ISSN 2321 – 2004
ISSN 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 1, Issue 6, September 2013

STUDY OF MAGNETO OPTIC SENSOR USING TDG ELEMENT

Priyatosh Mahish[1], Sarbani Chakrabarty[2]
Asst. Professor, National Institute of Science and Technology, Berhampur, India[1]
Professor, BIT Mesra, Ranchi, India[2]

Abstract- The magneto optic sensor is very fast (at the speed of light), sensitive, non-contact and EMI (electromagnetic interference) proof in operation. It senses magnetic flux density by rotating the plane of polarization of the incident beam of light passing through it based on Faraday Effect. The amount of rotation depends on the property (Verdet Constant) of the magneto-optic element and the magnetic flux density. The general behaviour of this sensor is nonlinear. But under certain condition it shows linear nature over a certain range about an operating point which can be utilized in various applications. In this project this linear region of operation has been found and selected. The system can be used as an optical switch operated by current. Terbium Doped Glass cylinder is used in the experimental setup as the magneto optic element which is of length 30 mm, diameter 10 mm and with Verdet constant -104.42 rad/T m at the wavelength of 543 nm. The magnetic flux density is produced by passing the current through a solenoid.

Keywords: Polarization, TDG, Malu’s Law, Mueller matrices, Polarizer, Analyzer, Stokes vector.

INTRODUCTION

The magneto optic effect is first discovered by Michael Faraday in the year 1845.So it is also called Faraday’s Magneto optic effect. This effect says that when plane polarized light is sent through a magneto optic element in a direction parallel to the magnetic field, the plane of polarization is rotated.

Polarization of light is nothing but the vibration of the light wave in a particular plane. Natural unpolarized light wave vibrates randomly in any plane. It means at a particular time the vibrating plane of a particular wave cannot be determined. If this unpolarized light beam is passed through a polarizer then this permits vibration only in a particular plane. Then that particular wave is said to be a polarized beam, polarized at that particular plane.

The optical sensors are recently getting importance for having several merits as they are free from stray electromagnetic effect, capacitive effect as well as advantages of electrical isolation, easy integration with digital control system and large bandwidth etc [2]. In this paper the magneto optic sensor system has been designed and from this nonlinear system a linear pattern has been found. The linear region of about 12 mm has been observed in the solenoid.

DESIGN OF EXPERIMENTAL SETUP

The experimental setup is designed to find out the linear behavior of proposed magneto optic sensor. The complete setup is clearly shown in Fig.1. The laser is the optical source which emits an unpolarized beam of particular wavelength. In this experiment two different laser (different wavelength) have been used. One is Red light which is of wavelength 635 nm and another is green light which is of 543 nm. The laser source used here is diode pumped solid state laser of 5 mW power. The optical unpolarized beam is first passed through a sheet type polarizer which polarizes the beam in a particular plane. In this setup the linear polarizer has been used and so the beam coming from the polarizer is linearly polarized beam. After that this particular beam has to pass through an electromagnetic solenoid which produces the magnetic field. The solenoid here used is of length 95 mm, diameter 12 mm, and number of turns is 2600. The coil is made of copper material and is wounded on an aluminum cylinder. Initially the solenoid remains unenergized. A regulated DC source and a regulated AC source have been used to feed current (energize) to the solenoid. The resistance of the coil is measured as 5.95 ohm. The polarized laser beam is passed through a magneto optic element (TDG) kept within solenoid. The same beam coming outside from the solenoid is passed through again another crystal polarizer called analyzer. At first this is very important to find out the linear region of the solenoid as the sensor (TDG) should be placed within this region of uniform magnetic field. So experiments are performed each for DC and AC input. The Fig.2 and Fig.3 are the plotted graph showing length vs. flux from the experimental data of the DC and AC input to the solenoid respectively. From this graph it can be noticed that in the region from 4.6 to 5.8 cm starting from one end of solenoid, the magnetic flux property is uniform. So the magneto optic sensor can be placed within the uniform region. In this setup the Terbium Doped Glass (TDG) is used as this particular sensor. The length of this glass is 30 mm and diameter is 10 mm. Another important property of magneto optic sensor is verdet constant. The value of verdet constant of this TDG used here is -104.42 rad/T m for laser wavelength 543 nm. After passing through analyzer the optical wave is focused on the photo detector. In this setup the HP PIN photodiode is used. In this case the photodiode output is measured as voltage output. Now if the current input to the solenoid is changed then the state of polarization of the output beam changes which can be measured either in terms of analyzer angle or in the form of photodiode output voltage. A number of experiments have been performed by measuring different parameters and the experimental data are plotted by using MATLAB 7.0. Most of the behaviors are nonlinear. But it is hopeful to see that some region show linear relation. So they have been considered. The data plotted in the Fig.4, Fig.5 show the relation between analyzer angle and photodiode voltage. Fig.4 is for DC input to the solenoid and Fig.5 is for AC input to the solenoid. For each curve the input current (DC or AC) is kept constant. These figures (Fig.4 and 5) are following Malus' Law.

