which are less efficient and not cost effective. NASA’s Inductrak Project [8-10] at Lawrence Livermore National Laboratory has conducted a lot of research into developing a suitable model for Electromagnetic propulsion. With this, Researchers are extending electromagnetics into space vehicles [11] and Dynamic suspensions [12] into robotics for different uses.

Electromagnetic Propulsion (EMP) is the physics of accelerating a body or an object the interaction of electrical current and magnetic fields. The lift and drag forces are influenced by a magnetic field distribution, induced currents and their interactions. In this project we try to incorporate this kind of propulsion system and improve the productivity by incorporating permanent magnets and electromagnets in obtain better and most effective propulsion. Hence, a basic model of Electromagnetic Propulsion system was developed and propulsion was demonstrated.

2. METHOD AND METHODOLOGY

Figure 1 shows the basic model considered for the analysis and evaluation of forces acting on the permanent magnet placed at the center whose properties are predefined. Whereas magnets on either side is considered to be electromagnets whose properties depends on the material and diameter of wire wound around it, current, thickness etc. In the preliminary analysis, the electromagnets are assumed to have same properties as that of permanent magnet.

![Fig. 1 Schematics of current model](image)

Here Neodymium magnet (NdFeB) with and coercivity of 155319 sqrt (42) and permeability of 1.05 is taken. The commercial software used for analysis is FEMM. For initial analysis the length of permanent magnet and electromagnet is taken as 20mm, the gap between...
electromagnet is taken as 5mm and gap between electromagnet and permanent magnet is taken as 5mm.

Figure 2 shows the analysis of the model to see whether the propulsion occurs in the required direction. Further parametric study has been done, to obtain maximum thrust and to establish a relationship between parameters.

The parametric study was conducted such that the gap between electromagnet (Sg) is set to a certain value then for different length of electromagnet (Sx), length of permanent magnet (Mx) is varied and force is calculated via Weighed stress tensor method. Then the values obtained are plotted using MATLAB.

![Figure 2 Electromagnetic analysis of the model using FEM software](image)

Figure 3, 4 and 5 show the front view of 3D plot of parameters permanent magnet length (Mx) along X-axis, Electromagnet Length (Sx) along Y-axis, and force acting on the permanent magnet (F) along Z-axis. In this plot, we can see that as the Volume of the magnets increases the force increases.

![Figure 3 3-D results plotted using MATLAB for Sg = 3mm](image)

![Figure 4 3-D results plotted using MATLAB for Sg = 4mm](image)

2.1 Findings of Parametric Study

The force is maximum when

- The force is maximum when the length of permanent magnet is equal to the sum of length of Electromagnet and gap between electromagnet i.e., Mx= Sx + Sg
- The force is maximum when the distance between electromagnet and permanent magnet should be minimum
- If width of the magnets is large, Force is large
- The magnetic field generated by electromagnet depends on the number of turns, dia of the wire used, voltage and current supplied etc

3. CASE STUDY

Figure 6 shows the arrangement of electromagnets and permanent magnet used for setting up the model for validation of results. In the setup Three Phase E I lamination core is used for electromagnet such that it produces opposite poles on either arm. In the above schematics we can see that the arrangement is made such that E I laminated electromagnets are placed on either side the permanent magnet so has to cause a propulsion. Note: only one set of electromagnets was used for fabrication and experimentation.

![Fig. 6 Schematics of EMP system modeled](image)

3.1 Specifications

Standard 3-phase EI-100 laminate of 0.5mm thick placed linearly for 50mm. 400 turns central winding using 18 swg copper wire. The permanent magnet of dimension 50x25x12.5 was placed in the holder, which was mounted on the linear bearing. The Fig. 7 shows the assembled setup.

Figure 7 shows the actual setup of the model used for validation. A pair of electromagnets are placed opposite to each other such that there is a free motion of...
permanent magnet between them. A gap of around 10mm was maintained between electromagnet and permanent magnet. At first, the polarity of the permanent magnet was checked. After finding the polarity of the permanent magnet, the electromagnet was connected such that the middle arm of the electromagnet produces same polarity as that of the permanent magnet face so that repulsion occurs at the middle arm. A slight angle was maintained between electromagnet so that the propulsion occurs in the required direction.

**4. VALIDATION**

**4.1 Analysis of Model using FEA Software**

FEA analysis was carried out on the above setup for force measurement.

Specifications:
- E core laminate material: M-22 Steel
- E core laminate thickness: 0.5mm
- Windings: 18swg with 400 turns
- Permanent magnet: NdFeB 37 MGOe
- Magnetic Flux: 1.2 T
- Distance between E laminate face to magnet core face = 13.25mm

Figure 8 shows the analysis of the fabricated model using FEMM Software. Here we can see the magnetic lines of force acting on the permanent magnet such that the middle arm is pushing the permanent magnet out where as the outer arm is pulling it towards it. Hence propulsion is obtained.

**4.2 Experimental Setup of Load Cell**

Load cell was mounted and force at different position along the length of the linear bearing was measured. Fig. 9 shows the position of load cell mounted for force calculation. The center of the middle arm of EM was taken as starting position.

**5. RESULTS**

Figure 10 shows the force acting on the permanent magnet at different positions measured and compared with the analytical result. In the above plot, we can see that the analytical force is almost equal to the experimental force acting on the permanent magnet.

**6. CONCLUSION AND FUTURE WORK**

EMP is without a doubt one of the most effective propulsion systems. In this paper we are just beginning to explore the concept of EMP and hence there a need for extensive research on the field. With the development of new concept, research and development has to be done for better results. We need to observe here that new concepts of EMP demands for modifications in the Propulsion vehicles as well. Otherwise, the new concepts make no sense without the modified propulsion vehicle in compatible with the concept.

From the paper, we can conclude that electromagnetic propulsion is much efficient in utilization of energy and production of thrust, required for propulsion of vehicles. The comparison of analytical and experimental values gives us the insight to the differences, which need to be considered while incorporating the design into practical applications. With much improved design strategy, much higher force can be obtained and hence can be used for
various applications where conventional propulsion system may be tiresome.

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REFERENCES


