DEVELOPMENT OF A COMPUTER ASSISTED LEARNING ENVIRONMENT OF ELECTROMAGNETICS AT THE UNDERGRADUATE LEVEL

S.C.Mukhopadhyay, D.N.Pinder , S.D. Karunanayaka

ABSTRACT

Conventional teaching of electromagnetics, based on lectures, static written materials, laboratories etc. has become rather difficult recently at all levels of education. The main objective of this paper is the development of computer assisted education material that teaches the theory and practical aspects of electromagnetics. The development described in this project has allowed us to teach the new paper in electromagnetics in a new and effective way, which help our students to master a difficult subject.

INTRODUCTION

The course 143.352, *Electromagnetics* offered by the Institute of Information Sciences and Technology (I.I.S.T) and the course 143.328 *Applied Electromagnetics* offered for the Physics specialisation under the Institute of Fundamental Sciences (I.F.S) of Massey University, New Zealand have been combined together and taught as a core subject for the 3rd year students. It was adopted as a core subject for the Information Engineering students from the academic year 2002. At many other places the course, *Electromagnetics* is taught in a standard lecture format using textbooks such as refs. [Ulaby, 2001; Kraus, 1992; Popovic and Popovic, 2000; Inan and Inan, 1999]. The authors have found that such courses are seldom popular because the many concepts taught in the course require the students to be able to think in abstract three or sometimes even in four dimensional spaces. Many students lacking this natural ability find this subject difficult and as a result uninteresting. *Electromagnetics* is a laboratory based subject and our course has a two hour laboratory class scheduled each week together with 3 hours of lectures and a one hour tutorial class. Electromagnetics theory is a key to understanding and modeling antenna and radio frequency propagation. The conventional teaching of electromagnetics, based on lectures, static written materials, laboratories etc. has become rather difficult recently at all levels of education. The main objective of this paper is the development of computer assisted education material that teaches the theory and practical aspects of electromagnetics. The development described in this project has allowed us to teach our new paper in Electromagnetics in an innovative and effective way.

Since *Electromagnetics*, contains many equations (Maxwell's equations and constitutive relations) it is very difficult to explain the subject without readily available graphic visualization [Trueman, 1999]. Moreover, providing the necessary laboratory facilities and equipment would present a heavy financial burden to the university. So we have started to explore other options, namely the development of computer assisted teaching and a computer based flexible interactive environment providing virtual experiments. We believe excellence in teaching can be achieved by developing this innovative way of

teaching the laboratory material through a computer based flexible interactive environment of virtual experiments.

We expect the outcomes of this project to be;

a) Enhanced student learning.
b) Saving of the considerable cost of setting-up a real electromagnetic laboratory and the running cost of that laboratory.
c) Provision of a powerful numerical analysis facility that can be used by both undergraduate and post graduate students engaged in project work.

The computer software such as PowerPoint [Microsoft, 1983-1997], Matlab [Math Works, 1984-2000], FEMLAB [COMSOL, 1984-2001] (a finite element package), Mathcad, etc. are used along with the computer and data projector for teaching. Since our aim is to provide an integrated learning system a description of each and every module is provided here.

SCHEDULE OF LEARNING

The subject *Electromagnetics* at Massey University, New Zealand is a single semester course taught in the second semester starting from mid-July and continuing till the middle of November. The semester spans a thirteen week period, so there are effectively 39 hours of lecture, 13 hours of tutorials and 13 two hour laboratory classes available. About half of the laboratory classes are spent on student projects the remaining classes are devoted to traditional experiments.

MEANS OF TEACHING

The following means of teaching have been adopted.
1) Microsoft PowerPoint (with and without animation),
2) OHP, Whiteboard and pen,
3) FEMLAB software,
4) Projects based on Matlab, FEMLAB and NEC,
5) Laboratory experiments (hands-on experimental work and report writing).

These are explained below in more detail.