The photodiode response is observed by setting the analyzer angle at 230 degree with respect to polarizer angle fixed to 273 degree. This polarizer angle should be taken as reference angle. So the relative angle between polarizer and analyzer is 43 degree. The Fig.6 is formed from the experimental data where the change of photodiode voltage output is measured with the change of solenoid input DC current and it is highly nonlinear. After this observation the analyzer angle is fixed to 270 degree where the polarizer angle is fixed at the same angle at 273 degree. So the relative angle between polarizer and analyzer is 3 degree in this case. The Fig.7 formed from this experimental data where the parameters have considered same seems to be considerably linear.Hence this figure can be considered practically. Both the figures have been shown in Fig.6 and Fig.7 respectively.

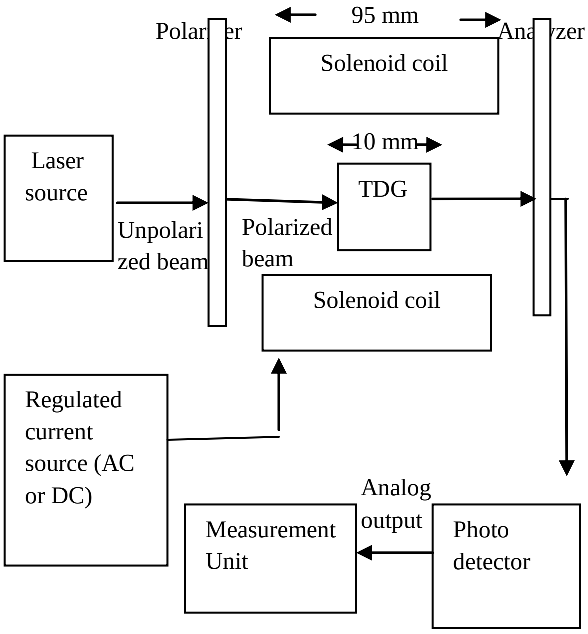

Fig.1. Schematic block diagram of the experimental setup.

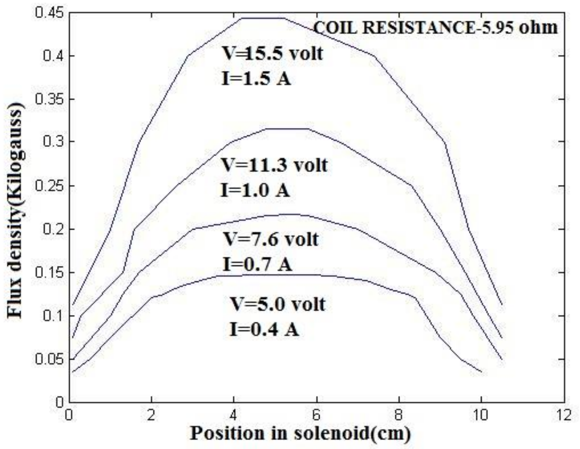

Fig.2. Electromagnetic characteristics curve of solenoid for DC input current.

