FIBER-OPTIC SENSOR OF THE OBJECT PERIMETER PROTECTION SYSTEM

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ABSTRACT

An analysis of the existing fiber-optic sensors of the system for detecting unauthorized entry into the territory of a protected facility was carried out. It is noted that an attractive feature of such sensors is immunity to electromagnetic radiation and electrical safety.As a result of the analysis, it was concluded that the well-known fiber optic sensors alone can detect only the fact of unauthorized entry, and with a multi-zone security system – both the fact and the zone of unauthorized entry, but not the reason for the operation of the fiber optic sensor, i.e. parameter of the offending object (small animal, person or vehicle).To expand the functionality, a fiber-optic sensor has been developed that allows you to determine not only the fact of penetration, but also the parameters of the intruder object, namely its mass.An optical fiber was chosen for the developed fiber-optic sensor and an optical fiber macrobend shaper with the highest susceptibility to macrobend – G 655. It was found that an increase in the length of the macrobend arc at a constant macrobend shaper radius leads to an increase in the attenuation of the optical radiation signal in the optical fiber. It is indicated that this dependence is close to linear in the range of macrobending arc lengths from zero to πR.

KEYWORDS: *Optical fiber, sensor, sensitive element, protected object, macrobend, deformation, vibration, attenuation coefficient, mass.*

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INTRODUCTION

In a fiber-optic sensor, an optical fiber is used as a sensitive element capable of detecting changes in information parameters about the state of a protected object and is a passive component of a fiber-optic communication line, which allows them to be used in various industries. It should be noted that at present, fiber-optic sensors have been developed that allow measuring deformation, displacement, vibration, pressure, temperature, tilt angle, acceleration, as well as detecting unauthorized entry into the territory of a protected object and are equipped with data recorders [2-10].

Optical fiber used to transmit information can be used as sensors to measure deformations, vibrations and other mechanical effects. Such sensors are increasingly used in modern security systems, in particular, in order to create signal lines to protect the perimeter of fenced objects. The applicability of fiber optic technologies is determined by the following factors, i.e. these sensors are immune to electromagnetic radiation (fields) and are electrically safe. In addition, in most cases, commercially available communication cables can be used as sensors, which are available in a wide range, and their cost is lower than the cost of specially developed cable sensors.

External influences, such as mechanical pressure, deformations or vibrations, change the parameters of the optical fiber and, as a result, the characteristics of the optical radiation signal passing through the optical fiber.

PROBLEM STATEMENT

At present, fiber optic sensors are known [1,12,13], which allow detecting only the fact of unauthorized entry into the territory of a protected object, cannot determine the reason for the operation of a fiber optic sensor, for example, a person, a small animal, a vehicle, etc.

In this regard, the task arises of developing a fiber-optic sensor for the perimeter security system of an object, which makes it possible to determine not only the fact of penetration, but also the parameters, namely the mass of penetrating objects (intruder).

For the development of a fiber optic sensor, an optical fiber of the G 655 type with the highest susceptibility to macrobending was chosen. It has been established that an increase in the length of the macrobending arc at a constant radius leads to an increase in the attenuation of the optical radiation signal in the optical fiber.

The purpose of this work is to develop a fiber-optic sensor of the perimeter security system of the object, which would allow to determine not only the fact of penetration, but also the parameters of the penetrating object (intruder), namely the mass.

To solve the problem, a classification of existing fiber-optic sensors was carried out, advantages and features were indicated.

Now let's look at them separately.

FIBER OPTIC SENSORS CLASSIFICATION

Fiber-optic sensors are divided into active and passive [2]. Active fiber-optic sensors under the influence of the measured value themselves generate optical radiation, which is fed through the optical fiber to the photodetector. The information parameter of the optical radiation generated by the fiber-optic sensor in this case is its intensity, i.e. optical power.