Microsoft PowerPoint (with and without animation)
Many graphical visualizations and various animations can be presented using Microsoft PowerPoint which help the students to understand many complex concepts. For example Coulomb's law is explained with the help of simple representation as shown in Figs. 1 and 2. This has been designed with custom animation so that the pictorial representations appear in sequence. If the charges are free to move they will move from their initial positions to new positions depending on their polarity which is clear from Fig. 2. The magnitude of the force, the acceleration and the distance covered can be calculated. Fig. 3 illustrates the analogy between the electric and magnetic circuit using animation. Fig. 4 shows the basics of magnetic circuit analysis.
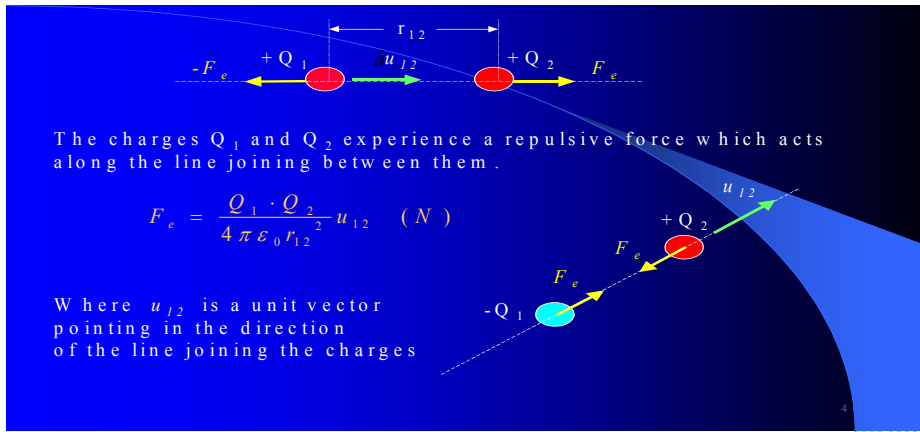
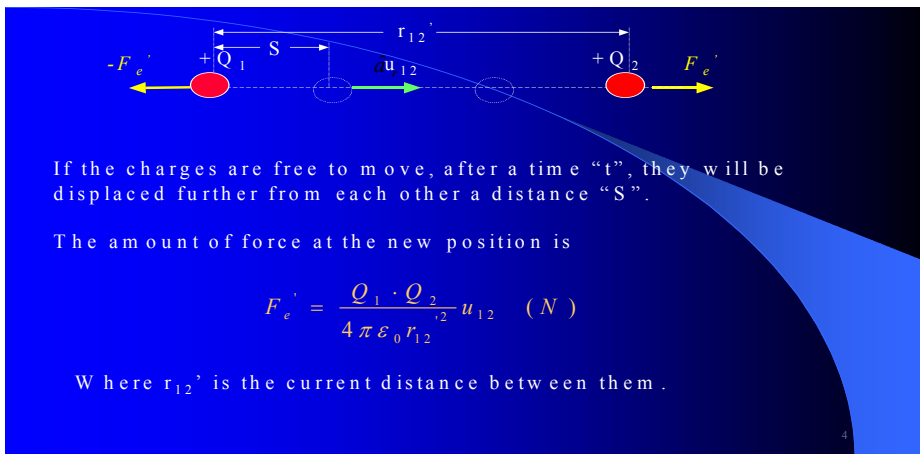Figure 1. Representation of Coulomb's law using PowerPoint, slide 1

Figure 2. Representation of Coulomb's law using PowerPoint, slide 2

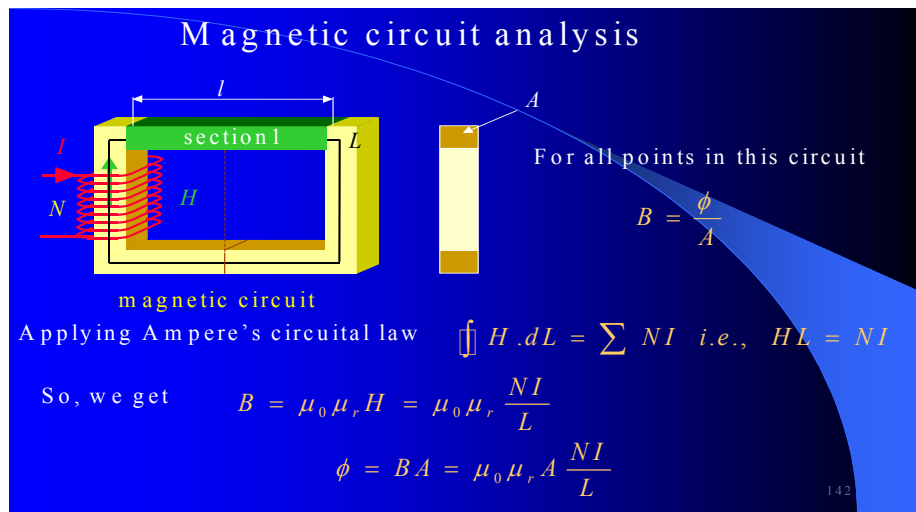Figure 3. Analogy of electric and magnetic circuit using PowerPoint

Figure 4. Explanation of magnetic circuit analysis using PowerPoint

Teaching using OHP, Whiteboard and pen

Although teaching is based on Microsoft PowerPoint presentations, sometimes it may be necessary to use OHP sheets [may be the computer fails or there is a communication problem between the computer and the data projector or the data projector malfunctions]. Back-up copies of OHP sheets have been kept. Since it is difficult for students to grasp the content of an OHP sheet full of mathematics, the mathematical part is explained using a whiteboard and pen to allow the students to follow the mathematical development and maintain their interest. A sample of OHP sheet is shown in Figure 5 which shows the magnetic field distribution due to permanent magnets and the effect on the field distribution of ferromagnetic material in the vicinity of the permanent magnet [9]. This OHP sheet is part of the topic *Basics of Magnetic Field*. The magnetic field can be created either by an electromagnet or by a permanent magnet.