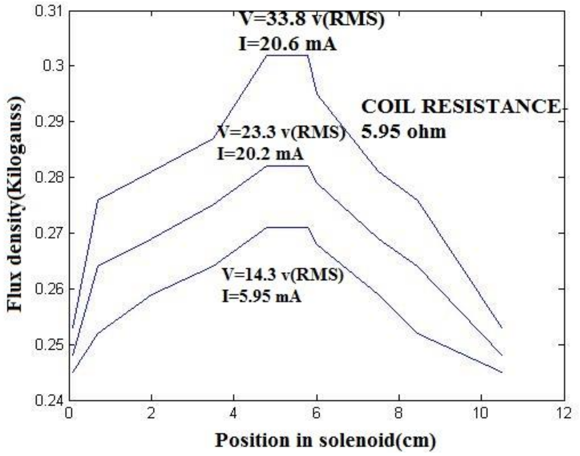

Fig.3. Electromagnetic characteristics curve of solenoid for AC input current.

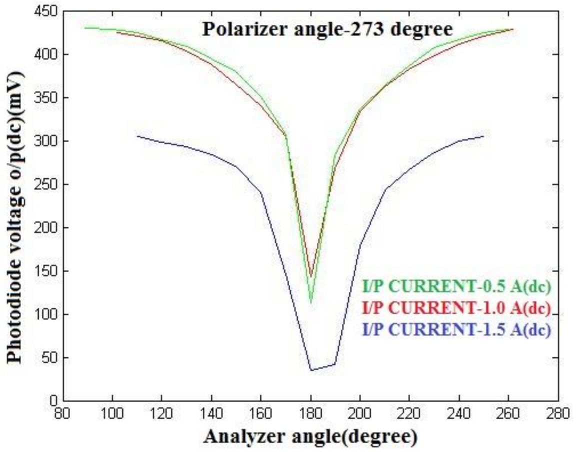

Fig.4. Analyzer angle vs. Photodiode voltage output curve for DC input current with Red laser(635 nm).

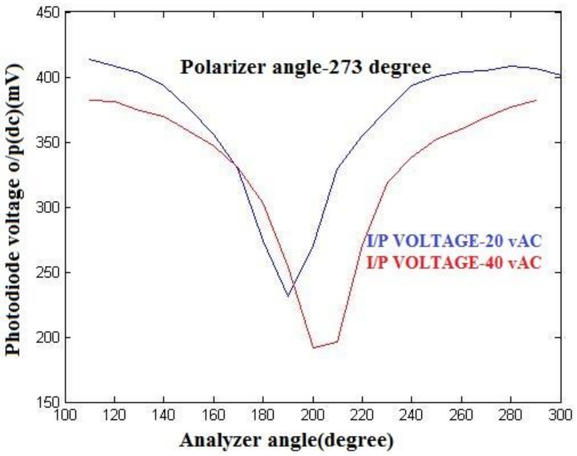

Fig.5. Analyzer angle vs. Photodiode voltage output curve for AC input current with Red laser(635 nm).

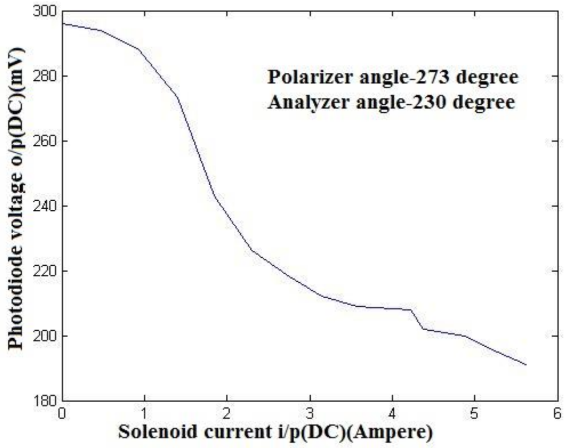

Fig.6. Photodiode response at analyzer angle in nonlinear region.