Passive fiber-optic sensors, in which the measured value modulates the flow of optical radiation passing through it, generated by an optical radiation source. It is expedient to base the classification of such fiber-optic sensors on the differences in optical modulation schemes of optical radiation with respect to the measured physical quantity, i.e. change in polarization, amplitude, phase modulation of the spectrum or duration of optical radiation, time intervals or pulse repetition rate.

In the simplest case, the measured value continuously modulates one of the above parameters, being adequately reflected in it.

Optical fiber sensors using optical fiber can be divided into sensors using optical fiber as the transmission medium and sensors using optical fiber as the sensing element. Along with these, there are point and distributed fiber optic sensors of various sizes.

Point FOS are divided into sensors of deformation, temperature, pressure, vibration, angle of inclination and linear displacements. Distributed sensors are divided into temperature and strain sensors.

FIBER OPTIC SENSORS BENEFITS

Fiber optic sensors using optical fiber have a number of advantages, i.e. possibility of multiplexing, remote measurement, resistance to electromagnetic interference, lack of electricity at the measuring point and long-term stability.

The works [2-10] show the possibility of creating fiber-optic sensors based on the macrobend of an optical fiber.

The advantages of such fiber-optic sensors in comparison with electrical ones include electrical safety, immunity to electromagnetic influences and the possibility of using in combination with those optical fibers through which data on the state of the protected object is transmitted. The latter makes it possible to avoid converting an electrical signal into an optical one and to simplify systems for diagnosing the state of objects.

FIBER OPTIC SENSORS FEATURES

The main features of fiber optic sensors include [3,5]:

– lack of active equipment on the perimeter (there is no electromagnetic radiation from fiber optic sensors along the protected perimeter), so it is difficult or completely absent to detect the location of the fiber optic sensor – cable, it is completely explosion and fire safe;

– the ability to protect complex and extended perimeters of objects;

– insensitivity of the fiber-optic sensor to external electromagnetic fields, radiation and interference;

– the ability to use standard types of optical fibers as a fiber-optic sensor, having a layer of strong and reliable Kevlar sheath under the outer insulation;

– the ability to use as a sensor one of the cores of an already laid fiber optic cable (the rest of the cores are used for their intended purpose for telecommunication signals in normal mode);

– the ability to integrate with perimeter security systems of a higher hierarchy level (using the Modbus protocol via TCP/IP, an open communication protocol based on the master-slave architecture, can be used to transmit data via serial communication lines RS-485, RS-422, RS-432 and TCP/IP networks);

– intuitive graphic interface at the workplace of the operator of the security system;

– the ability to differentiate the access level working with the personnel perimeter security system;

– maintaining a log of observations of the state of the protected perimeter with the ability to view and apply filters by types of events;

– the ability to notify the security system of an emergency situation by SMS and / or e-mail;

– linking the boundaries of the protected perimeter to real geographic coordinates using GPS;

– a trainable set of neuroalgorithms for recognizing events/attempts to violate the protected perimeter of an object;

– the ability to enable remote access to the software part of the security system;

– built-in elements of self-diagnosis of the state of the fiber-optic sensor;

– built-in means of self-diagnosis of the functioning of the software part of the perimeter security system - in case of software failures, automatic restoration of functioning within 60 seconds;

– protection of access to the software part of the fiber-optic perimeter security system with a programmable key.

DEVELOPMENT OF A FIBER OPTIC SENSOR

A branch of the optical radiation signal intensity from the optical fiber is created using a macrobend shaper, which is inseparably connected to the optical fiber in order to identify this optical fiber and create a short-term service link.

Along with this, they can also be used for unauthorized retrieval of information [2, 3, 9, 10].

A fiber-optic sensor with an optical fiber macrobend shaper (FMI) and a measuring device (MD) has been developed, the schemes of which are shown in Figures 1 and 2 [1].

