Methods of diagnostics of electrical equipment by fiber-optic sensors on the Faraday Effect

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Abstract. One of the important problems in the operation and creation of a complex technical system is the provision of diagnostics of electrical equipment. This is especially important when diagnosing electrical equipment at an industrial complex belonging to the class of spark-explosive production facilities. The task of ensuring the operability of electrical equipment and preventing emergency situations due to timely detected breakage or violation of the insulation properties of the equipment includes a whole range of certain measures. In the process of operation, technical diagnostics of electrical equipment occupies a special place among complex technical devices at oil refineries. One of the most modern sensors for diagnosing electrical equipment is multiplicative sensors, which use optical fiber. Fiber-optic sensors have special proper-ties. The Faraday Effect is the basis for the construction of fiber-optic sensors for diagnostics of electrical equipment. Methods for diagnosing electrical equipment with fiber-optic sensors based on the Faraday Effect depend on the principles of the sensors themselves. This article presents the results of the study of the creation of experimental fiber-optic sensors based on the Faraday Effect. In this paper, it is proposed to carry out diagnostics of electrical equipment at an industrial complex belonging to the class of spark-explosive production facilities, such as oil refineries, using the use of fiber-optic sensors based on the Faraday Effect.

1. Introduction

Providing diagnostics of electrical equipment is one of the most important problems in the operation and creation of a complex technical system. This is especially important when diagnosing electrical equipment in an industrial complex belonging to the class of spark-explosive production facilities, such as oil refineries.

The task of ensuring the operability of electrical equipment and preventing emergencies due to timely detected breakage or violation of the insulation properties of the equipment includes a set of measures starting from:

- determination of the location of electrical equipment depending on the influence of aggressive media on it;
- dimensions of electrical equipment;
- technical performance characteristics;
- operational performance characteristics;
- economic calculations of power supply or distribution systems, etc.
In addition, the performance characteristics of electrical equipment are inextricably linked with such objects of oil refineries as:

- overhead power lines;
- cable power lines;
- step-down substations and power transformers;
- cells, switches and disconnectors;
- current and voltage measuring transformers;
- switchgears;
- switches;
- static capacitors;
- current limiting reactors;
- synchronous and asynchronous motors of control systems and machine tools, installations of submerged centrifugal pumps;
- electric motor control stations;
- grounding devices;
- pumps of the supply system of reagents;
- other auxiliary equipment.

2. Theoretical and experimental methods of diagnostics of electrical equipment

Technical diagnostics of electrical equipment during operation occupies a special place among complex technical devices at oil refineries [1]. Due to the fact that electrical equipment is subject to the risk of defects, malfunctions and failures, equipment control is used for the equipment in the form of a diagnostic system GOST 20911-89. “Technical diagnostics. Terms and definitions” uses the phrase The System of Technical Diagnostics as “A set of means, object and performers necessary for carrying out diagnostics (control) according to the rules established in the technical documentation” in relation to the electrical equipment of oil refining enterprises. It is necessary to pay special attention to the means (sensors) used for diagnostics (control), taking into account their current state and improved technical and operational characteristics [2].

One of the most modern sensors for diagnosing electrical equipment is multiplicative sensors, which use optical fiber.

Fiber-optic sensors have special properties such as: high throughput, lack of electrical conductivity, small dimensions, weight, spark-explosion safety, etc.

Currently, a number of domestic and foreign scientists are engaged in the theory, calculation and design of fiber-optic sensors for diagnostics of electrical equipment: Busurin V. I., Burkov V. D., Vitsinsky S. A., Isakov V. N., Kazachkov Yu. P., Kirin I. G., Kuznetsova V. I., Lovchy I. L., Pimenov A.V., Williams P, Rose A, Day G, Milner T, Deeter M.

The development of such sensors is carried out by such companies as: the Canadian company NxtPhase T&D Corporation, the Swedish company PowerSense, the American companies OptiSense Network, Inc., Airak, InoFieldMetrics, Inc. (FMI). In Russia, the development and research of such sensors is carried out by LLC “Unique Fiber Devices”. Similar studies are conducted at the Ufa State Aviation Technical University, St. Petersburg ITMO University under the guidance of academician, Doctor of Technical Sciences, Professor Meshkovsky I. K. and other scientists of the University [4-5].