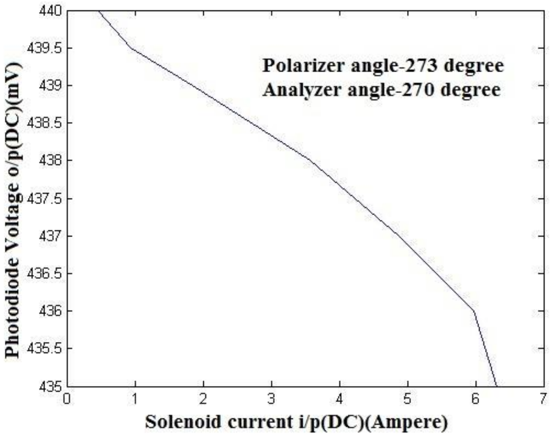

Fig.7. Photodiode response at analyzer angle in linear region.

Theory and anlysis

Fig.1 describes the whole setup of magneto optic sensor measurement. Let the beam coming out from polarizer is linearly polarized with azimuth α_p has intensity I_0. The intensity of the output coming from the analyzer can then written as

$$I_{out}=I_0 M_{rot} M_{ana} S_{in} \quad (1)$$

Where M_{rot} and M_{ana} are respectively the Mueller matrices of Faraday rotator and analyzer and S_{in} is the normalized stokes vector of the linearly polarized beam input [3].

$$M_{rot} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & -\sin 2\theta & 0 \\ 0 & \sin 2\theta & \cos 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$M_{ana} = \frac{1}{2}\begin{bmatrix} 1 & \cos 2\alpha_a & \sin 2\alpha_a & 0 \\ \cos 2\alpha_a & \cos^2 2\alpha_a & \cos 2\alpha_a \sin 2\alpha_a & 0 \\ \sin 2\alpha_a & \cos 2\alpha_a \sin 2\alpha_a & \sin^2 2\alpha_a & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (3)$$

$$S_{in} = \begin{bmatrix} 1 \\ cos 2\alpha_p \\ sin 2\alpha_p \\ 0 \end{bmatrix} \quad (4)$$

α_a is the transmission angle of the analyzer and α_p is the transmission angle of the polarizer. θ being the Faraday rotation.

Considering linearly horizontally polarized (α_p=0) monochromatic input beam and combining the Eqs. (1)-(4),the expression for detected intensity of the output beam is given by,

$$I_{out} = 0.5\, I_0 [1+\cos 2(\theta - \alpha_a)] \quad (5)$$

Solving Eqn. (5)

$$I_{out} = I_0 \cos^2\theta; \text{ When } \alpha_a = 0 \quad (6)$$

The Eqn. (6) follows the Malus' law and according to Malus, when completely plane polarized light is incident on the analyzer, the intensity I of the light transmitted by the analyzer is directly proportional to the square of the cosine of angle between the transmission axes of the analyzer and the polarizer [15].

$$I = I_{in} \cos^2\theta_i \quad (7)$$

Where I_{in} is the initial intensity and θ_i is the angle between transmission axes of the analyzer and the polarizer.

When a linearly polarized light passes through a magneto optic medium in a direction parallel to the uniform magnetic field, the Faraday rotation is given by the relation

$$\theta = V_{verdet} l B \quad (8)$$

Where V_{verdet} , l and B are wavelength dependent Verdet constant of the TDG element, length of magneto optic medium (TDG) and magnetic flux density of permanent magnet respectively [8].

DISCUSSIONS

Fig.2 and Fig.3 show the electromagnetic characteristics of solenoid. In both case a common linear region can be found which is lying within 4.6 to 5.8 cm from one particular side of solenoid. Only the uniform magnetic field in this region of the solenoid should be considered. Because remaining parts of both the graph is highly nonlinear. So the sensor (TDG) is placed within this region.