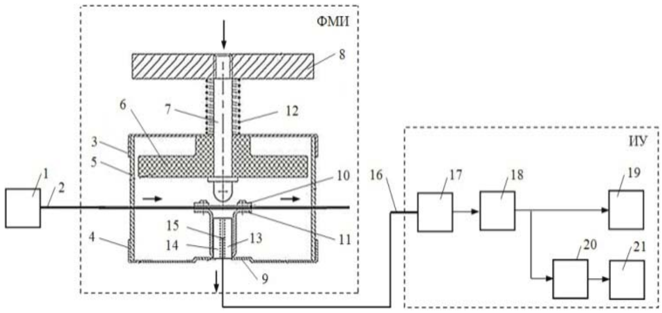

Figure 1. Fiber optic sensor diagram

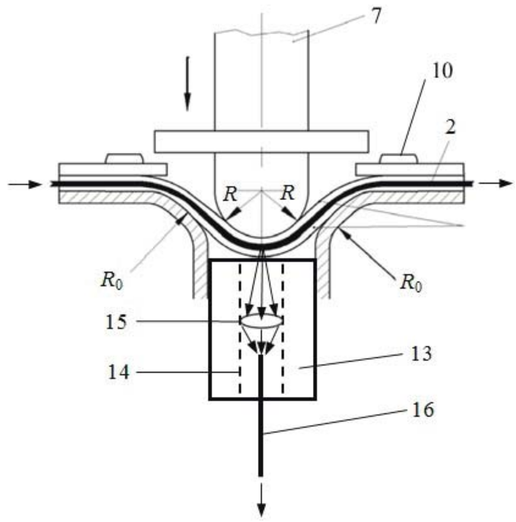

Figure 2. Optical fiber macrobend shaper diagram

FUNCTIONAL COMPONENTS OF THE FIBER OPTIC SENSOR

Fiber optic sensor of the object perimeter security system consists of an optical radiation source – 1, the first optical fiber – 2 with a core and a reflective coating, an upper – 3 and a lower cover – 4, a casing – 5, a guide – 6, a movable rod – 7, a button – 8, supports – 9, slats – 10, membranes – 11, spring -12, fixed rod – 13, funnel-shaped hole – 14, lens – 15 placed in the funnel-shaped hole – 14 and opposite the macrobend area, second optical fiber – 16 with a core and a reflective coating for transmitting a branched signal of optical radiation, a photodetector – 17, an amplifier – 18, a level meter – 19, an electronic reporting device – 20 that performs mathematical operations and an electronic indicator – 21 (see Figures 1 and 2) [1].

PRINCIPLE OF THE FIBER OPTIC SENSOR OPERATION

The fiber optic sensor works as follows [1]. In the process of unauthorized entry into the protected object, when the button – 8 is pressed by a body with a mass m, the movable rod – 7 moves down along the guide – 6 and is pressed against the membranes – 11.

An optical fiber is laid between the membranes. To prevent the first optical fiber – 2 from slipping to the sides during compression and creating a macrobend in the form of an arc of a circle, two low parallel guide rollers are placed in one of the membranes – 11. OB – 2 is located between these rollers. Such an arrangement prevents the OB – 2 from sliding to the side in the event that the movable rod – 7 acts on the membrane – 11, and when the impact stops, it contributes to the straightening of the OV.

When the impact on the button – 8 by a body with mass m – 8 spring – 12 opens, the movable rod – 7 returns to its original position, and the first OB – 2 returns to a straight position.

As a result of the action of movable rod – 7 on the membranes – 11, the process of macrobending of the first OF – 2 occurs, radius of which corresponds to the radius R of the round end of movable rod – 7 (Figure 2). With the help of the round end of the movable rod – 7, a macrobend of the first OB – 2 with the corresponding radius R is formed, and from this macrobend there is a branch of optical radiation that passes through the holes in the form of a funnel – 14, the lens – 15, placed in the hole in the form of a funnel, opposite the area with a macrobend and this radiation is focused by a lens onto the input of the second OB – 17, the input of which is located at the focal point of the lens – 15. From the output of the second OB – 17 it enters the input of the photodetector – 16, which converts the branched optical radiation into an electrical signal, from the output of the photodetector to the input of amplifier – 18, from the output of amplifier in parallel to the input of the level meter – 19 and electronic reporting device -20, which automatically performs mathematical operations, from the output of electronic reporting device -20 to the input of electronic indicator – 21.

