Effect for Changing Different Parameters of Rail and Actuator Used in Electromagnetic Levitation System

P.K. Biswas, S. Banerjee

Abstract—In this paper the effect of different parameters like size of actuator and rail, current density, no of turns of coil, permeability of magnetic material, winding dimension etc. has been studied.An FEM analysis of U-I structure of rail (guide-way) and actuator for electromagnetic levitation system has been performed by the utilizing of the ANSYS software. The design of electromagnets is primarily controlled by the input power to lift power ratio and lift power magnet weight ratio. These factors are dependent on the magnet dimensions, required gap flux and hence the required current density in the winding. The magnet configurations chosen on the basis of required pole-face area and necessary window area to house the excitation coils. In this work a FEM based analysis has done to find out the flux pattern, working flux density, field intensity, force etc. for single actuator based levitation system. The changing of different parameters of rail and actuator the flux pattern, working flux density, field intensity and force will change.

Index Terms—Electromagnetic Levitation, FEM analysis, eddy current effect, ANSYS software.

I. INTRODUCTION

Magnetic levitation trains are becoming a popular transportation topic all round the globe. Currently MAGLEV trains have been created in Germany and Japan for test runs only. Some other applications of electro-magnetic levitation, apart from the application in frictionless bearings and MAGLEV vehicles, are in the fields of levitation of models in a wind tunnel, vibration isolation of sensitive machinery, levitation of molten metal in induction furnaces, levitation of metal slabs during manufacture etc. There are different categories of magnetic levitation in which research and development efforts are being made. Based on the basic principle, magnetic levitation may broadly be classified into two types, electrodynamics levitation and electromagnetic levitation. The electrodynamics system actuates through repulsive forces. Most of such systems utilize superconducting magnets to generate the forces. One of the main constraints of the superconducting repulsion principle is that it cannot provide suspension force below some critical speed. The electrodynamics levitation system is inherently stable, but at high speed it possess stability problem due to negative damping. So some kind of passive damper is required in elctrodynamically levitated vehicle to maintain stability at high speed. In electromagnetic system, the levitation is produced due to the attractive force between electromagnets and ferromagnetic object. In electromagnetic levitation (attraction system), the electromagnets are driven either by AC or DC source. Although several experimental systems using AC sources have been built, these methods are considered to be suited for applications where mass of the suspended object is small. The severe constraints imposed by eddy current losses in the magnet and the rather complex control circuitry for power modulation makes the AC method of stabilization inappropriate for heavy payloads. In contrast, the explicit Dc method, technically known as the electromagnetic levitation system (EMLS), has a considerably simpler configuration with favorable power requirement. In DC EMLS, the current as well as the attraction force of the electromagnet can be effectively controlled by utilizing a switched mode power amplifier. Based on the basic principle, magnetic levitation may broadly be classified into two types, electrodynamics levitation and electromagnetic levitation. The electrodynamics system actuates through repulsive forces. In electromagnetic system, the levitation is produced due to the attractive force between electromagnets and ferromagnetic objects. The suspension of objects with no visible means of support is termed as levitation. Overcoming the effect of gravity has been a dream for generation of thinkers. Modern applications of levitation in equipments like magnetic bearings and magnetically levitated vehicles have given renewed impetus to research efforts in the direction of electromagnetic levitation. Advances in control electronics and superconducting materials have also contributed to further research in the area of electromagnetic levitation. The electromagnet (actuator) and guide-way (rail) combination along with associated closed loop control will make an EMLS. In the Fig.1 the electromagnet is made to remain suspended under the fixed ferromagnetic guide-way. This configuration is normally used in electromagnetically levitated vehicle and maglev train. The electromagnet acts as an 'actuator' which provides the basic suspension force. When the electric current is passed through a wire wrapped around a core of ferromagnetic material, magnetic

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***** Correspondence Author (s)
Pabitra Kumar Biswas*, Department of Electrical Engineering, Asansol Engg. College, Asansol-713305, West Bengal, India. Phone no. +91-9749148157, (Email: pabitra.biswas2009@gmail.com),
Subrata Bannerjee, Department of Electrical Engineering, National Institute of Technology Durgapur713209, WB, India. Phone no. +91-9434475974, (Email:bansub2004@rediffmail.com).

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flux is generated. This flux produces an attractive force on any nearby ferromagnetic material. Some important parameters like air gap flux, magnet dimension, winding arrangement, and current density in the winding dictates the above two factors.

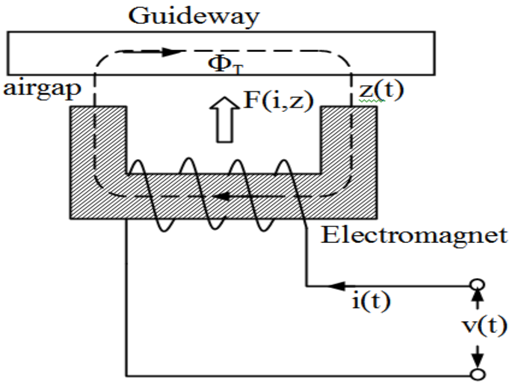

Figure.1: Simplified diagram of DC electromagnetic levitation system

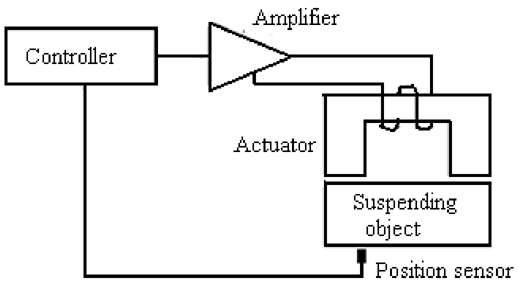

Figure 2: Basic block diagram of DC Electromagnetic levitation system

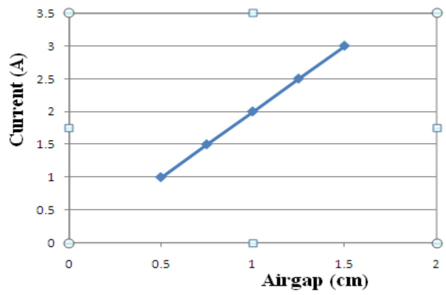

Figure.3 Current vs. Air gap for levitation system

EMLS requires two necessary subsystems: (i) a primary system for generating the magnetic field and (ii) a system for shaping or trapping the magnetic flux [6, 1]. In case of DC electromagnetic levitation, electric current in a wire wound coil produces the primary field while the ferromagnetic object or guide-way creates a means of shaping the magnetic flux. Generally the electromagnet is kept fixed and the ferromagnetic object is made to remain suspended under the magnet as shown in Fig.1. Alternatively, the scheme is just inverted and the electromagnet is part of the levitated object under a fixed ferromagnetic guide-way (Figure.1). The electromagnet (actuator) and guide-way (rail) combination along with associated closed loop control will make an EMLS (Figure.2). The electromagnet acts as an 'actuator' which provides the basic suspension force. When the electric current is passed through a wire wrapped around a core of ferromagnetic material, magnetic flux is generated. This flux produces an attractive force on any nearby ferromagnetic material. Assuming idle condition, the magnetic force produced by the coil shown in Fig.1 can be written as [1, 2].

