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USING OPTICAL FIBERS (OF) TO CONTROL THE STRESS-STRAIN STATE OF STEEL STRUCTURES SUBJECT TO FATIGUE FAILURE

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The article presents the results related to developing and practical testing the method of monitoring the stress-strain state of steel structures of mine hoisting machines. Certain positive properties of optical fibers make it possible to use them for measuring the stress-strain state of steel structures. An optical fiber of the ITU-T G.652.D standard is used as a sensor. The analysis and review of the current state of development of fiber-optic conductors is performed. The proposed method of non-destructive testing the stress-strain state of metal structures is capable of providing continuous measurements in real time. The proposed method is universal and suitable for monitoring the stress-strain state of any metal structures subject to fatigue failure.

Keywords: mine hoisting machines, brake, fatigue crack, stress-strain state, optical fiber

INTRODUCTION

Long-term service metal structures are subject to fatigue failure. The practice has shown that over time operational loads lead to the formation of fatigue cracks in the body of mine hoisting machine (MHM) brake device steel. There is an industrial problem associated with controlling fatigue failure of steel structures of MHM.

This problem has already been described earlier in work [1] on the example of the Arcelor Mittal metallurgical company. The statistical data given in [1] form the relevance of research aimed at developing methods to combat fatigue failure of metal structures.

There is some positive experience of using strengthening elements in practice. The use of strengthening elements makes it possible to eliminate the consequences of fatigue failure and to restore steel structures strength. As time passes, in metal structures accidental hazardous destruction zones are formed. They can lead to complete destruction of the structure, which entails the development of a dangerous emergency situation [1]. To prevent the threat of metal structures sudden destruction, non-destructive testing methods are used that help to identify timely hidden fatigue cracks and to take measures to localize them [1].

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LITERATURE SOURCES ANALYSIS

The basis of this article is the experience in the developing methods of combating fatigue failure with the use of strengthening elements. The process of fatigue crack development in metal structures was analyzed [2]. The mechanism of fatigue failure of structural steel is described in detail in work [3], as well as the understanding of the basic laws of fracture mechanics when calculating strength and reliability of metal structures [4]. It is important to assess the achievement of the limiting state of structures in the event of emergency [5]. An important point is non-destructive testing as the main method of finding cracks in steel structures. There was studied the experience of assessing the performance of metal structures with cracks [7]. Optical fibers (OF) have found wide use as various sensors [8]. There is some positive experience of using it in coal mines to control the roof of working deformation [9, 10]. The stages of development of fiber optic technology are detailed in [11]. All the above sources helped to develop methods of monitoring the stress-strain state (SSS) of steel structures for their subsequent strengthening in places of fatigue failure.

SELECTING THE METHOD OF STEEL STRUCTURE STRESS-STRAIN STATE CONTROL

The method to combat fatigue failure proposed in [1] is not limited to the design of the mine hoisting brake beam and can be used in the repair of any metal structures. The previously published article [1] does not include materials related to the control of the metal structure SSS with the use of optical fiber. Fiber optic technologies are rapidly developing and are widely used in information processing and transmitting systems. Certain positive properties of optical fibers make it possible to use them not only as a means of transmitting information in telecommunication systems but also as a tool for non-destructive testing of metal structures [8, 9]. Continuous monitoring of the stress-strain state of metal structures allows timely identifying the emergency-hazardous destruction zones. OF allows controlling the deformation of the steel structure with high accuracy and the lowest energy consumption. Using an optical fiber as a sensor, it is possible to build a distributed system for monitoring the stress-strain state of metal structures [9, 10]. Unlike strain gauges that are widely used to control the deformation of various objects, OF does not require transmitting electric current through the conductors of the measuring channels.

It is not an electrical signal that is transmitted over the optical fiber but a light wave. External mechanical action on the optical fiber changes the properties of the propagated light wave and principally, its phase and length [9, 10]. Accordingly, if the OF is fixed on the surface of a metal structure, then during its deformation, the OF will also be deformed. When the optical fiber is deformed, the refractive index of light between its core and cladding changes. The stronger the deformation, the greater the additional losses in the OF. All the changes are recorded by a television matrix, on which the light wave is incident at the exit from the optical fiber. Specially developed software is used to process the obtained data. As mentioned earlier, fatigue failure is typical for a wide range of mine equipment designs, both for mining and transport purposes. The selected method has been successfully tested. In the future, it is possible to use optical fiber to control the stress-strain state of various steel structures and to expand the scope of the selected method, as well as to move from periodic control to the continuous monitoring of the equipment structural parts technical condition.

PRACTICAL USE OF THE METHOD AND RESULTS

The experiments involved the structures that passed both the restoration stage and structures that were not yet subject to fatigue failure. Figure 1 shows the options for the OF placement on the side faces of the braking device beam metal structure.