Teaching with FEMLAB software

FEMLAB is extremely useful for teaching Electromagnetics as it is a powerful, interactive environment for modeling and solving scientific and engineering problems. It is basically a finite element analysis software configured around MATLAB. One particular problem has been selected to show the utility of this software. In high frequency applications dealing with conducting and magnetic materials we usually come across the phenomena of "skin-depth". Visual representation of magnetic fluxlines generated from a finite element analysis is an effective way to explain skin depth to students.

If a conductive or magnetic material is placed close to a high frequency exciting source the electromagnetic wave gets progressively attenuated as it penetrates the medium and may become a negligible percentage of the incident wave at short distance from the point of launching. The effective depth of penetration, often called "skin depth" (δ) is defined as the depth at which the wave amplitude is attenuated to 1/e (approximately 37%) of its original value.

Basics of Magnetic field

The magnetic field can be due to either permanent magnet or an electromagnet. The major interest is the *magnetic field* due to current carrying conductor.
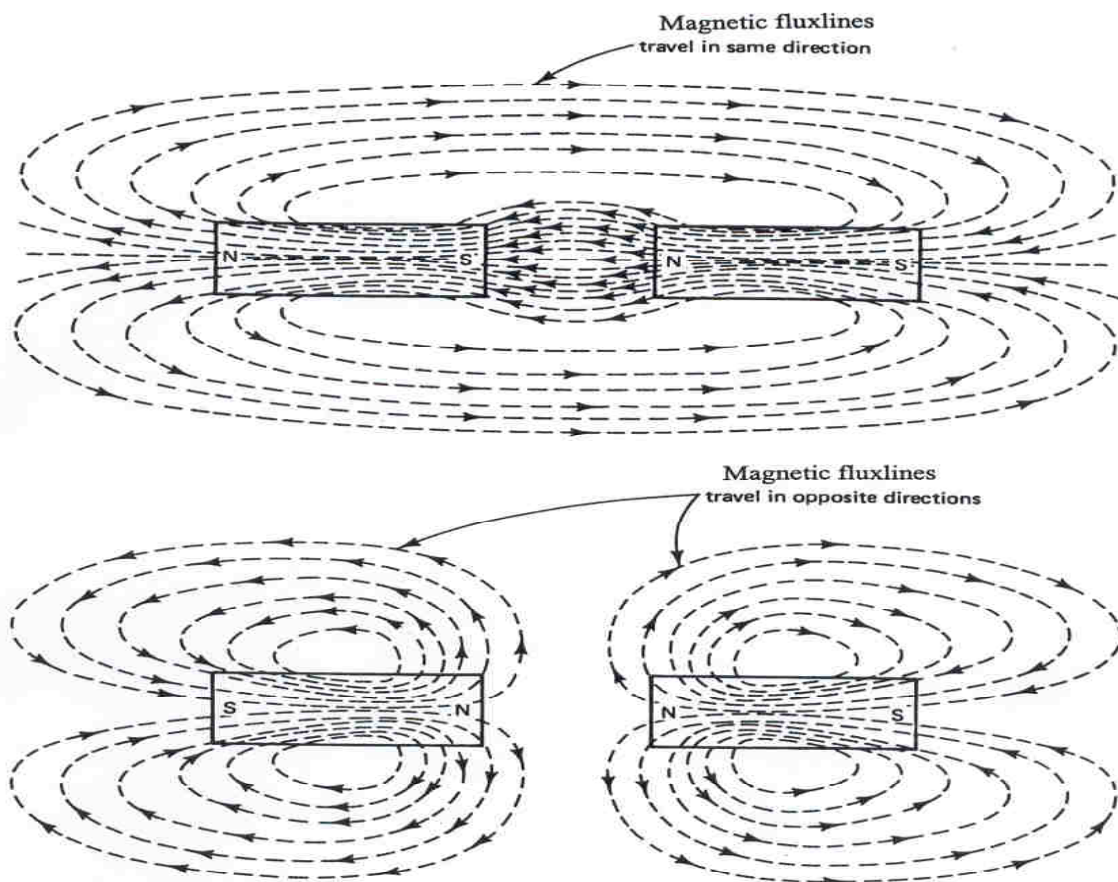
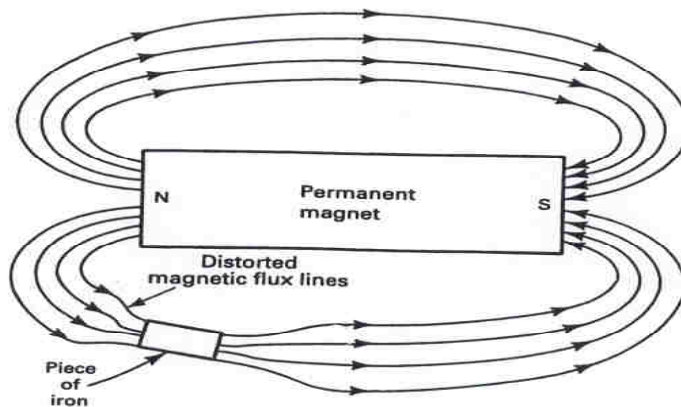Fig. 4   Magnetic flux lines when magnets are placed end to end