$$F(i,z) = \frac{\mu_0 N^2 A}{4}\left[\frac{i(t)}{z(t)}\right]^2 \qquad (1)$$

Where, N= No of turns of the coil, A= Magnet pole-face area, i(t)= Instantaneous current through the coil, z(t)= Distance between the pole-face of the magnet and ferromagnetic object.

The two factors (i) input power to lift power ratio and (ii) lift power to magnet weight ratio greatly influences the design of actuator for a DC EMLS. Some important parameters like air-gap flux, magnet dimension, winding arrangement, and current density in the winding dictates the above two factors. The magnet configuration is selected on the basis of required pole face area and the necessary window area to house the excitation coils [1, 7]. This eddy current will reduce the lift force. Laminated core structure is a better option as far as eddy current losses and faster response time of the magnet are concerned [4, 5]. Another important variable that will have a direct effect on the dynamic characteristics of EMLS is the time-constant of the magnet-coil. The inductance of the coil under some simplifying assumptions is given by the equation (2).

$$L(z) = \frac{\mu_0 N^2 A}{2z(t)} \qquad (2)$$

From the equation (2) it is clear that selecting small number of turns, smaller pole face area and larger air-gap between magnet pole-face and guide-way can reduce the magnet electrical time constant but all these factors simultaneously will reduce the lift force [1,2]. So there should be a compromise between dynamic characteristics and lift-force of the actuator while selecting all the above parameters.

II. Simulation of U-I Type Structure Using ANSYS-Software

ANSYS is an engineering simulation software provider founded by software engineer John Swanson. It develops general-purpose finite element analysis and computational fluid dynamics software. There are so many different finite element methods are used for analyses the in above six structures. In this paper ANSYS is used for analysis purpose of different structure While ANSYS has developed a range of computer-aided engineering (CAE) products, it is perhaps best known for its ANSYS Mechanical and ANSYS Multiphysics products. The ANSYS program has many finite-element analysis capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis. Electromagnetic simulation from ANSYS provides industry leading analysis tools that enable the accurate simulation of electromagnetic fields. ANSYS electromagnetic solutions enable engineers and designers to accurately predict the behavior of electrical and electromechanical devices. The ANSYS electromagnetic product suite contains both

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general purpose and application specific products to address a broad array of industry applications, different engineering disciplines. ANSYS Mechanical and ANSYS Multiphysics software are non exportable analysis tools incorporating pre-processing (geometry creation, meshing), solver and post-processing modules in a graphical user interface. These are general-purpose finite element modeling packages for numerically solving mechanical problems, including static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems.ANSYS Mechanical technology incorporates both structural and material non - linearity's. ANSYS Multi physics software includes solvers for thermal, structural, CFD, electromagnetic, and acoustics and can sometimes couple these separate physics together in order to address multidisciplinary.

For the analysis of above structure we can define as four materials properties. These are given below

1. **Armature or rail**: It is the moving component of the actuator. It's taken as upper or lower side of the back iron. Moving this flat rail the air-gap between rail and back iron will change i.e. the flux, force and field will change.

2. **Back iron:** It is the stationary iron component of the actuator that completes the magnetic circuit around the coil.

3. **Coil:** It is a stranded, wound coil supplying a predefined current. These coils are placed in either upper two limbs of back iron.

4. **Air-gap:** It is the thin rectangular region of air between the armature and pole face of the back iron. The air-gap value for all case varying from 5 mm to 20 mm.

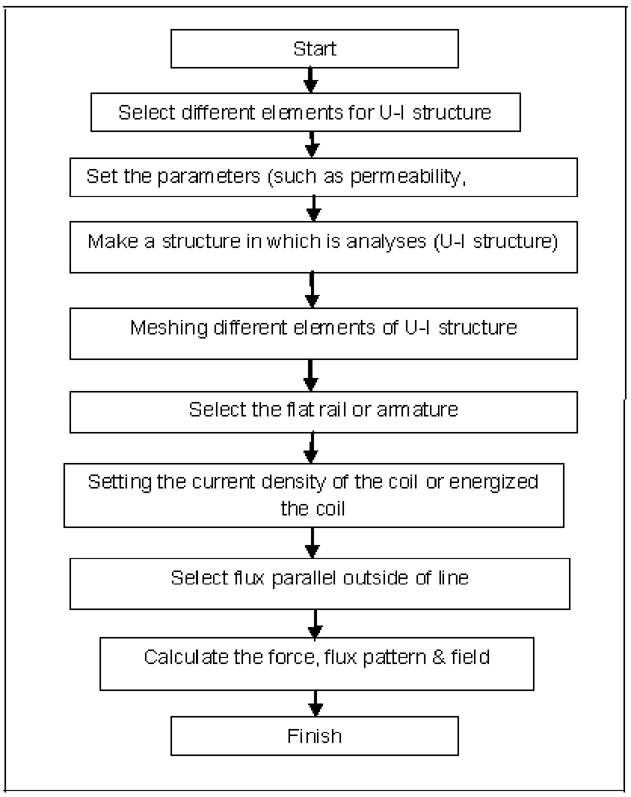

Figure.4. Flow chart of calculation of force, flux & field by using ANSYS software for U-I structure.

