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IMPROVING THE METHOD OF CONTROLLING THE STRESS-STRAIN STATE OF STEEL STRUCTURES OF ELECTROMECHANICAL SYSTEMS

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The article presents the results of improving the method of controlling the stress-strain state of steel structures of mine hoisting machines, which can be attributed to electromechanical systems. The method of controlling the stress-strain state of steel structures of electromechanical systems subjected to fatigue failure is based on the use of mechanical properties of an optical fiber (OF) and the effect of photoelasticity arising from its deformation. The optical fiber is used as a sensor and allows to controlthe stress-strain state of metal structures in real time.

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

INTRODUCTION

Fatigue failure is formed over time during intensive operation of steel structures of mine hoisting machines, which can be attributed to electromechanical systems. There is a problem of the lack of technical means for constant controlling of the stress-strain state of steel structures of mine hoisting machines and the establishment of “Emergency hazardous zones” where fatigue cracks are formed. At the moment, there are only periodic methods of flaw detection and controlling of the stress-strain state of steel structures of mine hoisting machines.

Information about the problems of fatigue failure and their extent can be found in earlier works. There is also a description of methods for combating fatigue failure using elements for reinforcing and increasing the strength of steel structures. Modern production organization requires the introduction of Industry 4.0 technologies and digitalization of production processes. One of the solutions to the applied problem is the developed method ofcontrolling the stress-strain state of steel structures of mine hoisting machines capable of operating in real time, which uses digital and fiber-optic technologies.

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LITERATURE SOURCES ANALYSIS

The long-standing practice of observing steel structures of electromechanical systems, in particular, mine hoisting machines, has shown, that over time and during intensive operation, operational loads lead to the formation of fatigue cracks in the body of steel beams of the braking device of mine hoisting machines (MHM).

There is a production problem associated with the lack of systems for controlling the fatigue failure of steel structures of MHM in real time. This does not allow timely measures to strengthen the structure and prevent its sudden destruction, as well as lead to an emergency situation. This problem has already been described earlier in [1] on the example of the metallurgical company Arcelor Mittal, there is practical experience in testing methods to combat fatigue failure. The statistical data given in [2] form the relevance of research aimed at developing methods to combat fatigue failure of metal structures. There is a positive experience of using reinforcement elements in practice. The use of reinforcement elements makes it possible to eliminate the consequences of fatigue failure and restore the strength of steel structures. Over time, “Emergency-hazardous destruction zones” are formed in metal structures, which can lead to the complete destruction of the structure, which entails the creation of a dangerous emergency situation. To prevent the threat of sudden destruction of metal structures, non-destructive testing methods are used, which help to identify hidden fatigue cracks in a timely manner and take measures to localize them. Analysis of the literature has shown that the problem of fatigue failure of steel structures is quite acute and scientists around the world are looking for ways to solve it. The article uses the accumulated world experience in the development of methods of controlling the fatigue failure and combating this phenomenon. There were analyzed the structural failure features of various steel alloys having fatigue cracks [3]. The causes and nature of the appearance of cracks and S-N characteristics for various steels and the behavior of the S-N curves [4]. Also, the article [5] was analyzed to understand the process of fatigue cracks development in metal structures. There is a description of the process of fatigue failure of steel structures [6, 7], which was used in conducting our own strength calculations. Information was obtained from [8] on how to assess the achievement of the limit state of structures in the event of an emergency situation. Special attention was paid to the use of optical fiber (OF) for measuring and controlling various physical quantities, as well as sensors created on the basis of OF [9]. It can be noted that the world has accumulated quite a lot of experience in the successful use of OF as sensors.

RESEARCH METHODS AND RESULTS

As stated earlier, the basis of the proposed method for controlling the stress-strain state of steel structures of electromechanical systems subject to fatigue failure is considered in detail in the previously published article [1]. The present article is a logical continuation of the previously started scientific work and complements the previous scientific report in terms of adjustments and improvements of the proposed method. Also presents some results of practical testing.

The measuring part was changed, as it was previously proposed to use optical fiber loops as sensors, which did not quite justify itself in practice, since it complicated the installation of optical fiber on the surface of a steel structure that was subjected to deformation. Loops with a diameter of 3 to 4 mm were formed on the surface, the distance between them was from 50 to 200 mm. The optical fiber was glued to the surface of the metal structure with epoxy glue, but the loops were not glued, which allows them to change their diameter when the surface is deformed (Figure 1).

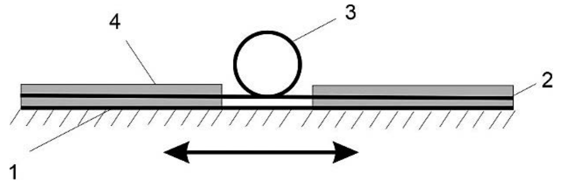

Figure 1 Sensor design having an optical fiber loop (sensor): 1 – side face of the beam, 2 – optical fiber, 3 – optical fiber loop (sensor), 4 – layer of epoxy glue [1]

This caused a number of difficulties during installation, when it is necessary to form loops and further operation, when they can be damaged during MHM repair or maintenance. In other respects, this sensor turned out to be quite sensitive to the stress-strain state of steel structures of mine hoisting machines.

The control system was installed on 10 MHM and observations carried out from May to October 2022 showed that the method is workable and allows to control the deformation of steel beams of MHM in real time. Constant controlling of thestress-strain state of metal structures makes it possible to identify "Emergency-hazardous destruction zones" in time. OF allows to control the deformation of a steel structure with high accuracy and with the lowest energy consumption. The sensor design has been modified to simplify it. The software has also been changed to take into account the change in the sensor design. The updated version of the sensor is shown in Figure 2.