The optical fiber was placed on the side walls of the brake beam in the accident-hazardous destruction zones, which were determined on the basis of the existing experience. The optical fiber was fixed with epoxy glue. The place where the fiber was located was preliminarily cleaned of paint for better fixation. The measurement diagram is shown in Figure 2. The device for measuring mechanical stresses and strains was pre-calibrated with the use of the ZET 058 measuring strain gauge system.

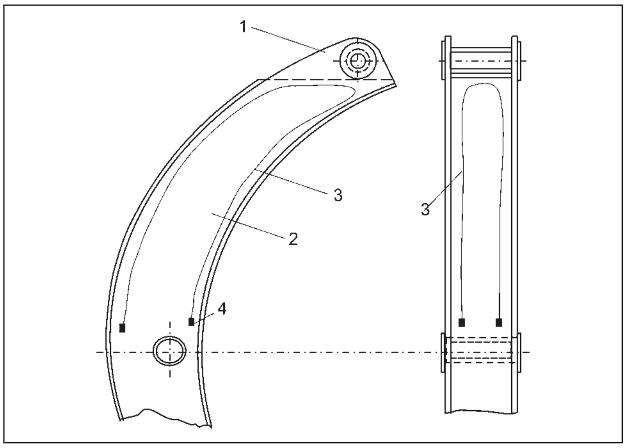

Figure 1 Variants of optical fiber placement on the side faces of the braking device beam metal structure: 1 - ring for fastening the hub, 2 - braking device beam, 3 - optical fiber (sensor)

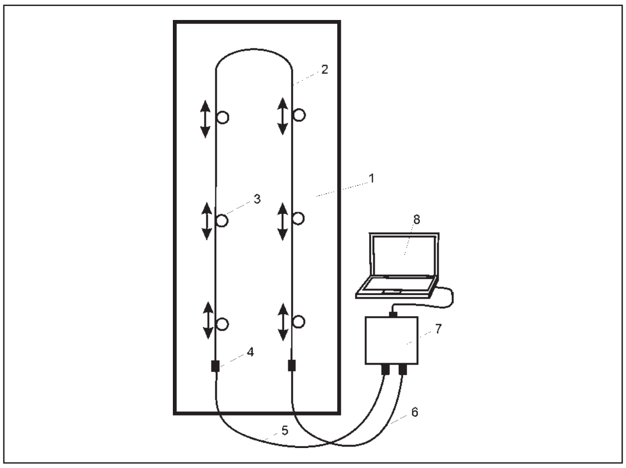

Figure 2 The measurement diagram: 1 - lateral edge of the beam, 2 - optical fiber, 3 - optical fiber loop (sensor), 4 - connector, 5, 6 - optical patch cords, 7 - data processing unit, 8 - laptop

An optical fiber of the ITU-T G.652.D standard was used as a sensor. The OF diameter was 125 μm.

To protect against moisture and mechanical damage, a protective acrylic shell is used. With the shell applied, the total diameter was 245 μm.

This works in the following way: on surface 1, with the help of glue, optical fiber 2 is preliminarily fixed through which a light wave of the visible range with the length of 650 nm is transmitted. The main measuring element is loops 3 that, when surface 1 is deformed, change their original diameter. Surface deformation is shown by arrows. The sensor is connected by means of detachable connectors 4, as well as optical patch cords 5 and 6 with data processing unit 7. The data processing unit contains a laser radiation source that feeds a light wave through patch cord 5 into the measuring channel. Having passed through optical fiber 2 and loops 3, the light returns to block 7, where it falls on the surface of the television matrix, which fixes all the changes of the

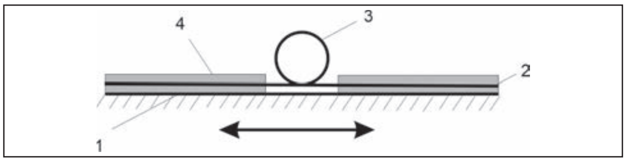

Figure 3 Optical fiber loop design (sensor): 1 - lateral edge of the beam, 2 - optical fiber, 3 - optical fiber loop (sensor), 4 - epoxy adhesive layer

