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APPLICATION OF MAGNETO - OPTICAL SENSORS IN MODERN TECHNOLOGY

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ABSTRACT

In this article the modern fiber-optic sensors based on magneto-optical Faraday effect and intended for automated technological processes and manufactures in the electric power industry, electrochemistry, non-ferrous metallurgy and other industries, where it is necessary to control electric currents, high voltages and magnetic fields are considered. This research performed per State Research Program of epy Republic of Uzbekistan №FA-A3-003 on subject "Development of control-measurement device for fiber-optic systems diagnostics" (2017-2018).

KEYWORDS: sensor, electric current, magnetic field, fiber-optic sensor, magneto-optical Faraday effect, transformer sensor, speed, information-measuring device, magneto-optical element, Malus law, ferrite-garnet film, rotate of the plane of polarization.

INTRODUCTION

Modern production in the conditions of market economy requires creation of modern competitive technologies and effective management systems to ensure high technical-economic indicators. It is impossible without use of modern computing and control technology and effective sensors, providing information about controlled physical values, their processing and transmission through the communication channels.

In many branches of industry it is necessary to measure the electric currents, high voltages and magnetic fields. In traditional systems for measuring DC up to 500 kA are used complex current transducers usually built on the Hall effect. They are accurate and reliable, however, due to their complexity the time consuming installation and entering them in usage operations are required.

In order to minimize potential errors due to the asymmetry of magnetic fields or crosstalk from adjacent conductors it is necessary to take special measures.

In 2002, in the West appeared magneto-optical devices developed by the American-Canadian company NXTPh, which were intended for use in the power industry. Swedish-Swiss concern ABB has developed in 2005 fiber-optic sensor based on Faraday effect for measuring the high direct currents.

In Uzbekistan, the specialists of the Tashkent Phisical-Technical Institute, having experience of creation of fiber-optic system parameters measurement systems have engaged in this field for almost 5 years later.

Compared with conventional transformer current sensors fiber-optical have a number of advantages.

They can measure AC and DC currents record up to 100 harmonics of the fundamental frequency (50Hz) due to bandwidth, thereby they controlling the quality of electricity. In addition high performance on overloading allows to use such sensors in the protection systems of high voltage equipment.

MATERIALS AND METHODS

In the recent years in Uzbekistan have appeared a large number of publications on creation of fiber

Optical sensors, which can remotely measure the current in the high-voltage transmission line, square bus or in a wire without breaking the electric circuit Similar sensors are being developed for

Measuring magnetic fields

The principle of operation of these sensors is based on Faraday effect, which manifests itself in the following. Two light waves, having circular polarization in the absence of a magnetic effects are distributed in a transparent medium with the same speed. When applying the longitudinal magnetic field the velocities of these waves are change: first begins to spread faster, the second one - slower. This is equivalent to the emergence of the time and phase delay between light waves whose magnitude is proportional to the current flowing through a conductor.

The following describes the developed in Ufa State Aviation Technical University information- measuring devices based on the magneto-optical Faraday effect.

Fig. 1 shows the structural scheme of the information-measuring device controls the magnetic field and electric current.[6]

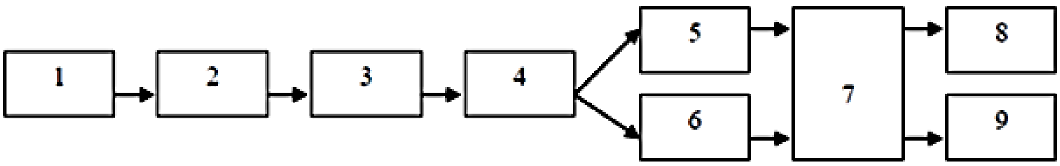

Fig. 1: Magneto-optical measuring system controls an electric current and magnetic field.

This device contains a source of optical radiation 1, polarizer 2, magneto-optical element 3 which provides the rotation of the plane of polarization of the beam on the Faraday angle.

$$\varphi = VHL$$

Where *V* —Verdet constant, *H* — intensity of the magnetic field, L - length of the light beam path in magneto-optical material.

