Computer assisted magnetism studies

Amit Garg, Reena Sharma, Vishal Dhingra
Department of Electronics, Acharya Narendra Dev College,
University of Delhi, Govindpuri, Kalkaji, New Delhi-110019, India

E-mail: amit_andc@yahoo.co.in

Abstract

The basic objective of this pedagogical activity on magnetism studies is to expose students to a computer assisted learning environment by using various sensors and advanced tools for data acquisition and analysis. Three important studies namely magnetic field variation in different types of disk magnets, solenoid and electromagnetic induction have been done using magnetic field, motion and voltage sensors. This automation of experiments allows a student to continuously acquire and analyse the data online during experimentation leading to better conceptual understanding.

Keywords: Electromagnetic Induction, Magnetism, Sensors, Data Acquisition, LabVIEW.

Resumen

El objetivo básico de ésta actividad pedagógica sobre estudios del magnetismo es exponer a los estudiantes a un ambiente de aprendizaje asistido por computadora usando varios sensores y herramientas avanzadas para la adquisición de datos y su análisis. Tres importantes estudios a saber, la variación del campo magnético en diferentes tipos de discos magnéticos, solenoides e inducción magnética se han hecho utilizando sensores de campo magnético, movimiento y voltaje. Esta automatización de experimentos permite a los estudiantes el continuamente adquirir y analizar los datos en línea, mientras el experimento se lleva a cabo, conduciendo a un mayor entendimiento conceptual.

Keywords: Interacción Electromagnética, Magnetismo, Sensores, Adquisición de datos, LabVIEW.

I. INTRODUCTION

A computer-learning environment with sensors and advanced tools for data acquisition and analysis offers many opportunities for students to perform experiments in science and technology in real time to investigate physical phenomena [1-4]. Students performing experiments with traditional methods in laboratory generally fail to understand the importance of the steps and precautions which are required to be followed during an experiment. The relevance of the steps is only realized after an experiment has been performed and analyzed by the students. Also, the time lag between experimentation and its subsequent analysis often leads to wastage of time resulting in limited variations in the experiments being performed by students during their course of study. This results in limited understanding and inability of students to analyze different experimental conditions.

To address these problems, we have developed a computer assisted environment that includes USB based data acquisition hardware with sensors and data analysis software based on student version of Windows based National Instruments (NI) LabVIEW 8.5 for magnetism studies. This paper describes the set of three basic physics experiments based on magnetism performed at first year undergraduate level namely magnetic field studies in various types of magnets, solenoid and electromagnetic

induction. The developed application provides real time measurements and analysis of these experiments. Therefore, students can concentrate on the understanding of the scientific phenomenon. The developed experiments provide students the opportunity to repeat measurements many times and run experiments at convenient time. Essential properties of the developed automated studies are its cost-effectiveness and that the experiment can be performed at any time using computers and NI LabVIEW software with enhanced accuracy and reliability.

II. THEORY

The above mentioned experiments are based on some of the important and fundamental aspects of magnetism. A brief review of these concepts in the light of the experiments performed is as under:

A. Investigation of Magnetic Fields

A.1 Disk Magnets

The magnetic field along on-axis at a distance x from the center of a disk-shaped magnet is similar to that of a solenoid and may be expressed by the integral

$$B(x) = \frac{\mu_o}{2} \int_{x-l/2}^{x+l/2} \frac{a^2 M}{(a^2 + z^2)^{\frac{3}{2}}} dz, \qquad (1)$$

where l and a are the thickness and radius of the disk magnet, M its magnetization, and μ_o is the permeability of free space which is 4π x 10^{-7} N/A^2. Assuming M to be constant within the magnet, this may be integrated to yield [5]:

$$B(x) = \frac{\mu_o M}{2} \left[\frac{x+l/2}{\sqrt{(x+l/2)^2 + a^2}} - \frac{x-l/2}{\sqrt{(x-l/2)^2 + a^2}} \right]. \qquad (2)$$

The part of this expression in parentheses is purely geometric, and if the dimensions of a disk magnet are known, this function has in fact only one free parameter, which is M, a property of the magnetic material. Since the dependence on M is linear, data analysis tools can be used for online plotting of the data and then determining the single- fit parameter.

A.2 Solenoid

The solenoid is a device which generates magnetic fields when current is passed through it. A long solenoid, that has a larger length compared to its radius, consists of a long enamelled wire wound in the form of a helix where the neighbouring turns are closely spaced. So each turn can be regarded as a circular loop. The net magnetic field is the vector sum of the fields due to all the turns.