Figure 5. Magnetic fluxlines distorted close to a piece of iron. [A sample of OHP sheet (redrawn from ref. 9]

The expression of δ is given by

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = \sqrt{\frac{1}{\pi f \mu\sigma}}$$

The variation of skin depth with frequency for a few commonly used materials are shown in Figure 6.
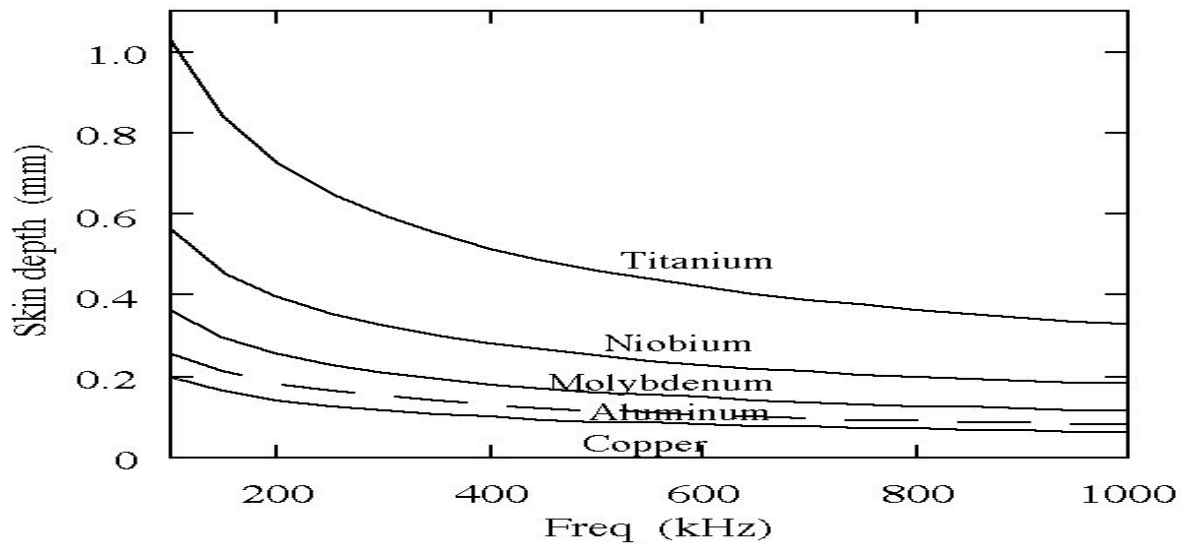
Figure 6. Variation of skin depth with exciting frequency for various metallic conductors at room temperature

A FEMLAB software model has been developed to illustrate magnetic flux penetration into a conductor. Two parallel conductors carrying equal sinusoidal currents are situated close to a 1 mm copper slab. The frequency of excitation is varied and the effect on the fluxlines is observed. Figure 7 shows that at 1 kHz the fluxlines pass right through the slab and reach the base which is made of non-conducting material. When the operating frequency is increased to 100 kHz as shown in Fig. 8, no fluxlines pass through the slab as they are restricted to the upper portion of the slab. When the frequency is increased further to 1 MHz as shown in Figure 9, the fluxlines are restricted to the upper surface of the copper slab.
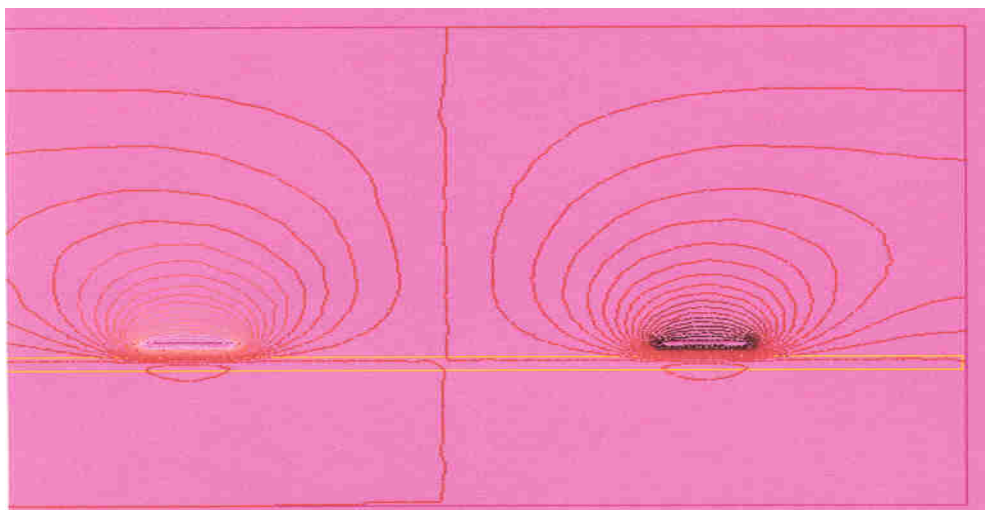