The first OF – 2 together with the membranes – 11 is attached to the supports – 9, and the distance between them is equal to the diameter of the movable rod – 7. The edges of supports – 9 are made in the form of a round funnel with a radius R, which makes it possible to exclude attenuation of the branched optical radiation at the edges of supports - 9 during macrobending (see Figure 2).

The movable rod – 7 rests on the shoulders of supports – 9, to limit its movement, support – 9 is used, which prevents rupture of membranes – 11 and the first OF – 2 in the event of a strong impact.

When the button – 8 VOD is acted upon by any mass, process of branching of optical radiation transmitted by the source of optical radiation – 1 along the first OF, which passes through the lens – 15, placed in a hole in the form of a funnel, opposite the section with a bend, and the second OF – 16 in parallel enters the input of the level meter – 19 and electronic reporting device – 20. The level meter – 19 Δa measures the attenuation of the branched optical radiation.

On the other hand, the relationship between damping Δa and mass m is given by the following expression:

$$\Delta a = (mg)/k, \quad (1)$$

where m is the mass acting on the button of the fiber optic sensor; g – free fall acceleration; k – coefficient of spring stiffness.

Using expression (1), the relationship between the mass m acting on the button of the fiber optic sensor and the attenuation Δa created in this case can be determined as follows:

$$m = (\Delta a \cdot k)/g. \quad (2)$$

After the value of attenuation change is known, at the output of electronic reporting device – 20, which performs mathematical operations according to expression (2), the value of physical quantity proportional to the penetrating mass m is obtained, which is transmitted to the input of electronic indicator – 21, the scale of which is calibrated in proportion to mass m. On the scale of the electronic indicator, a value proportional to the mass is obtained, which makes it possible to determine the mass m of the person carrying out unauthorized entry into the protected area of object.

Thus, the introduction into the proposed fiber-optic sensor of a source of optical radiation, a fixed rod with a hole in the form of a funnel, a lens placed in this hole, opposite the section with a bend, a second optical radiation that provides transmission of branched optical radiation, a photodetector, an amplifier, a level meter, an electronic reporting device that automatically performs mathematical operations.

An electronic indicator, depending on the intensity of the branched optical radiation, allows you to detect unauthorized entry into the protected area of the object, an increase in the measurement range due to the amplification of branched optical radiation, selection of spring stiffness coefficient increases the measurement limit of object body weight at unauthorized entry and thereby expand its functionality.

Applications of fiber optic sensor

Fiber optic sensors can be used in many areas, such as in fiber optic systems for protecting the perimeter of an object from unauthorized entry, construction, aerospace, energy and oil and gas industries. Monitoring systems based on this technology are cost-effective when used on large-scale facilities – where hundreds of FOS are required for continuous measurements of various physical parameters.

Conclusion

Thus, depending on the intensity of the branched optical radiation, the developed fiber-optic sensor of the perimeter security system of the object allows detecting unauthorized entry into the protected area of the object, increasing the measurement range, attenuation of the branched optical radiation due to its amplification, the correct choice of the spring stiffness coefficient increases the measurement limit of body mass object of unauthorized penetration and thereby expand its functionality.

In addition, it has been experimentally established that less than 50% of the output power of the optical radiation signal source is transmitted to the outputs of the fiber-optic sensor, and the main part of the output power is transmitted to the direct output. When the output power value of the optical source is 0 dBm (1.0 mW) transmitted through the optical fiber, and the efficiency of the fiber optic sensor is about 5% (-13dB), the bending loss of the optical fiber is approximately 1.0 db. This means that in order to form a channel for branching the output power of an optical radiation signal source, it is possible to form a macrobend with a diameter of 5.0-60 mm in the optical fiber.

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