Figure 1 represents this idealised picture. The field outside the solenoid approaches zero. We shall assume that the field outside is zero. The field inside becomes everywhere parallel to the axis [6].
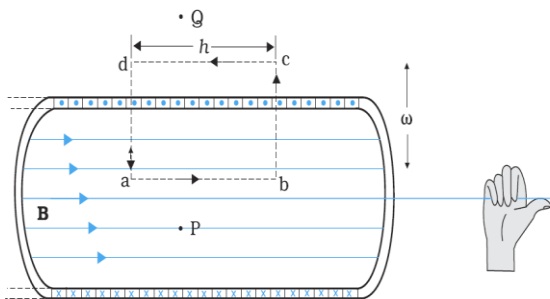

FIGURE 1. Magnetic Field in a solenoid.

Consider a rectangular Amperian loop abcd. Along cd the field is zero. Along transverse sections bc and ad, the field component is zero. Thus, these two sections make no contribution. Let the field long ab be B. Thus, the relevant length of the Amperian loop is, $L = h$. Let n be the number of turns per unit length, then the total number of turns is nh. The enclosed current is, $I_e = I(n\,h)$, where I is the current in the solenoid. From Ampere's circuital law

$$BL = \mu_o I_e \Rightarrow Bh = \mu_o I(nh), \qquad (3)$$

$$B = \mu_o nI. \qquad (4)$$

The direction of the field is given by the right-hand rule. The solenoid is commonly used to obtain a uniform magnetic field. The television uses the solenoid to generate magnetic fields needed.

B. Electromagnetic Induction

Electromagnetism is based upon the fundamental observations that a moving electric charge produces a magnetic field and that a charge moving in a magnetic field will experience a force. The magnetic field produced by a current is related to the current, the shape of the conductor, and the magnetic properties of the medium around it. The experiments of Michael Faraday in England and Joseph Henry in USA, conducted around 1830, demonstrated conclusively that electric currents were induced in closed coils when subjected to changing magnetic fields The process of inducing an EMF (electromotive force) in a conductor whenever the magnetic flux linked with it changes, is known as electromagnetic induction. The EMF so developed is called induced EMF and the current so obtained is called induced current. Faraday found that the EMF produced around a closed path is equal to the negative of rate of change of the magnetic flux through any surface bounded by that path. Mathematically,

$$\xi = -n \frac{d\phi}{dt}. \qquad (5)$$

Where n is the number of turns and Φ is the magnetic flux through a single turn. Figure 2 shows the induced voltage waveform when a magnet is dropped into the coil. The voltage first develops in one direction, comes back to zero and then increases in the opposite direction [7].
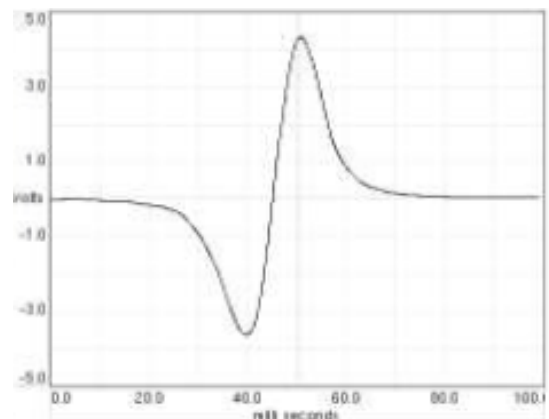

FIGURE 2. Induced voltage waveform.

Electromagnetic induction underlies the operation of generators, transformers, induction motors, synchronous motors, solenoids, and most other electrical machines.

III. EXPERIMENTAL SETUP AND RESULTS

A. Investigation of Magnetic Fields

A.1 Disk Magnets

The experimental setup for measuring the magnetic field as a function of distance is as shown in Figure 3(a).
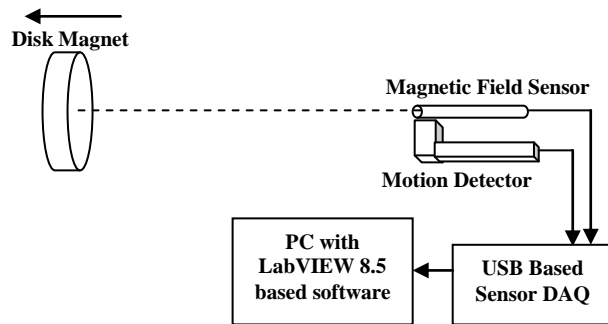

FIGURE 3(A). Experimental Setup for Disk Magnet Study.