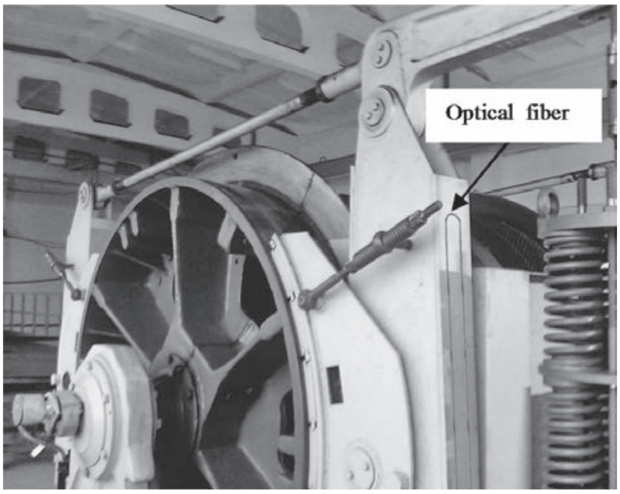

Figure 4 The location of the sensor on the side surface of the brake beam

light wave parameters. For data analysis, specially developed software installed on laptop 8 is used. The number of measuring channels and measuring points is practically unlimited but in the experiments 4 measuring channels were used and accordingly, one light source and four television matrices, one per measuring channel. The optical fiber is glued in a special way to the side edge of the beam. Loops with the diameter of 3 to 4 mm are formed. They do not stick to the surface of the beam, which allows changing their diameter when the surface is deformed (Figure 3).

If the surface is deformed, that is, stretched or contracted, then the loop is also deformed, that is, it also stretches or contracts, which causes changing the properties of the light passing through it. All the changes in the additional losses of the light wave passing through the optical fiber during its deformation are recorded by the data processing device. Figure 4 shows one of the options of placing sensors on the side surface of the brake beam.

The results of measuring the stress-strain state of the brake beam are presented in two graphs in Figures 5 and 6.

Depending on the growth of mechanical stresses and deformation, the loss of optical power grows. The optical fiber is capable of detecting changes in the stress-strain state of the brake beam with a sufficiently high accuracy.

The relative error in the measurement of mechanical stresses was 2,112 %, the Student's coefficient was 1,092 with the confidence interval of 0,95.

The relative error in the relative deformation was 3,453 %, the Student's coefficient was 1,899 with the confidence interval of 0,95.

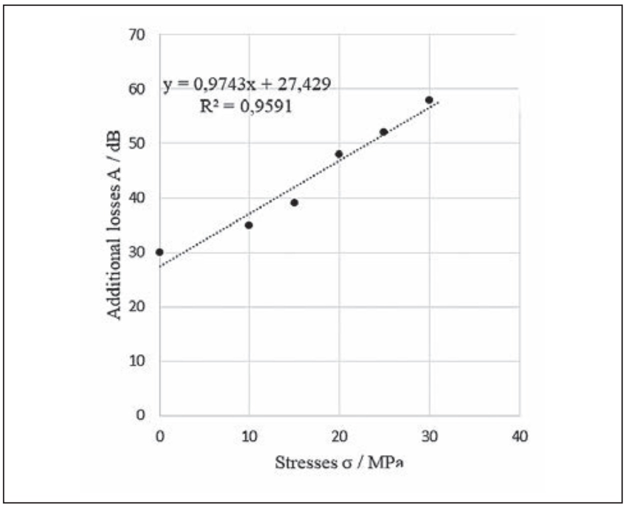

Figure 5 Graph of the additional losses of a light wave growth with increasing mechanical stresses of the beam

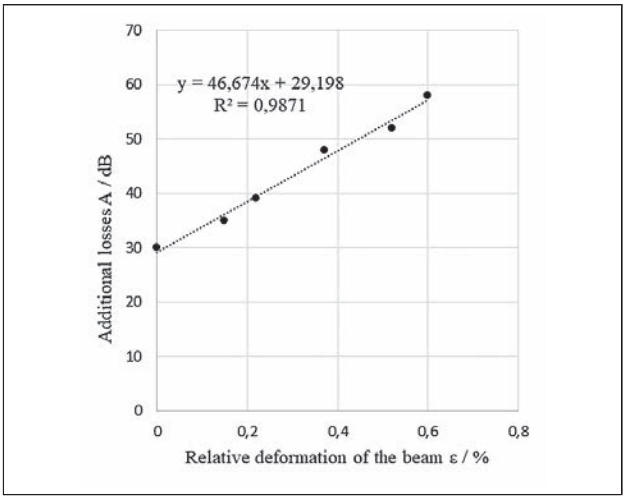

Figure 6 Graph of the additional losses of a light wave growth with increasing the relative deformation of the beam

DISCUSSION AND CONCLUSIONS

Using the OF, it is possible to develop a distributed system for monitoring the stress-strain state of various metal structures that works in real time. It is also possible to establish with high accuracy the places of occurrence of mechanical stress concentrators and to determine timely the zones of fatigue failure. The considered method is universal and suitable for monitoring the stress-strain state of any metal structures subject to fatigue failure, for example, made of channel, I-beam and box-shaped steel sections.

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