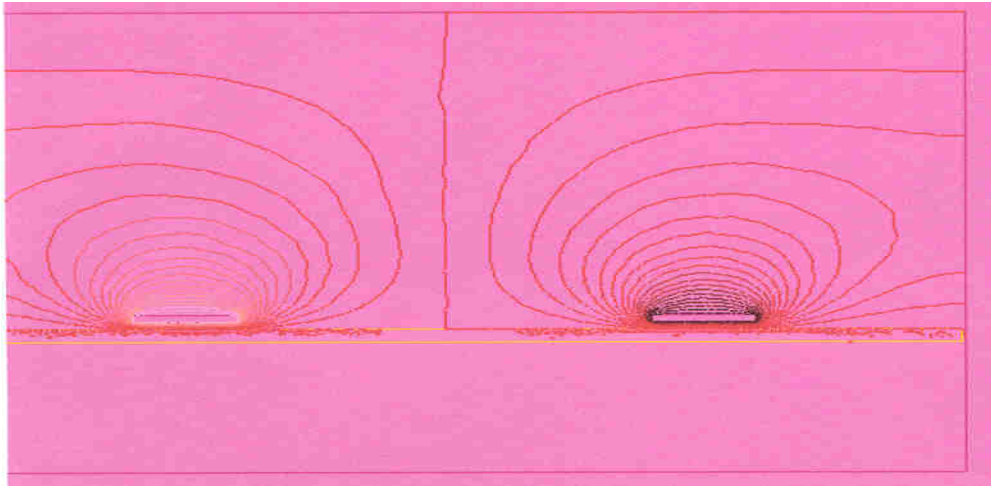Figure 7. The fluxlines at operating frequency 1 kHz

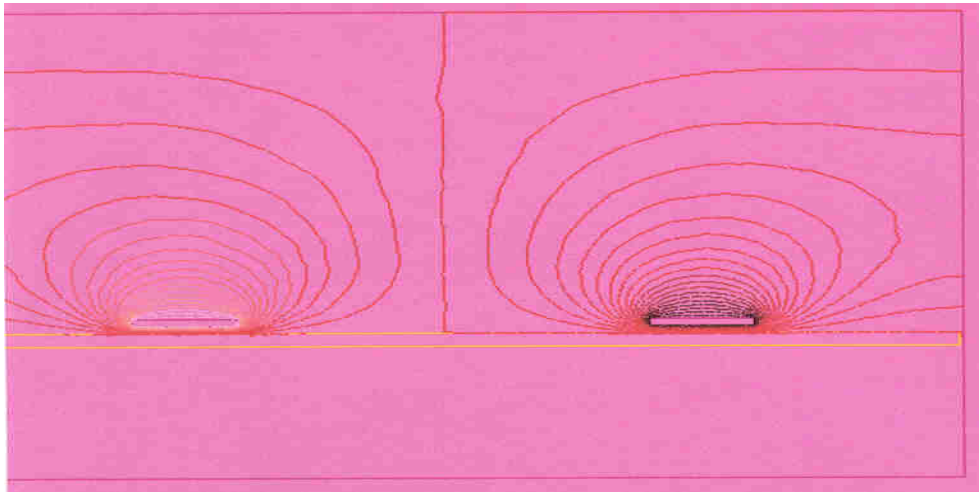Figure 8. The fluxlines at operating frequency 100 kHz

Figure 9. The fluxlines at operating frequency 1 MHz

The above figures produced by the finite element analysis present a clear description of skin depth which the students have found easy to comprehend.

Projects using Matlab and FEMLAB

The following projects have been offered to students to develop their familiarity with different kinds of electromagnetic problems and to enhance their knowledge of problem thinking and solving. They are required to use FEMLAB and Matlab to formulate and solve the problem. At the end of the course they give an oral presentation to the whole group (fellow student and staff) using PowerPoint to improve their data preparation and presentation skills. Each student also produce a written report.