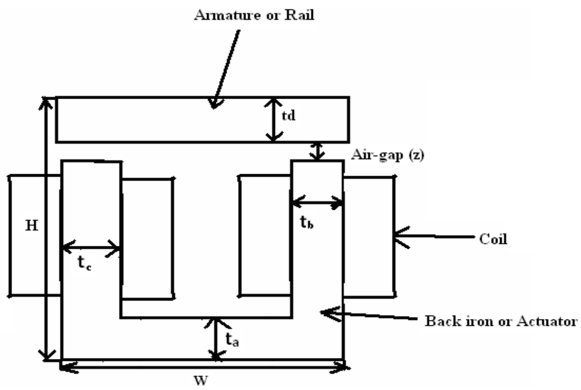

Figure.5. Basic Diagram of U-I Structure

III. ANSYS SIMULATION RESULTS AND DISCUSSIONS

Two-dimensional FEM simulation has been carried out to determine flux pattern, working flux density, field intensity, force etc. in the actuator and guide-way. Commercial FEM software ANSYS has been used for this purpose.

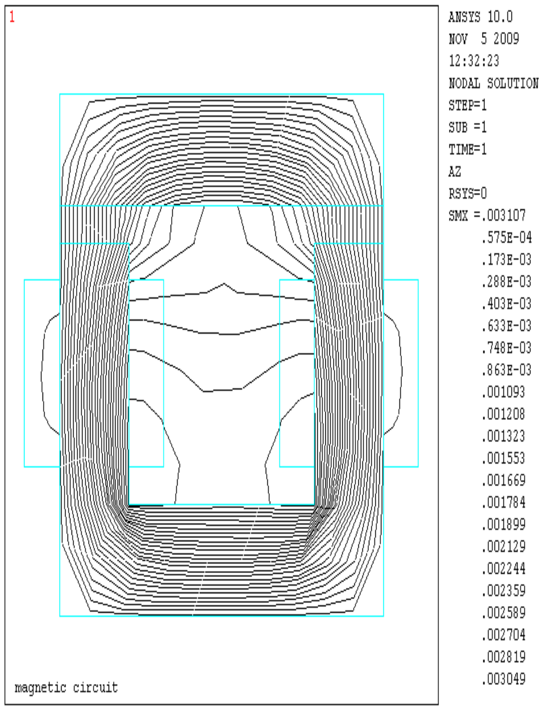

Figure.6. Flux pattern for U-I structure where N=500 and z=1 cm

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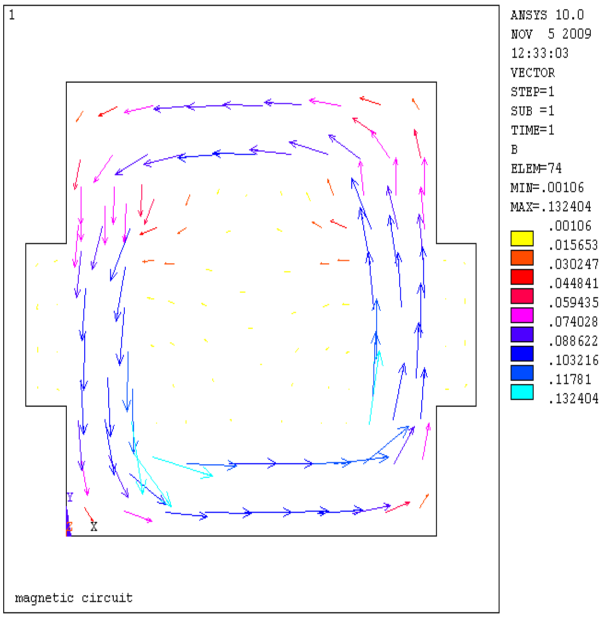