The Faraday Effect is the basis for the construction of fiber-optic sensors for diagnostics of electrical equipment. It consists in turning the plane of polarization of linearly polarized light in a sensitive element in the form of a coil of optical fiber with linear double refraction, under the action of a magnetic field created by a conductor with a measured current, the magnetic lines of force of which coincide with the direction of light [3].
Quantitatively, the effect is described by the formula:

\[ \phi = V \cdot H \cdot L, \]

where \( \phi \) is the angle of rotation of the plane of polarization (or often called Faraday rotation); \( L \) is the optical path of a plane-polarized wave in a medium whose magnetic rotational capacity is characterized by the Verde constant \( V \). The Verde constant depends on the properties of the substance, the wavelength of light, and temperature.

Methods for diagnosing electrical equipment with fiber-optic sensors based on the Faraday effect depend on the principles of construction of the sensors themselves (table 1).

**Table 1.** Principles of construction of fiber-optic sensors based on the Faraday Effect and the measurement range.

| The principle of construction by fiber-optic sensors on the Faraday effect | Measuring range |
|---|---|
| Rotation of the plane of polarization of light propagating in an optical fiber under the influence of a magnetic field (the angle of rotation of the plane of polarization of light is \( \pm 45^\circ \)) | at rated current values, the measurement range is from 200 to 20 kA |
| Splitting the light beam from the output of the optical fiber coil into two beams | measurement of current in a small specified range of currents-usually up to 120% of its rated current value |
| Interweaving of input and output optical fibers of an optical fiber turn. | high-voltage power engineering (> 10 kV), requires breaking the power line |
| Serial connection between each other (n-1) sensitive elements of the light guide | registers current pulses with a duration of not more than 30 ns and not less than 1 ns |
| Serial connection of an optical fiber with a mirror piezoceramic membrane | DC analog output signal range (20-4=16 mA) |
| Rotation of the polarization plane in a Faraday element with plane anisotropy | current measurement limits from \( 10^2 \) to \( 10^5 \) A |
| Light input into the optical fiber of the branched part in the first arm | dynamic range of magnetic field measurements: from 50 \( \mu \)T (40 A / m) to 150 mT (120 ka / m) |

The paper presents the results of a study of the creation of experimental fiber-optic sensors based on the Faraday Effect.

The construction of such sensors can be based on the following example.

Taking into account GOST 20911-89, we will consider the construction of an experimental diagnostic system for monitoring the magnitude of electric current with a fiber-optic sensing element based on the Faraday Effect (figure 2). The system consists of three parallel fiber-optic chains [6]. And it works as follows: when a controlled electric current \( I \) flows from a controlled power source 1, a
A magnetic field of intensity \( H \) is created on the first fiber-optic chain. This field acts on the sensing element (SE) 4 (twisted optical fiber). The coherent monochromatic radiation \( J_1 \) generated by the laser diode 2 in the polarizer 3 is converted into a linearly polarized light wave \( J_2 \). In the sensing element 4, under the action of an external magnetic field of intensity \( H \), the plane of polarization of light propagating along the direction of the magnetic field rotates. The light flux \( J_3 \) from the output of the sensing element 4 passes through the analyzer 5 and gets to the photodiode 6, then to the amplifier 7 and the analog-to-digital converter 8, which transmits the output signal from the first fiber-optic chain to the computer 15.

**Figure 1.** Functional diagram of the information and measurement system for monitoring the electric current of an electric desalting plant with a built-in digital system.

In the second fiber-optic chain, the signal from the sensitive element that controls the temperature \( T \) 9, in the form of an electrical signal, enters the amplifier 10 and also enters the ADC 11, which transmits the output signal from the second fiber-optic chain to the computer 15.

The third fiber-optic chain works in the same way as the second only through the sensing element 12-the pressure control \( P \), the amplifier 13 and the ADC 14, which transmits the output signal from the third fiber-optic chain to the computer 15.

The outputs of the ADC (8, 11, 14) of the three fiber-optic circuits are connected to the computer 15, which is connected to the liquid crystal display (LCD) 16, the data output device for printing 17 and the data input device in the computer 18, the output of the computer by means of a control signal transmission device is connected to an adjustable power source 1.

In addition, fiber-optic sensors based on the Faraday effect for the diagnosis of electrical equipment can be easily interfaced into information and measurement systems to obtain information about various parameters of the controlled object, which must be processed, i.e., compare the obtained parameters with the parameters set as reference, determine the signs and values of the difference in the measurement parameters, calculate some derived parameters, etc. (figure 2).