The setup consists of a magnetic field sensor, motion detector, magnets (neodymium and ferrite), USB based SensorDAQ connected to the computer. The disk magnet and the magnetic field sensor are placed at a distance larger than 15 cm relative to motion detector ,which being the minimum distance requirement of the motion sensor to sense. The magnet and the magnetic field sensor are in absolute proximity with each other at the start. This is taken as the zero position. The software application developed in LabVIEW is as shown in Figure 3(b)
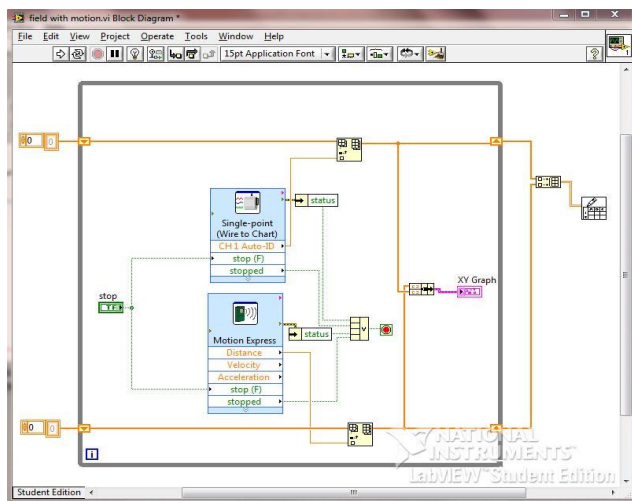

FIGURE 3(B). LabVIEW based software for study of disk magnets.

A "neodymium" (Nd) magnet in the form of a disk 9.99 mm thick and 43.58 mm in diameter, with magnetic field perpendicular to its flat faces, was moved in front of the motion detector and the corresponding on axis field was measured with the magnetic field sensor. The measurement accuracy of the motion detector and magnetic field sensor are 1 mm and 0.002 mT respectively. The online data from the Nd magnet are shown in Fig. 4(a), with the best fit of the $B(x)$ function obtained by Least Absolute Residual method in the linear region through variation of the value of M, with l and a fixed to the measured values of that magnet. An excellent fit has been obtained and the value of $\mu_o\, M$, deduced from the fit, is 1.30 T. Further, two cursor movements have been provided in the developed application which can be placed anywhere in the linear region for calculation of the value of $\mu_o\, M$.
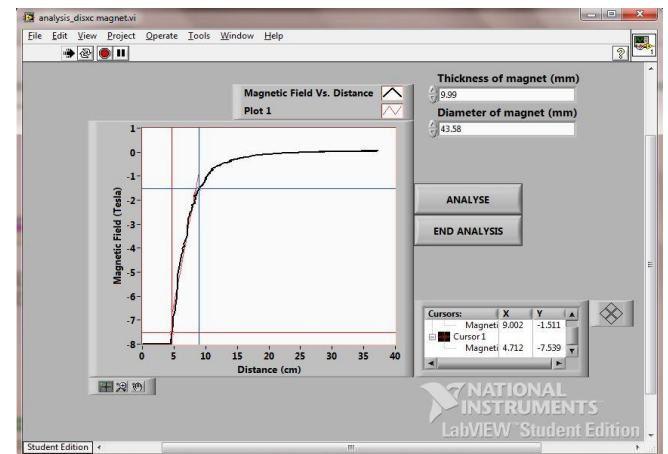

FIGURE 4(A). Magnetic Field variation in an Nd disk magnet.

For various Nd magnet alloys, the value of remanent magnetization Br ranges from 0.98 to 1.43 T. The measured value of $\mu_o\, M$ is consistent with the disk magnet being made of one of the good-strength Nd alloys.
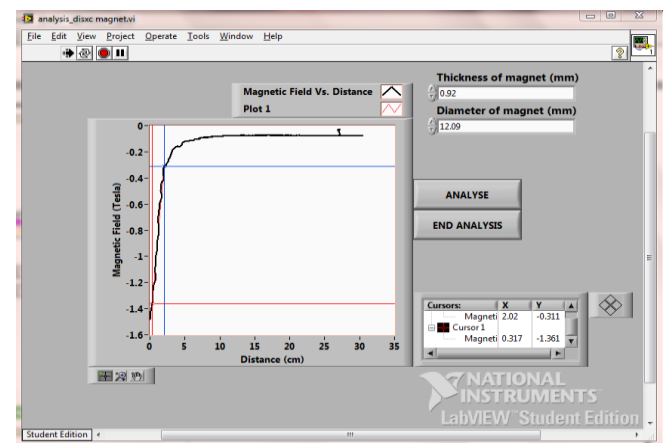

FIGURE 4(B). Magnetic Field variation in a ferrite disk magnet.