Figure.7. Flux density for U-I structure where N=500 and z=1 cm

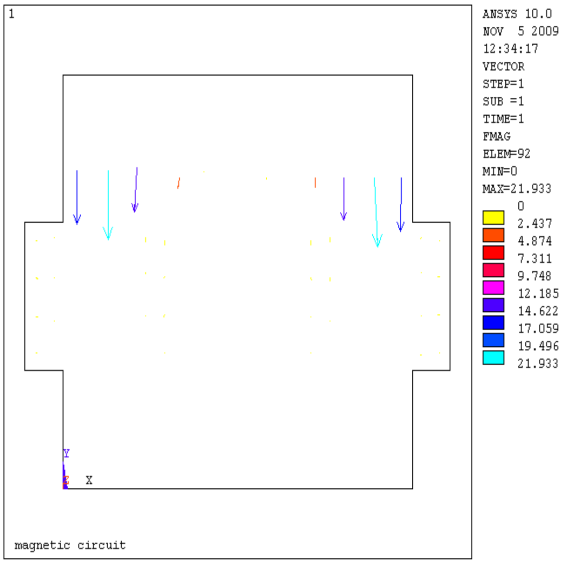

Figure.8. Force for U-I structure where N=500 and z=1 cm

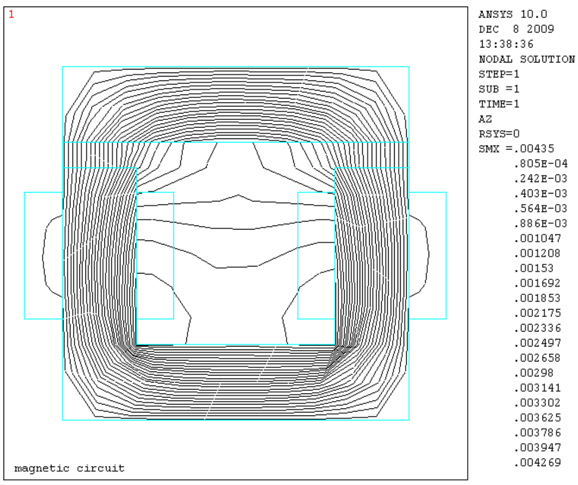

Figure.9. Flux pattern for U-I structure where N=700 and z=1 cm

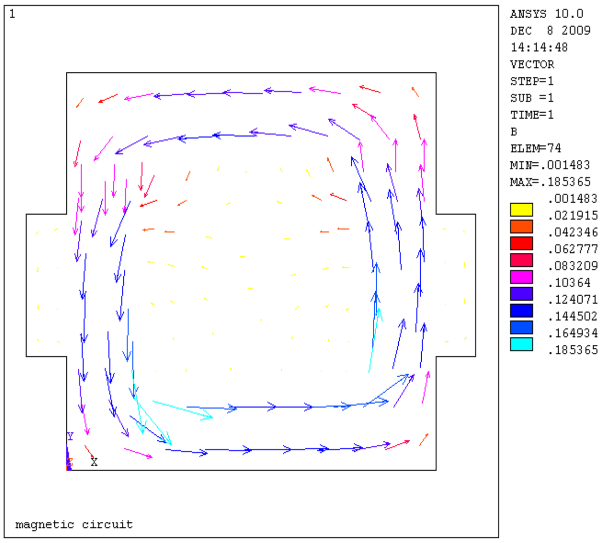

Figure.10. Flux density for U-I structure where N=700 and z=1 cm

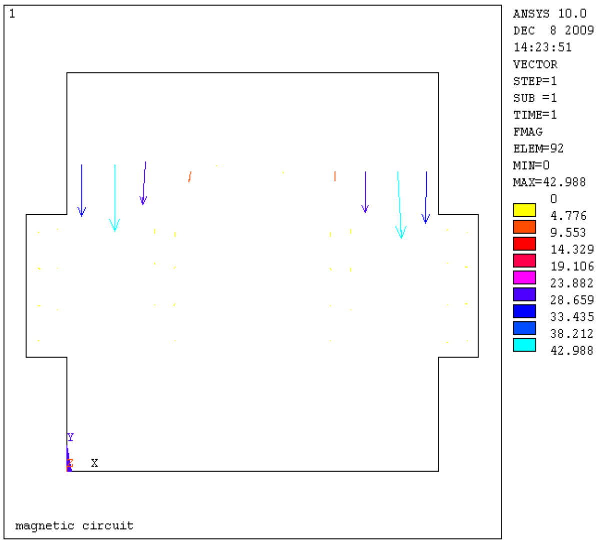

Figure.11. Force for U-I structure where N=700 and z=1 cm

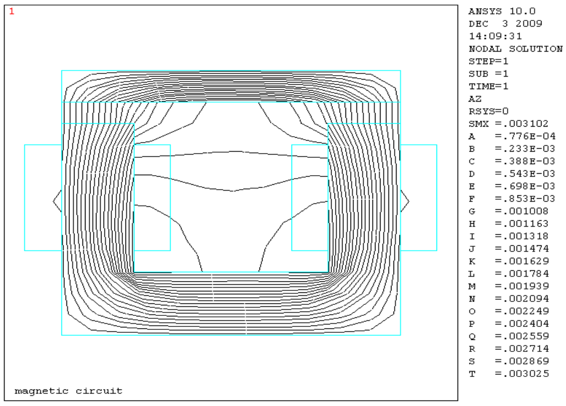

Figure.12. Flux pattern for U-I structure where rail thickness (td= 1.5 cm) and z=1 cm

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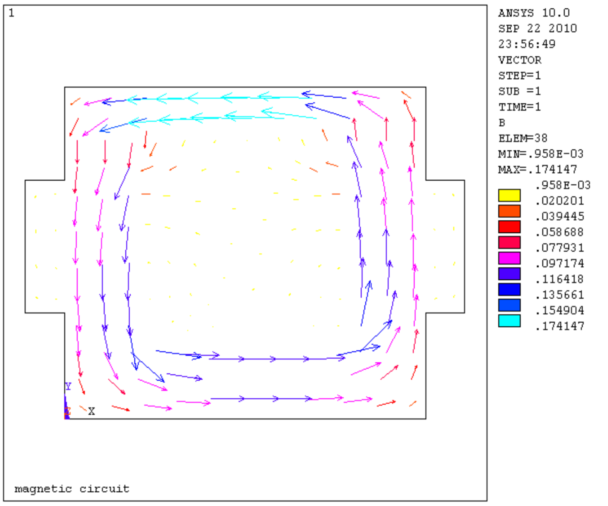

Figure.13. Flux density for U-I structure where rail thickness (td= 1.5 cm) and z=1 cm