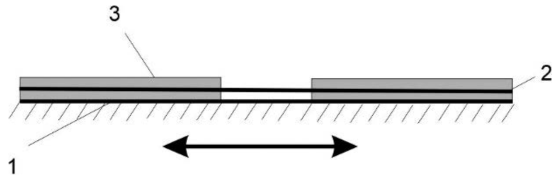

Figure 2 Advanced sensor design without an optical fiber loop (sensor): 1 – side face of the beam, 2 – optical fiber, 3 – optical fiber loop (sensor), 4 – layer of epoxy glue

The measurement scheme has been improved. It has become possible to increase the number of measuring channels from 4 to 16 (Figure 3). A detailed description of the scheme and the principle of its operation has already been presented earlier in [1].

The laser beamis emitted from the adapter 6, passes through the OF and returns to the adapter 7, after which

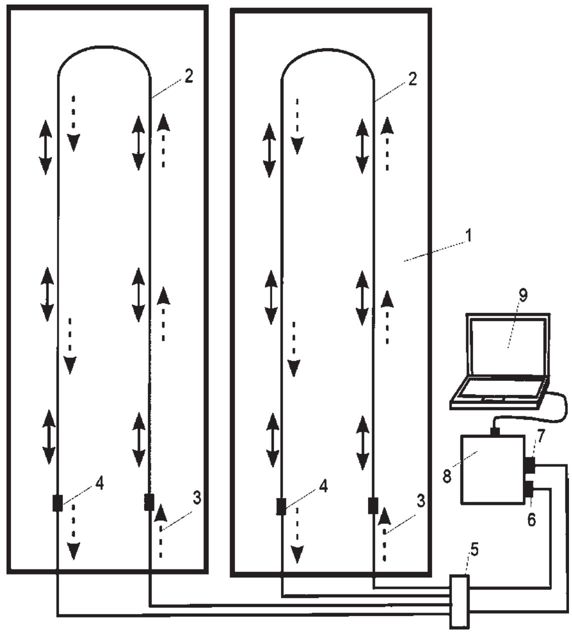

Figure 3 Measurement scheme: 1 – side face of the beam, 2 – optical fiber, 3 –direction of movement of the light wave through the sensors, 4 – connector, 5 – optical distribution frame for connecting patch cords, 6 – output adapter, 7 – input adapter, 8 – data processing unit, 9 – laptop with software

it falls on the surface of the 4 K high-resolution photo matrix. The matrix simultaneously controls up to 16 light spots falling on its surface.

This is an important change that made it possible to replace 4 HD matrices in the first version with one 4 K matrix.

The change lies in the presence of an optical distribution frame 5, which allows to expand the number of connected channels from 4 to 16, which is necessary for better controlling of all metal structures of the MHM, since 4 channels did not provide complete control. Sensors are installed similarly and a light wave generated by a semiconductor laser with a wavelength of 650 nm is transmitted through them. The movement of the beam is shown by the dotted arrow 3.

Figure 4 shows the updated results of measuring the deformation of steel structures using the improved measurement scheme.

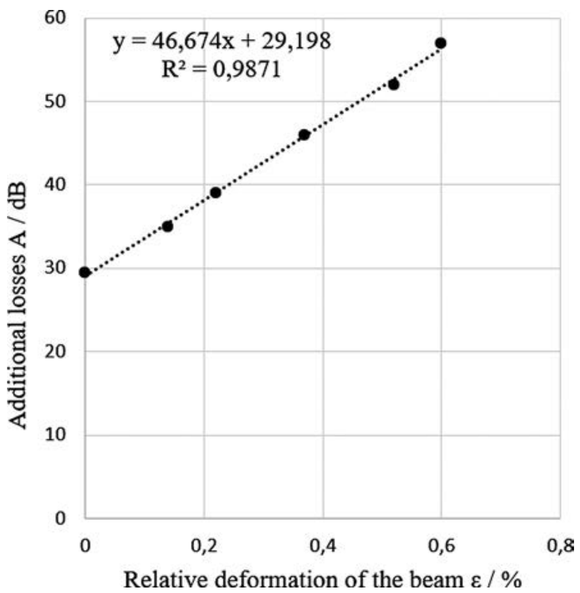

Figure 4 Graph of the additional losses of a light wave growth with increasing mechanical stresses of the beam

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.

DISCUSSION AND CONCLUSIONS

The improvement of the stress-strain state measurement system made it possible to increase the measurement accuracy, as well as increase the number of measuring channels to 16 and improve the operational characteristics of the control system. During the operation of the control system, it was revealed that the semiconductor laser must be strictly coherent, and also have a minimum pulsation and deviation not exceeding 1 %. Large deviations reduce the measurement accuracy and can cause significant noise in the measuring channels. For this purpose, the power supply has been upgraded, which now provides not only stabilization of the supply voltage of the semiconductor laser, but also its pumping current. The use of a 4 K high-resolution photo matrix made it possible to controlup to 16 channels in real time and analyze 16 light spots falling on its surface.

The proposed method of non-destructive testing of stress-strain state of metal structures has been practically tested and is universal, since it can be used in various industries where it is necessary to control the stress-strain state of metal structures. Using the OF, it is possible to create a distributed stress-strain state control system for various metal structures that works in real time. It is also possible to determine with high accuracy the places of occurrence of mechanical stress concentrators and timely determine fatigue failure zones.

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Note: Tranlated from Russian into English by N. Drak, translator of Karaganda Technical University