The coupler 4 carries out the separation of the light beam into two orthogonal linearly polarized light-signal. The photodetectors 5 and 6 convert polarized light into an electrical signal proportional to the light intensity, which is determined by the Malus law. Then the signal goes to the microcontroller 7, is displayed on the LCD display 8 and recorded by device 9.

Thus, the proposed magnetooptical measuring control system of electric current and strength of the magnetic field provides a higher accuracy of measurements and enhanced functionality. As magnetooptical Faraday cell uses ferrite-garnet films doped with bismuth, which has a high value of the Verdet constant, which allows increasing the sensitivity of the measuring system. When you measure the strength of the magnetic field it acts directly on the magneto-optical Faraday cell, resulting in a rotation of the plane of polarization of the light beam when it is passed through the polarizer on an angle.

When the it is necessary to measure electric current I, it is passed through a bus, remote from the sensor on a distance R. In this case the magnetic field affect on the Faraday cell and the intensity of the magnetic field

$$H = \frac{1}{2\pi R}$$

RESULTS AND DISCUSSION

The advantages of the described sensor are small size and ability to remote measurement. The structural scheme of fiber-optical device for measuring the magnetic field and electric current.[4] is presented in figure 2. The sensor has the source of optical radiation in form of a laser or a laser diode 1. Connected in series with polarizer 2, optical fiber 3, rolled into a coil inside which passes the conductor 4 with the measured current I. Analyzer 5 optically coupled with photodiode 7 in series with the amplifier 8, analog-to-digital converter 9, memory register 10 and liquid crystal display 11. The sensor provides a communication with external devices through analog 12 and digital 13 outputs.

When the light emitted by laser or laser diode 1 is passing through the polarizer 2, he becomes flat polarized. When electric current I passed through the conductor 4 around it generates a magnetic field H.

A coil of optical fiber is magneto optical element of Faraday.[2] The influence of magnetic field on this coil leads to the rotation of the polarization plane of the flat polarized light beam on Faraday angle.

$$\varphi = VN_0I$$

Where I — electric current; N_0 — number of turns of the fiber optic coil; V — Verdet constant.

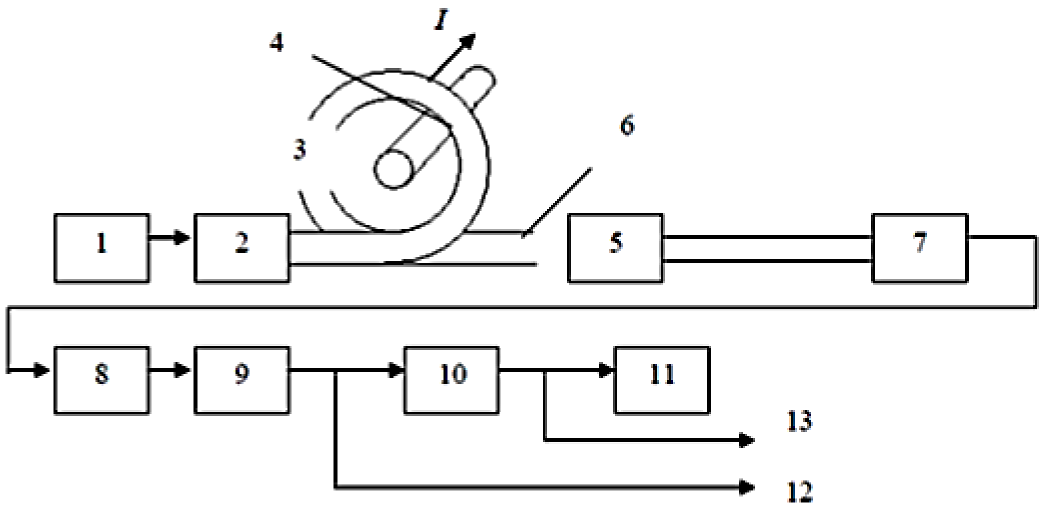

Fig. 2: Fiber-optic device for measuring the magnetic field and electric current.