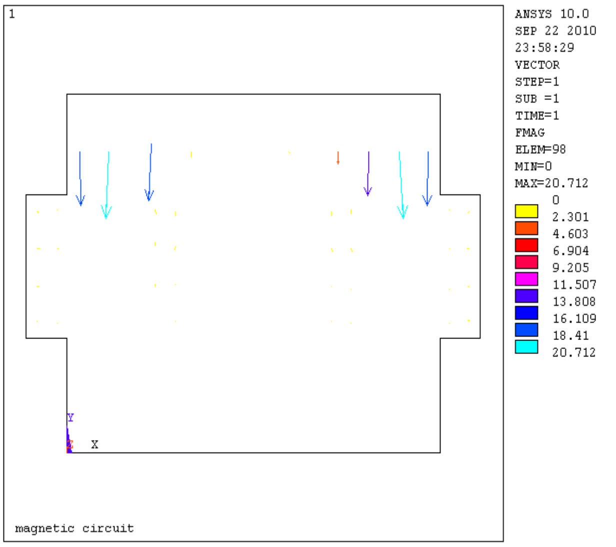

Figure.14. Force for U-I structure where rail thickness (td= 1.5 cm) and z=1 cm

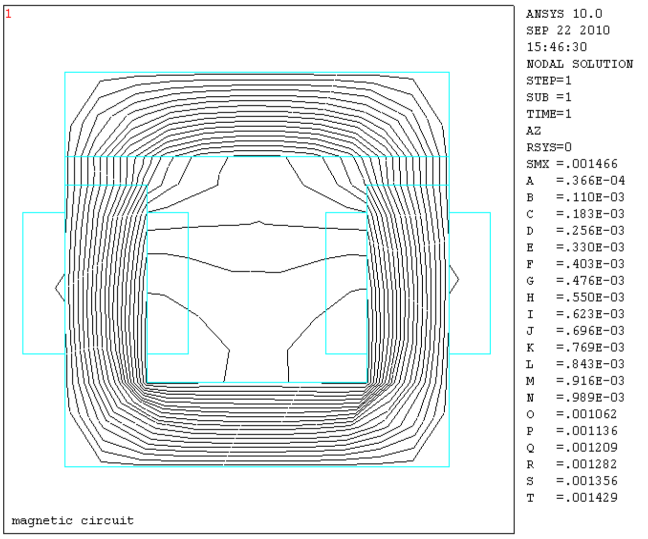

Figure.15. Flux pattern for U-I structure where i= 2A and z=1 cm

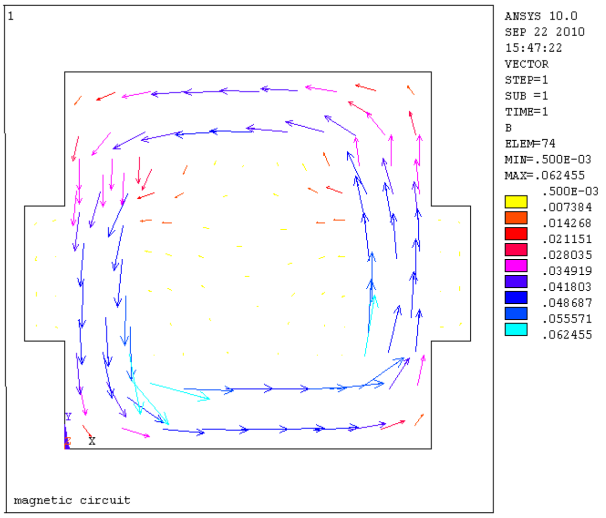

Figure.16. Flux density for U-I structure where i= 2A and z=1 cm

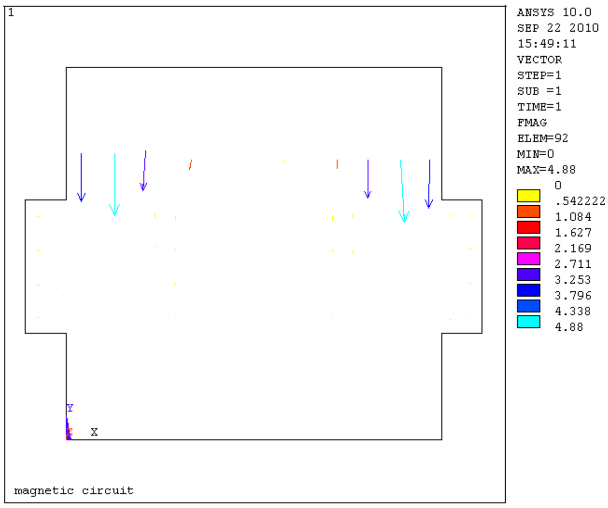

Figure.17. Force for U-I structure where i= 2A and z=1 cm

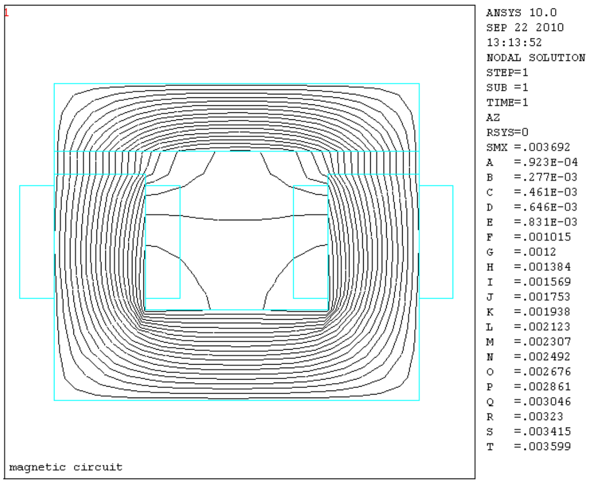

Figure.18. Flux pattern for U-I structure where back iron thickness (ta=tb=tc=4cm) and z=1 cm

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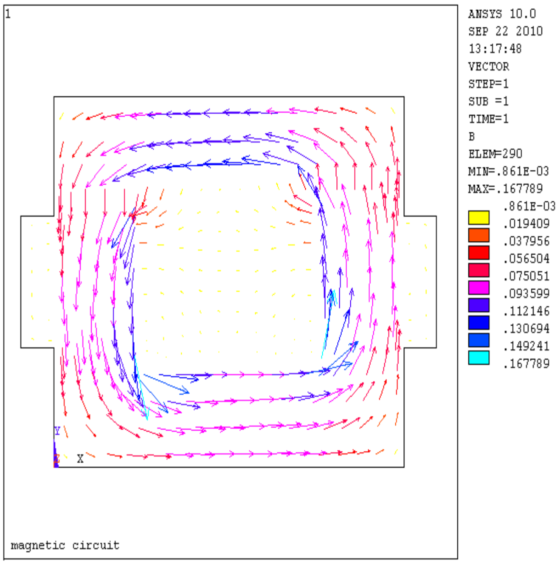

Figure.19. Flux density for U-I structure where back iron thickness (ta=tb=tc=4cm) and z=1 cm

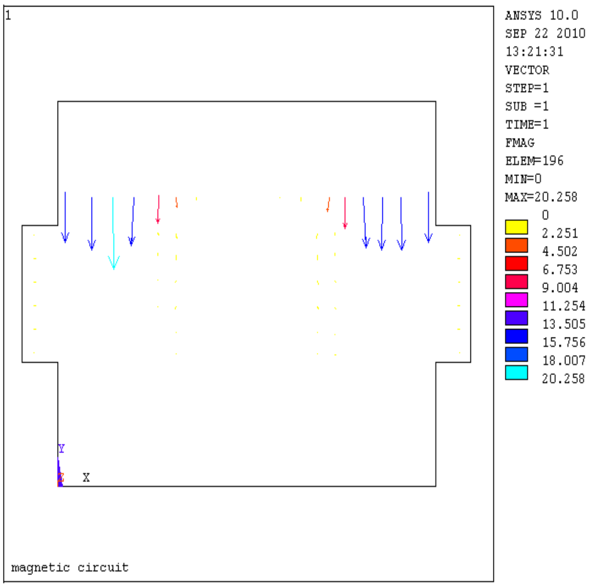

Figure.20. Force for U-I structure where back iron thickness (ta=tb=tc=4cm) and z=1 cm

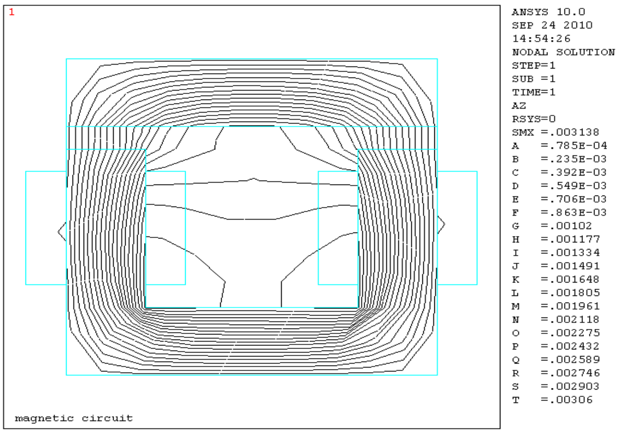

Figure.21. Flux pattern for U-I structure where Relative permeability (μr=2000) and z=1 cm