*Problem***:** Force between two ring permanent magnets along X, Y and Z axes.
Outer magnet: Nd-Fe-B magnet, Outer diameter = 100 mm, , Inner diameter = 80 mm, Thickness = 15 mm, Bc = 1.1 T, Hc = 0.4 MA/m.
Inner magnet: Strontium-ferrite magnet, Outer diameter = 75 mm, Inner diameter = 60 mm, Thickness = 10 mm, Bc = 0.4 T, Hc = 0.27 MA/m.

Problem: Force between a set of 24 disc permanent magnets arranged on an aluminum disc (refer to Fig. 10).

Dimensions of 24 disc magnets: Diameter = 10 mm. Height 2 mm. Aluminum Disk 1: Outer diameter = 100 mm, Inner diameter = 90 mm. Aluminum Disk 2: Outer diameter = 95 mm, Inner diameter = 85 mm. Disks are made up of aluminum.

Problem: Force distribution due to two circular current carrying loops.
Conductor diameter = 1 m, distance = 0.25 m to 1 m, Current varied 1 A ~ 5 A, Turns = 1 ~ 5.

Problem: Field distribution due to a solenoid.
Length = 60 mm, Diameter = 40 mm, Number of turns = 90, Current 1 ~ 5 A

Problem: Field and force distribution due to Electromagnet.
An annular electromagnet: Outer diameter = 140 mm, Inner diameter = 100 mm, Depth = 40 mm, Current 1 ~ 5 A.

Problem: Impedance characteristic of a planar meander coil adjacent to different substrates.
Half pitch of the coil = 2.1 mm, Length = 14.6 mm, Periodic, 7 number of half pitches.

Problem: Analysis of permanent magnet biased saturatable core.
C-type core: Length = 50 mm, thickness = 10 mm, A permanent magnet of 1 mm thick is sandwiched between the cores. Magnet Br = 1.1 T, Hc = 0.4 MA/m, μ_m = 1.14μ_0 . Core Bc = 0.4 T, Hc = 1200 A/m, μ_u = 3000 m0, μ_s = 50 μ_0.

Problem: Analysis of super conducting fault current limiter.

Some results from students reports are presented in the following diagrams. Fig. 10 shows a schematic representation of problem 2. Most of us dealing with permanent magnets have experienced that the like poles repel each other. But if the pole strength are too weak, they will attract when they are brought very close to each other. The students calculated the forces between two sets of permanent magnets, there are four different forces among the four poles (N1, S1, S2 and N2) of the two permanent magnets.

Figure 10. Circular permanent magnets arranged in disk

Figure 11 shows the variation of repulsive force as a function of gap width between the two disks for different thickness of permanent magnet.
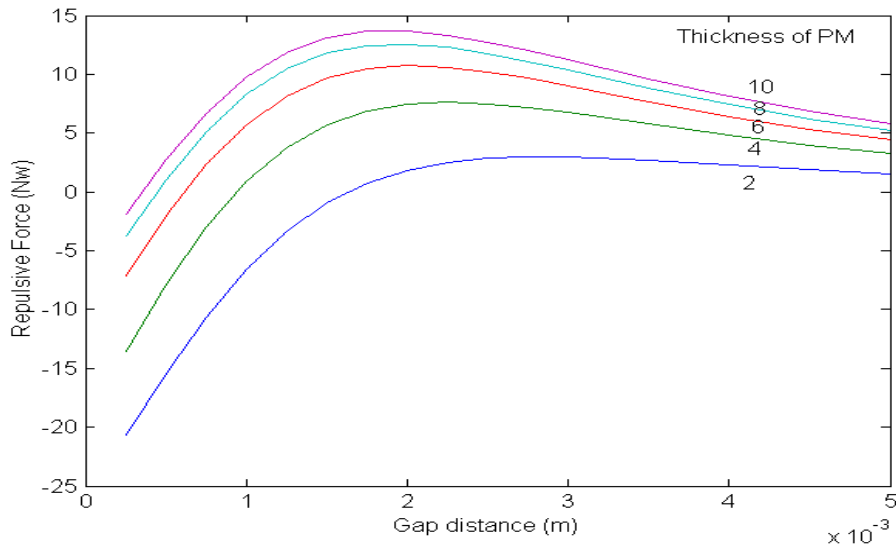
Figure 11. Variation of repulsive force with gap width