**Figure 2.** Block diagram of the information and measurement system for monitoring the magnetic field.
Information from the object of research 1, goes to the primary measuring transducers 2 ... N, then the information goes to a single data collection point 3 and along the highway 4, the information goes to the computer 5, from where through the interface 6 to the device for forming control actions 7.

Here it is necessary to pay attention to one of the significant shortcomings. The measurement of a controlled physical quantity strongly depends on the quality of the information obtained at the initial stage of measurement. Thus, the highest requirement should be placed on the quality of information [7-9]. In addition, it is necessary for the measured means to ensure the mutual conjugation of its elements with each other. The solution of this problem can be achieved through consistency of information obtained in a form suitable for direct perception of a human operator and information in the fiber-optical sensors the Faraday Effect is presented in the form of a specific physical quantity, convenient for transmission, and further transformations in automation systems. This value is called a signal, and it is uniquely related to the controlled physical quantity or parameter of a particular technological process [10].

Modern state systems of industrial devices cover only a part of the controlled values that are most often used in production. These values are classified in five groups:

- heat and power (temperature, pressure, differential pressure, level and flow rate);
- electric power (DC and AC currents and voltages, power, power factor, frequency and insulation resistance);
- mechanical quantities (linear and angular displacement, angular velocity, force, hardness, vibration);
- chemical composition (concentration, chemical properties, composition);
- characteristics of physical properties (humidity, density, electrical conductivity, viscosity, illumination, etc.).

Fiber-optic sensors on the Faraday Effect for diagnostics of electrical equipment can be connected to form structural schemes, for example, a single direct conversion, with feedback, sequential direct conversion [11, 12].

The experimental fiber-optic sensors based on the Faraday Effect and systems based on them (figures 1 and 2) presented as a result of the study consist of a single sensing element. In the case of serial connection of several fiber-optic sensors on the Faraday effect, the output value of the previous one is the input value of the subsequent one (figure 3 (a, b). The scheme of fiber-optic sensors based on the Faraday Effect for diagnostics of electrical equipment with feedback (figure 3 (c)) is characterized by high accuracy, versatility and low dependence of the measurement coefficient on external disturbances.

![Diagram](image)
c) Figure 3. Serial connections of several measuring instruments

Thus, it is necessary to apply a systematic approach, which in this case may mean that when solving the problem of creating fiber-optic sensors based on the Faraday effect for the diagnosis of electrical equipment, there is a solution to the complex of works aimed at:

- agreeing on the maximum level of unification and standardization of fiber-optic means of measuring the magnetic field;
- establishment of nomenclature requirements and administrative documents that ensure compliance with the requirements for modern measuring instruments, a certain number of modifications of the measuring instrument of the same type (from the point of view of the totality of coordination of two different subject areas in the design, manufacture and operation);
- deepening of the subject and technological specification and specialization of enterprises-designers and manufacturers.

Conducting this complex of works gives the creation of an integrated complex—a fiber-optic means of measuring the magnetic field [13].

3. Conclusion

In this paper, it is proposed to carry out diagnostics of electrical equipment at an industrial complex belonging to the class of spark-explosive production facilities, such as oil refineries, using fiber-optic sensors based on the Faraday Effect.

It is particularly important to note that it is necessary to take into account the system approach to the development of functional schemes of such sensors, which, due to their construction principles, can diagnose such parameters as electric current or magnetic field in the places of insulation breakage at power cables.

The application of a systematic approach in this case may indicate that the development and design of fiber-optic sensors on the Faraday Effect reduces the problem of the following parameters:

- coordination of the maximum level of unification and standardization of the fiber-optic magnetic field measuring device;
- establishment of nomenclature requirements and administrative documents that ensure compliance with the requirements for modern measuring instruments, a certain number of modifications of the measuring instrument of the same type (from the point of view of the totality of coordination of two different subject areas in the design, manufacture and operation);
- deepening of the subject and technological specification and specialization of enterprises-designers and manufacturers.
Conducting this complex of works gives the creation of an integrated complex—a fiber-optic means of measuring the magnetic field, which is required according to GOST 20911-89 “Technical diagnostics. Terms and definitions” in the formulation of the system of technical diagnostics.

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