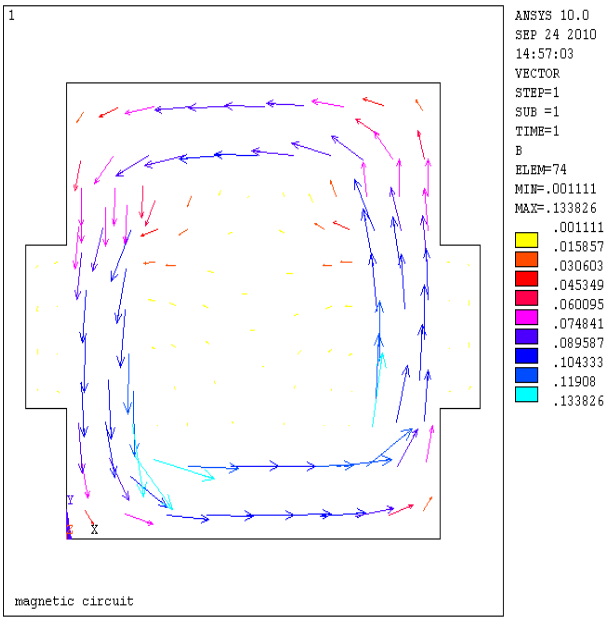

Figure.22. Flux density for U-I structure where Relative permeability (μr=2000) and z=1 cm

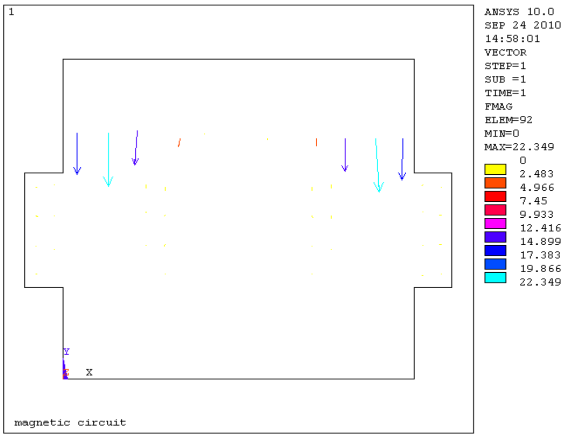

Figure.23. Field intensity for U-I structure where Relative permeability (μr=2000) and z=1 cm

From Figure.6 to Figure.11 represents flux, flux density, and force and field intensity Annoys simulation plot for different number of turns of coil. It has been noticed from Figure.5 and Figure.8 that the generated flux of the actuator increase with the increase of air-gap between the pole-face of electromagnet and guide-rail and the flux increases with the increase of number of turns of coil. It has been observed from Figure.15 that the flux decreases with the decrease of current through the coil where air-gap is taken same. With the increase of air-gap leakage flux is increased and the flux linkage between magnet and guide-way is decreased. The force of the actuator decreases with the increase of air-gap between the pole-face of electromagnet and guide-rail and the force increases with the increase of current of the coil. Force mainly depends on current flows through the coil and air-gap between actuator and rail.

From Figure.28 and Figure.29 represents the 3-D curve for flux, flux density, and force

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and field intensity curve for different number of turns of coil. By varying number of turns of coils (N) of U-I structure, the flux, flux density, force and field intensity will varying with air-gap. By increasing number of turns of coils (N) the flux will increase. Hence, flux is increasing by increase of number of turns of coil, so the flux density also increase. The flux density is decreased with the increase of air-gap between U-type electromagnet and I-type armature. The force is inversely proportional to the square of air-gap and directly proportional to the square of number of turns of the coil. The force is increased with the increase of number of turns of the coil. The force is decreased with the increase of air-gap between U-type electromagnet and I-type armature. From above observation we can say that the field intensity is increased with increase of number of turns of the coil. From Figure.26 and Figure.27 represent 3-D curve for flux, force, and flux density of U-I structure for same air-gap. The generated flux of the actuator increases with the increase of current through the coil and the flux density increases with the increase of current of the coil. With the increase of air-gap leakage flux is increased and the flux linkage between magnet and guide-way is decreased. The force also increased with the increase of current through the coil. From Figure.12 to Figure.14 are represents Ansys simulation plot for flux, flux density and force for the different thickness of flat rail and Figure.29 and Figure.31 are represents 3-D curve for flux, force, flux density and field intensity curve for different dimension of flat rail. For changing the different thickness of armature of the U-I structure, the value of flux will change very small value. The armature or rail thickness (td) is varied from 1.5 cm to 4 cm. It has been notice from Figure.5 and Figure.11 that the flux is increased with increase the thickness of armature (td) of the U-I structure. Due to the effective area of the U-I structure is increased with the increase of the thickness of armature and air-gap. It has been observed from Figure.31 the flux density is increased with the decrease of the thickness of armature and air-gap of the U-I structure. At td=1.5 cm, the flux density is more than other structures. From Figure.15 to Figure.17 are represents Annoys simulation plot for flux, flux density and force for the different current through the coil for different air-gar of the U-I structure and Figure.24 and Figure.25 are represents 3-D curve for flux, force, flux density and field intensity curve for the different current through the coil for different air-gar of the U-I structure. It has been observed from Figure.24 and Figure.25 that the flux, flux density and force increase with the increase of current through the coil for different air gap. From Figure.18 to Figure.20 are represents Annoys simulation plot for flux, flux density and force for the different thickness of back iron (ta, tb and tc) of the U-I structure and Figure.32 is represents 3-D curve for flux and force curve for the different thickness of back iron (ta,tb and tc) of the U-I structure. It has been noticed from Figure.32 that the generated flux decreases with the increase of air-gap between electromagnet and guide-rail and the flux increases with the increase of thickness of back iron (ta,tb and tc). From Figure.21 to Figure.23 are represents Annoys simulation plot for flux, flux density and force for the different relative permeability of back iron of the U-I structure and Figure.33 and Figure.34 is represents 3-D curve for flux, force, flux density and field intensity curve for the different t relative permeability of the back-iron or actuator with same air-gar of the U-I structure. It has been observed from Figure.33 that the generated flux and force increase with the increase of relative permeability of back iron or actuator. The flux density also increases with the increase of relative permeability of back iron or actuator.