The force characteristic between two disks has been measured for a magnetic thickness of 2 mm. Figure 12 shows the measured force vs. gap width characteristic. This system has been used to develop a magnetic bearing in which the repulsive force between two sets of permanent magnets is used to levitate the rotor of a motor. A 4th year student has been working on the development of magnetic bearing, and the analytical results of this project have been useful to him. Also the 3rd year electromagnetic students have appreciated their work having application to a real practical system. The fabricated magnetic bearing scheme is shown in Figure 13.
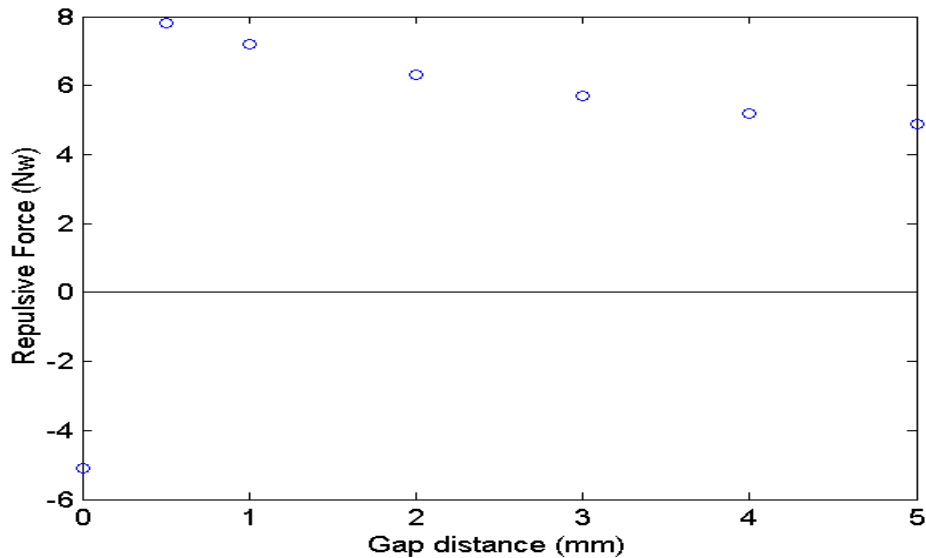

Figure 12. Measured repulsive force vs gap distance characteristic for two disks
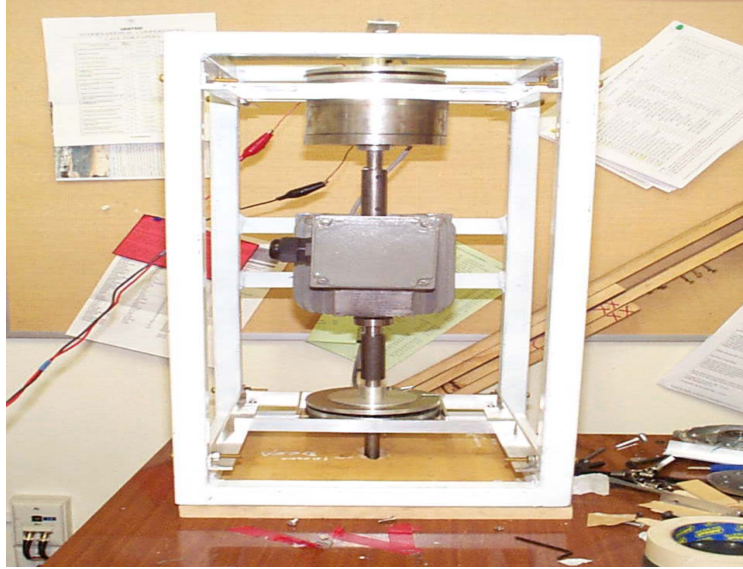
Figure 13. Fabricated magnetic bearing system

Fig. 14 shows the coil configuration for project 3. This project investigated the establishment of an homogeneous magnetic field in a defined region of space. Such a field has wide application, in our case the uniform magnetic field with controllable strength will be applied to DNA solutions to study the effect of magnetic fields on biologically important macromolecules. Fig. 15 shows the variation of the magnetic field as a function of coil separation at different (x, y) coordinate points. It is seen from Figure 15 that uniformity of the field distribution is achieved when the coil radius is exactly equal to the separation between them (Helmholtz condition). This helps the students to understand electromagnetics in a simple way.
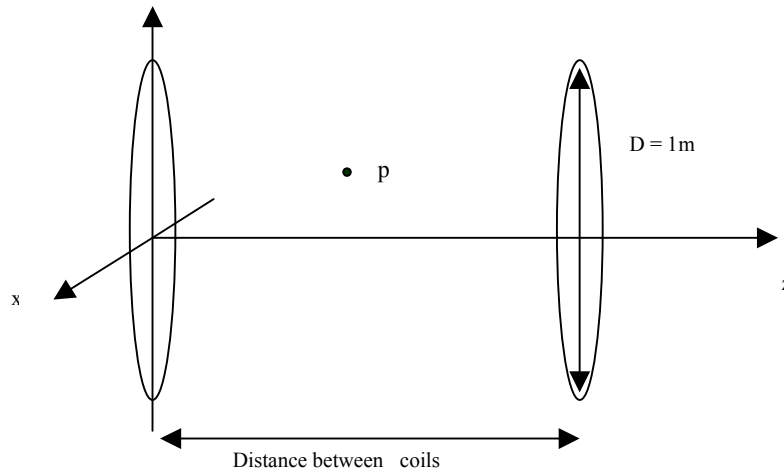