The experiment was repeated for common ferrite magnet. This magnet has a thickness of 0.92 mm and diameter of 12.09 mm. As shown by Figure 4(b), with the geometric parameters of the magnet used, the value corresponding to the remanent magnetization *B*r is 0.53 T. This value is almost consistent with the range (0.1 -0.5 T) of ferrite magnets of various alloy compositions.

A.2 Solenoid

The experimental setup for measuring the magnetic field as a function of distance for different current values is as shown in Figure 5(a). The setup consists of a magnetic field sensor, motion detector, solenoid, constant current power supply and a USB based SensorDAQ connected to the computer. In this arrangement, for a given current, the magnetic field sensor was placed at the end of the solenoid and then the solenoid was moved towards the sensor. This arrangement was done so that the position measurements by the motion detector could be done.
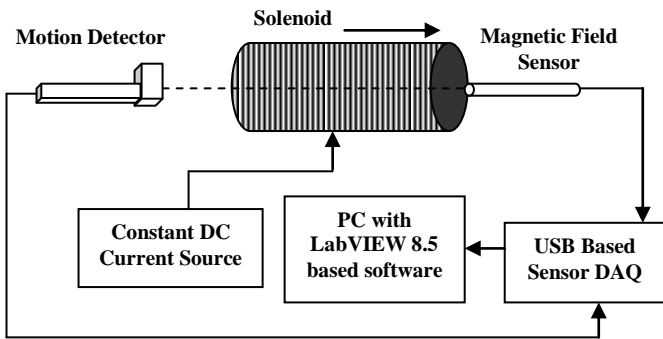

FIGURE 5(A). Experimental Set up for solenoid studies.

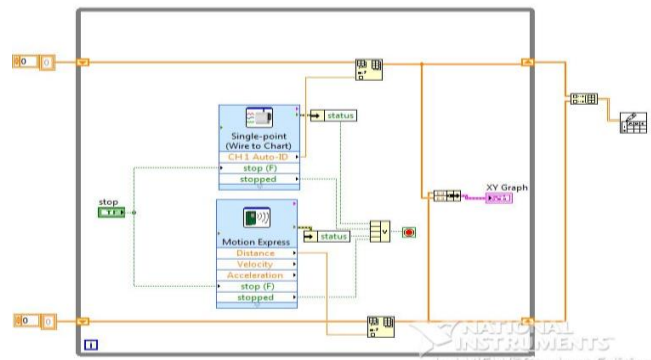The software application developed in LabVIEW is as shown in Figure 5(b).

FIGURE 5(B). LabVIEW based developed software application for solenoid studies.

The solenoid used in the setup has *n*=3600/m. The value of the magnetic field measured outside the solenoid for different current values was zero. The magnetic field

measured for different current values is listed in table I. It can be seen that the experimental results are matching with the theoretical results. Also the magnetic field is almost constant along the axis of the solenoid as shown in Figure 5(c).

TABLE I. Magnetic field measurements in a solenoid.

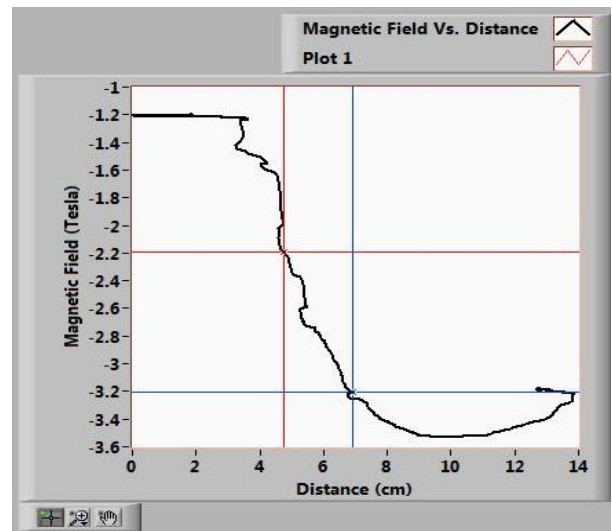| S.No	Current (Ampere)	Distance from centre to end (cm)	B(experiment al) mT	B(theoretical) mT
1	0.25	6	1.2-1.3	1.13
2	0.52	6	2.3-2.5	2.35
3	0.75	6	3.2-3.5	3.39

FIGURE 5(C). Magnetic Field variation along the axis of solenoid at I = 0.75 A.