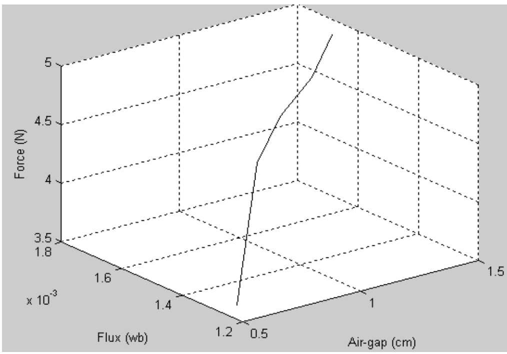

Figure.24. Force, Flux vs. air-gap for U-I structure for different air-gap and different current.

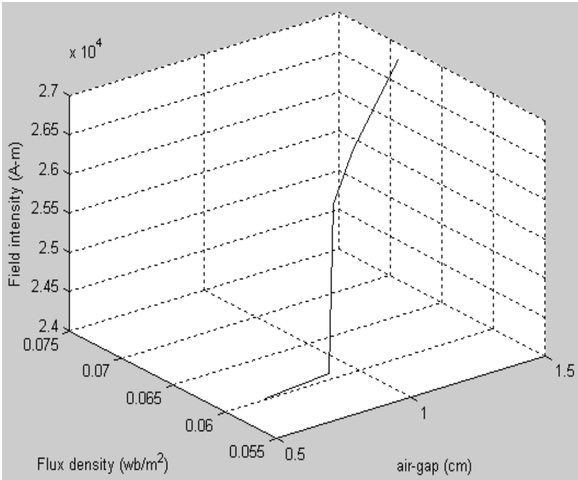

Figure.25. Flux density, Field intensity vs. air-gap for U-I structure for different air-gap and different current.

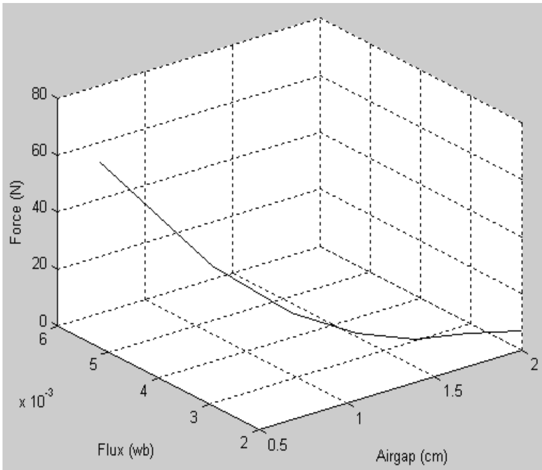

Figure.26. Flux, Force vs. air-gap for U-I structure for different air-gap and same current.

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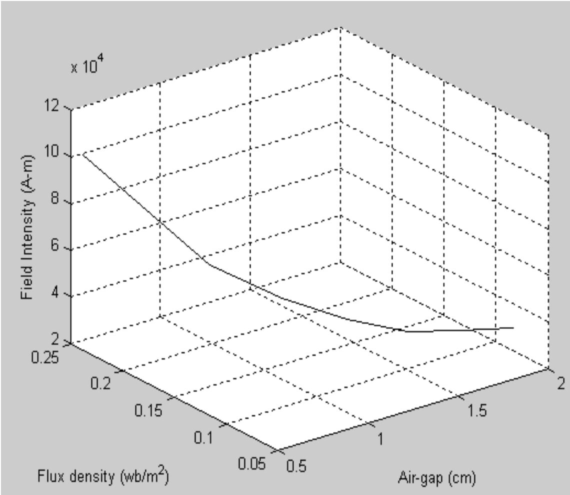

Figure.27. Flux density, Field intensity vs. air-gap for U-I structure for different air-gap and same current.

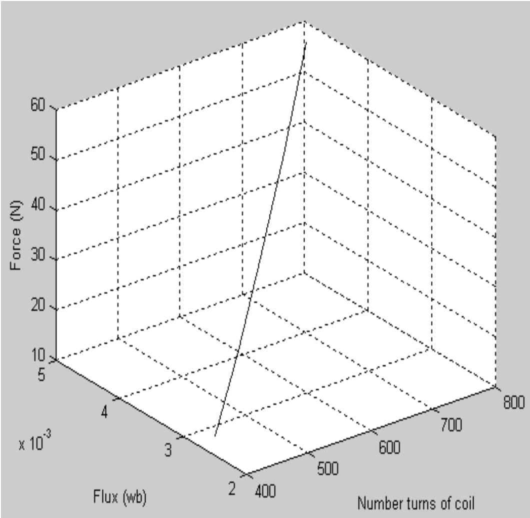

Figure.28. Flux, Force vs. Number of turns of coil for U-I structure for same air-gap (z=1 cm)

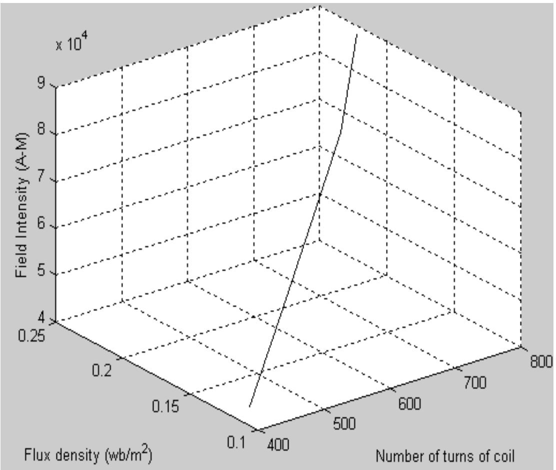

Figure.29. Flux density, Field intensity vs. Number of turns of coil for U-I structure for same air-gap (z=1 cm)

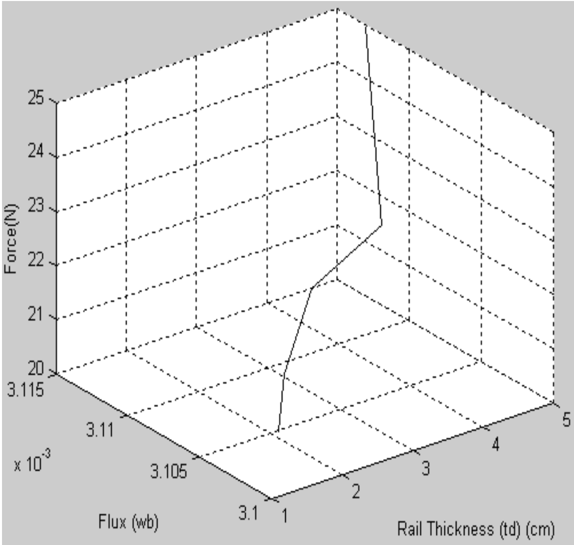

Figure.30. Flux, Force vs. Rail thickness (td) for U-I structure for same air-gap (z=1 cm)