Figure 14. Configuration of coils for project#3

Teaching with laboratory experiments
It is our experience that although students can demonstrate familiarity with the theoretical aspects of the subject they may still lack sufficient practical knowledge. The following experiments are conducted to increase their practical skills and knowledge and to give them the opportunity to become acquainted with many instruments and experimental procedures. They are expected to conduct the experiments by themselves although laboratory support is provided. At the completion of an experiment they are allowed one week to complete their analysis and submit a report using the computers provided.
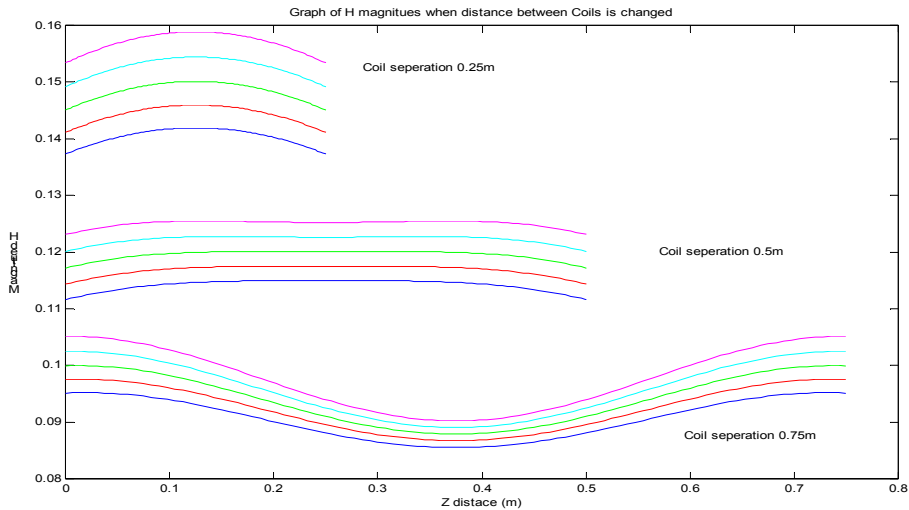
Figure 15. One simulated result for project#3

The experiments are:
(1) Magnetic Field of a solenoid (Biot-Savart law),
(2) Microwave optics,
(3) Phased Array antenna,
(4) Laplace Equation,
(5) Fresnel Equations.

Figure 16 shows part of the laboratory with computer facility. The students can access the computers while conducting their laboratory experiments. Fig. 17 shows the set-up for the microwave experiment.

Figure 16. Laboratory set-up for conducting electromagnetics experiment

CONCLUSIONS

A comprehensive method for teaching electromagnetics at undergraduate level has been presented. The main purpose has been to make the complex, abstract subject as simple as possible with the help of computer assisted teaching environment so that the students can learn more effectively with enthusiasm and interest. The development work is going on to make it interactive so that students can obtain immediate feedback. The development so far reported in this paper has helped us to teach this subject with more satisfaction and our students have enjoyed this subject with computer assisted learning environment. Another software NEC package has been procured recently which will be used for the design and analysis of antenna performance in future. This will help the students to increase their interest of this subject.

Figure 17. The set-up for microwave experiment

REFERENCES

Ulaby, F.T., (2001). Electromagnetics, Prentice Hall.

Kraus, F. (1992). Electromagnetics (4th Ed), Mcgraw-Hill.

Popovic, Z. and Popovic, B.D. (2000). Introductory Electromagnetics, Prentice Hall.

Inan,U.S., and Inan, A.S., (1999), Engineering Electromagnetics, Addison Wesley.

Trueman, C. W., (1999). Teaching transmission line transients using computer animation, 29th ASEE/IEEE Frontiers in Education Conference, paper no. 12a9-11, November 10-13, San Juan, Puerto Rico.

Microsoft product, Microsoft corporation, 1983-1997.

MATLAB: The Math Works Inc., Ver. 6, 1984-2000.

FEMLAB, Finite Element Software package, COMSOL, AB, 1984-2001.

Patrick, D.R. and Fardo, S.W., (1999). Electricity and Electronics, A Survey, (4th Ed), Prentice Hall.

S. C. Mukhopadhyay and S.D.Karunanaya
Institute of Information Sciences and Technology
Massey University (Turitea)
Palmerston North 5301
New Zealand
Email: S.C.Mukhopadhyay@massey.ac.nz, shanaka67@hotmail.com

D. N. Pinder
Institute of Fundamental Sciences
Massey University (Turitea)
Palmerston North   5301
New Zealand
Email: D.N.Pinder@massey.ac.nz