B. Electromagnetic Induction

The experimental setup for demonstrating the electromagnetic induction is as shown in Figure 6(a). The setup consists of a coil, small Nd magnet, voltage sensor and a USB based SensorDAQ connected to the computer.
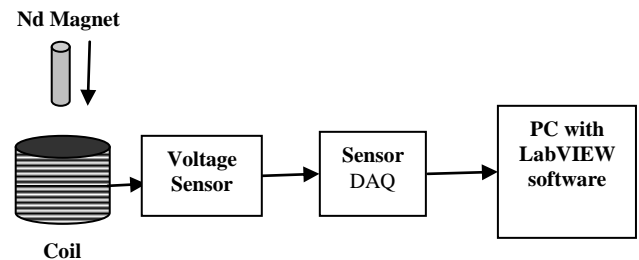

FIGURE 6(A). Experimental Setup for Electromagnetic Induction study.

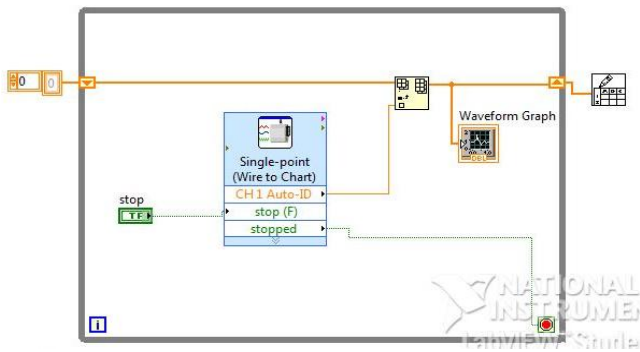The software application developed in LabVIEW is as shown in Figure 6(b).

FIGURE 6(B). LabVIEW based software application for study of electromagnetic induction.

A small strong Nd magnet moves with a constant velocity through a coil having 5000 turns and about 1 cm in diameter with its length along the coil axis. The two ends of the coil are connected to the voltage probe which in turn is connected to a PC through SensorDAQ. A magnet is dropped into the coil and the induced voltage waveform is captured as shown in figure 7(a).
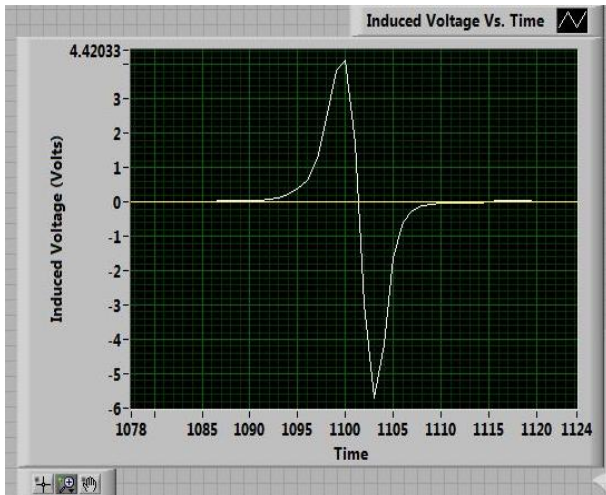

FIGURE 7(A) Induced Voltage Waveform for a coil.