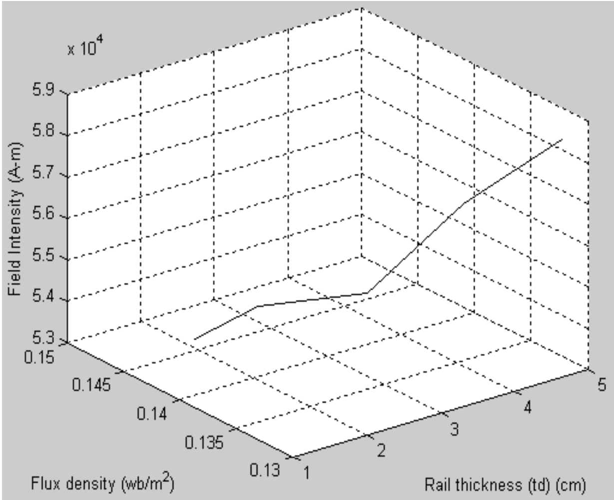

Figure.31. Flux density, Field intensity vs. Rail thickness (td) for U-I structure for same air-gap (z=1 cm)

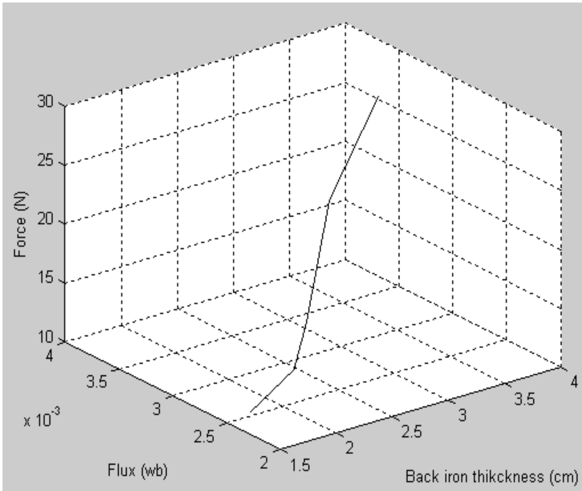

Figure.32. Flux, Force vs. Back iron or Actuator thickness (ta) for U-I structure for same air-gap (z=1 cm)

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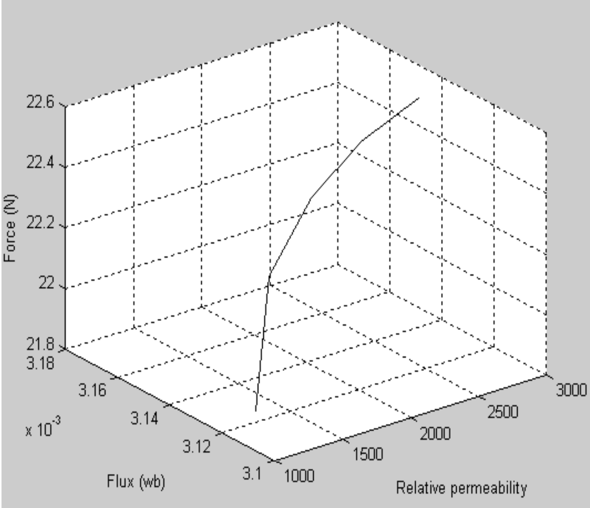

Figure.33. Flux, Force vs. Relative permeability for U-I structure (where two coil are connected upper two limb) for same air-gap (z=1 cm)

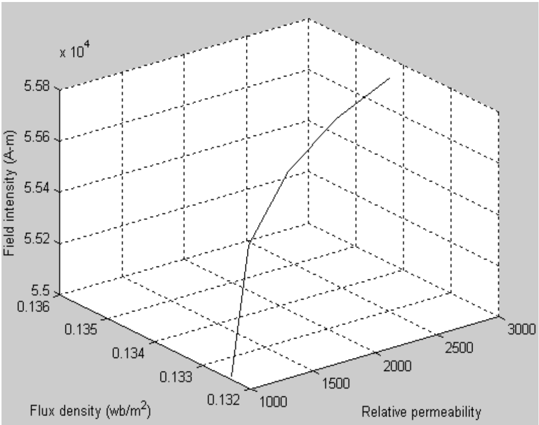

Figure.34. Flux density, Field intensity vs. Relative permeability for U-I structure for same air-gap (z=1 cm)

IV. CONCLUSION

The effect of change of different parameters like size of actuator and rail, current density, no of turns of coil, permeability of magnetic material, winding dimension etc. has been studied. A two dimensional FEM analysis has been carried out utilizing ANSYS software. 3-D curve for Flux, Flux density and Force for U-I structure has been presented. ANSYS simulation plots of flux pattern, vector plot of flux density and force has been presented. The simulated results of flux, flux density and force are determined by FEM-based analysis using the Maxwell's stress tensor and virtual work.

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Pabitra Kumar Biswas completed B.Tech from WBUT, India. He received his ME. Degree from Bengal Engineering and Science University, Shibpur, Howrah, West Bengal, India. He is presently perusing PhD. Programmed under external registration at the department of Electrical Engineering, NIT, Durgapur, India. He is presently working as a Assistant professor in electrical engineering in Asansol Engineeng College, Asansol, India. He has total experience four years in teaching. His research interests include Electromagnetic Levitation and Power electronics & Drives. Email:pabitra.biswas2009@gmail.com

Subrata Banerjee was born in 1968. He received B.E. (Electrical) in 1989, M.E. (Electrical Machines) in 1994 and Ph.D in Electrical Engineering from Indian Institute of Technology, Kharagpur in the year 2005. He is presently working as an associate professor in electrical engineering in national institute of technology, Durgapur, India. He has published a numbers of research papers in National/International Conference Records/Journals. His research interest includes Control Systems, Electrical Machnies and Power Electronics. He is a life member of Systems Society of India, Institute of Engineers (India) and member of IEEE (USA). His Biographical inclusion is in Marquis Who's Who 2007 and IBC FOREMOST Engineers of world-2008. He has worked many research and consultancy projects. Dr. Banerjee has received some academic awards and has visited different countries in IEEE conferences and seminars.
Email: bansub2004@rediffmail.com