Fig.4 and Fig.5 both are following Malus' law. By comparing both these graph a common linear region can be found which is in a range of 260-270 degree analyzer angle (with respect to polarizer angle 273 degree). If the polarizer angle is made different then at different analyzer angle the linear pattern will come.

In Fig.5, it has been observed that the blue and red curve makes phase difference of about 10 degree which is due to thermally induced strain of solenoid (retardance). This can be reduced to practically considerable range by releasing temperature, produced by ohmic loss, after each observation.

Fig.6 is obtained by keeping analyzer angle 230 degree. From Fig.4 or Fig.5 it is clear that this angle is lying within nonlinear region. So the change of photo diode output with change in solenoid input current (Fig.6) is highly non linear.

Fig.7 is obtained by keeping all the parameters same except the analyzer angle which is changed to 270 degree. From the Fig.4 or Fig.5 it is observed that this angle is lying in the linear region. So the change of photo diode output with change in solenoid input current (Fig.7) is practically linear.

CONCLUSION

The sensitivity of the magneto optic sensor can be evaluated from the Fig.7. Another important parameter to control sensitivity of the magnetooptic sensor is verdet constant. It is different for different magneto optic element as well as for different wavelength. In this experiment the TDG material has been used. TDG has considerable good value of verdet constant. To reach more sensitivity other material can be used like Terbium Gallium Garnet (TGG). Verdet constant of TGG and TDG at 632 nm is -134 and -70 rad/T m.

Other parameters to increase sensitivity are length of the magneto optic element in the uniform magnetic field and magnetic flux density of the solenoid (Eqn.8). With magnetic flux increase the Faraday rotation will also increase. But it has a limit because more flux will cause more heating to solenoid and more heating will cause more retardance. So the phase displacement of Fig.5 also will more.

The linear response of this magneto optic sensor can be applied to different industrial applications involving magnetic field. As an example it can be used to sense relay in power system. This is non-contact type sensor so its response is much faster than any other contact type sensor.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support of the EEE, BIT Mesra, Ranchi.

REFERENCES

[1] Eugene Hecht, Optics, *Low price edition.*

[2] Francis A. Jenkins, Harvey E. White, Fundamental of Optics, *McGraw - Hill International Edition.*

[3] William A. Shurcliff, Polarized Light Production And Use, *Harvard University Press, Cambridge, Massachusetts, 1962.*

[4] Alan Rogers, Essential of Optoelectronics with Applications, *Chapman & Hall Publishers.*

[5] Solid State Lasers: A Graduate Text, Walter koechner, Michael Bass, *Springer Publishing.*

[6] Hp 5082-4204 pin photodiode datasheet, *http://www.datasheetarchive.com*.

[7] Hp 5082-4200 series.pdf, *http://www.datasheetarchive.com*.

[8] S.C Bera, S.Chakraborty, "Study of magneto-optic element as a displacement sensor", *Elsvier, vol.44, Issue 9, November 2011,* pp.1747-1752.

[9] M. Kanoi members, Optical voltage and current Measuring system for electric power system, *IEEE Transactions on power delivery, vol.PWRD-1, No.1, January 1986,* pp. 91-97.

[10] Peng- Gang Zhang, Dave Irvine- Halliday, Faraday Effect Optical Current Sensor, *IEEE Trans. on Magnetics, vol Mag-7, No-1, January 1996,* pp. 871-875.

[11] A.J. Rogers, Optical technique for measurement of Current at high voltage, *PROC.IEEE, vol.120, No.2, February 1973,* pp-261-267.

[12] High Performance Permanent Magnets Catalogue, Catalogue -7, Magnet Sales and Manufacturing Inc., CA 90230, USA, Copyright 1995. <http://www.magnetsales.com/Info_R2.htm>

[13] Rudra Pratap, Getting started with MATLAB, *Oxford University Press, Indian edition.*

[14] Physics Hand Book. *www.physicshandbook.co*