Under direct influence of the magnetic field the Faraday rotation angle is given by:

$$\varphi = VHL$$

Where L — length of the way of the light in the optical fiber coil.

In the analyzer 5 angle of rotation of the polarization plane of flat polarized beam φ is converted to a change of optical signal power.[1]

$$P = 0{,}5P_0(1 + sin\ \varphi)$$

Where P_0 — power of the light in the absence of magnetic field.

The optical signal from the output of the analyzer 4 goes through an optical fiber and enters to the photodiode 7, then as an electrical signal to the amplifier 8, amplified analog signal in analog-digital converter 9 is converted into a digital code that can be stored in the memory register 10 and the result of measuring the electric current or magnetic field is displayed on the LCD 11.

CONCLUSION

Advantages of the considered sensor are broad functional capabilities and high accuracy. In Fig. 3 shows a structural scheme of the information-measuring system to control electric current and magnetic field.[5]

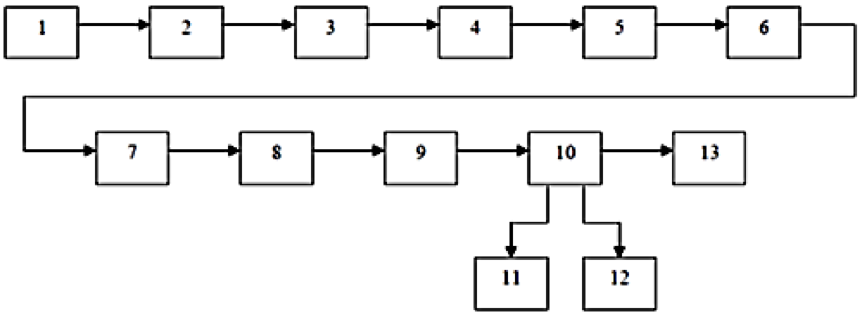

Fig. 3: Information-measuring system to control electric current and magnetic field.

The system contains optically coupled light source in the form of a laser or laser diode 1, fiber 2, polarizator 3, magneto-optical Faraday cell 4, the analyzer 5, 6 optical fiber, the receiver of optical radiation in the form of a photodiode 7. Photodiode output is electrically connected with series amplifier 8, analog-to-digital converter 9 and microcontroller 10 containing a microprocessor.

Microcontroller connected to the output of printing 11 and 12 recording devices that provide printing and recording of the information about measured magnetic fields and electric currents. Connected to the microcontroller LCD indicator 13 displays controlled currents and magnetic fields Connected to the microcontroller keyboard 14 controls the microcontroller. In magneto-optical cells made of optically active ferromagnetic materials due to the high magnetization of saturation $4\pi M_s$ Faraday effect is stronger. Then depending on the correlation between the intensity of the external magnetic field and magnetization of saturation the angle of rotation is defined as follows:

$\varphi = [\varphi_S 4\pi M_S]HL$ under $H \leq 4\pi M_S$

$\varphi = \varphi_S L$ under $H \geq 4\pi M_S$

where φ_S — angle of rotation under $H = 4\pi M_S$.

In MO Faraday cell made of optically active diamagnetic materials rotation of the polarization plane is due to not only the Faraday effect, but also the optical activity. Therefore, the rotation angle φ will be expressed by the sum

$\varphi = VLH + \Theta_A L$

Where Θ_A — optical activity

Rotation angle φ is converted by analyzer 5 in light intensity, which is determined by the Malus law.

Then the light is transmitted by fiber 6 in photodiode 7 and its optical power when the polarizer and the analyzer crossed at an angle 45º is given by (5).

Output current of the photodiode 7 is converted to a voltage by the converter «current - voltage», amplified by the amplifier 8 and in the analog-to-digital converter 9 is converted to a digital code, which is served to the microcontroller 10. The value of the measured electric current or intensity of magnetic field is displayed on the LCD 13 in the digital form.

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