The voltage first develops in one direction, comes back to zero and then increases in the opposite direction. The experimental curve obtained satisfies what is predicted by theory of electromagnetic induction. The amplitude of the induced voltage depends on the velocity and strength of the magnet, dimensions and number of turns of the coil while the width of the waveform depends on the time taken by the magnet to pass through the coil. In order to demonstrate the effect of the velocity of the magnet on the amplitude of the induced voltage, we dropped the magnet from different heights. The curves obtained for various heights are shown in Figure 7(b) -7(d) which satisfy the theoretical predications.
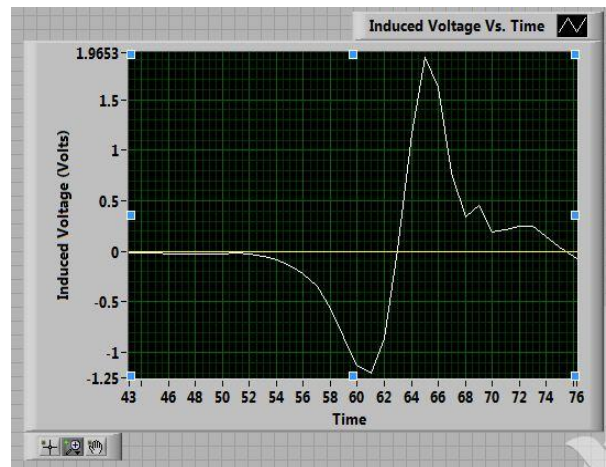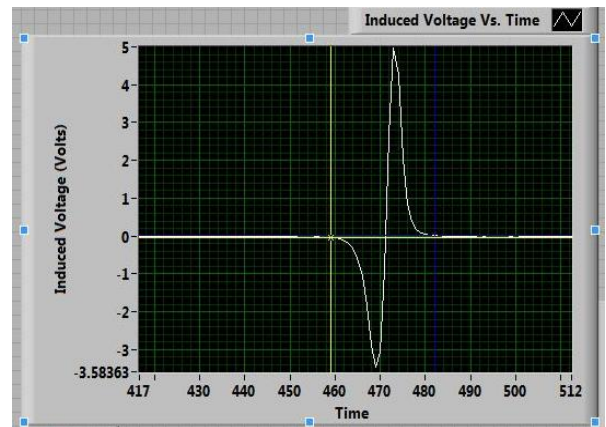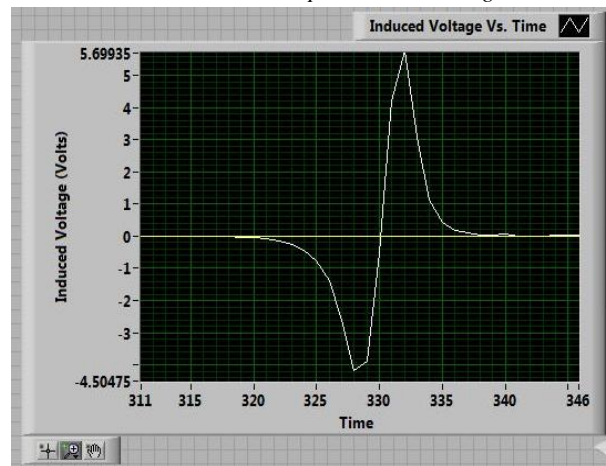

FIGURE 7(B)-(D). Induced voltage for different magnet velocities.

The detailed studies are in progress to experimentally measure and verify the amplitude of the induced voltage due to various parameters like velocity and strength of the magnet, dimensions and number of turns of the coil, etc.

Amit Garg, Reena Sharma, Vishal Dhingra

IV. CONCLUSIONS

The present development shows how a computer-assisted automation implemented through various sensors, data acquisition and graphical analysis tools can be used for understanding magnetism concepts. The students can measure various relevant parameters and can understand their physical meaning. Taking advantage of the developed system, students can avoid manual data collection and analysis, dedicating more time to observing the physical phenomenon, applying variations and interpreting the results. Detailed studies are in progress for a complete understanding of these magnetism concepts.

ACKNOWLEDGEMENTS

REFERENCES

[1] Fullekrug, M., *Exploration of the Electromagnetic Environment,* Physics Education **44**, 133-137(2009).
[2] Kraftmakher, Y., *Measurement of Small Optical Polarization Rotations*, Eur. J. Phys. **30**, 271–276(2009).
[3] Hsu, W.T., Bahrim C., *Accurate Measurements of Refractive Indices for Dielectrics in an Undergraduate Optics Laboratory for Science and Engineering Students*, Eur. J. Phys. 30 1325–1336(2009).
[4] Amrani, D., Paradis, P., *Malus's law of light polarization using a Computer-Based Laboratory*, Lat. Am. J. Phys. Educ. **3**, 229-231 (2009).
[5] Connors, M., *Measurement and Analysis of the Field of Disk Magnets*, The Physics Teachers **40**, 308-311 (2002).
[6] NCERT Text book Class XII, chapter 4, Page 150-152, http://ncertbooks.prashanthellina.com/class_12.Physics.Phy sicsPartI/ Chapter%204.pdf. Visited on 05th July 2010
[7] Rowland, S. C., Kingman, R., Clark, S. and Popescu, S., *An experimental observation of Faraday's law of induction*, Am. J. Phys. **70**, 595-598 (2002).