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METHOD OF COMBATING FATIGUE DESTRUCTION OF STEEL STRUCTURES OF MINE HOISTING MACHINES

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The article presents the information of the identified defects of fatigue failure of steel structures of the brake mechanism of mine cable hoisting machines used to transport metallurgical coke from the mine to the surface. Using non-destructive testing methods a survey was carried out of the brake mechanisms of sixty mine cable hoisting machines. A method was developed to combat the fatigue failure of steel structures through the use of reinforcing elements to reduce their metal consumption and increase resistance to fatigue failure, while the use of expensive high-strength alloys is completely eliminated. To study the stress-strain state and fatigue failure of steel structures, a computer simulation method was used. Using the ANSYS computer program, the optimal forms of reinforcing elements were established and the loaded part of steel structures in continuous operation was simulated. Eleven computer models of a steel beam with various reinforcing elements were developed. The research results were used in practice in the repair of steel structures.

Key words: mine hoisting machines, brake, fatigue strength, fatigue crack modeling, stress-strain state

INTRODUCTION

At the mining and metallurgical company ArcelorMittal, for transportation of metallurgical coke from the mine to the surface, there are used rope mine hoisting machines (MHMs). Metallurgical coke is mined only by underground mining, since the main reserves are located at great depths. In 2019, sixty MHMs were examined using non-destructive testing methods. Comprehensive studies of the fatigue failure causes of their brake mechanism steel structures were carried out. All the MHMs in operation have a significant period of the mechanism operation within 30 - 60 years.

The causes of the conditional destruction of steel structures, which are associated with increasing the mechanical load on the elements of the MHM, were established. The volume of daily transportation of coking coal increased and the speed of movement of the hoisting vehicle along the shaft increased.

The relevance of the work lies in the development of a method of combating the formation and development of fatigue cracks in steel elements of the MHM braking mechanism, to ensure trouble-free and reliable operation. In the future, it is possible to develop steel structures with desired properties and reduced metal consumption. Fatigue cracks lead to the sudden destruction of the steel structure of the brake mechanism and occurrence of an emergency. The percentage of the identified fatigue defects of steel structures of the MHM braking mechanism is shown in Figure 1.

These defects affect the accuracy of the braking mechanism and develop a danger of its sudden failure and destruction due to the development of fatigue cracks. Elimination of the above-mentioned malfunctions requires expensive labor-consuming repairs related to disassembling the main components of the brake mechanism, which causes a long-term MHM idle time.

The task is to develop a method to combat the fatigue failure and increase strength of the brake mechanism

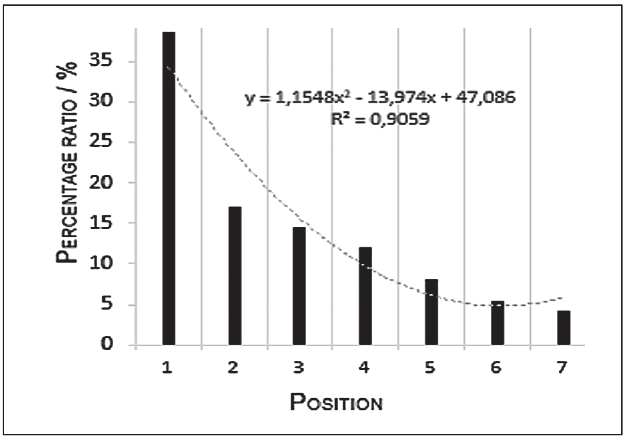

Figure 1 The percentage distribution of the detected defects of the brake system elements by their type: 1 - destruction of the hinge joints; 2 - cracks in the area of the bushings mounting eyes; 3 - cracks in vertical and horizontal brake rods; 4 - damage to the brake rim; 5 - cracks in the studs of the suspension; 6 - cracks in the rods of the drive vertical traverse; 7 - others

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steel structures. It is necessary to find an optimal shape of the structure capable with a smaller wall thickness to withstand the fatigue failure. In practice, the method has been used in the repair of existing steel structures of the existing MHMs in long-term operation.

ANALYSIS AND RESEARCH METHODS

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 [1, 2]. The causes and nature of the appearance of cracks and S-N characteristics for various steels and the behavior of the S-N curves [3], especially in the mode with a high fatigue cycle [4, 5] were considered. There were analyzed the causes and factors affecting the mechanism of fatigue failure of steel structures [6, 7].

To obtain the numerical data of mechanical stresses, the metal magnetic memory method was used using the IKN-1M instrument, and ultrasonic defectoscopy was used to determine the dislocation and parameters of fatigue cracks. To carry out computer modeling, the ANSYS program was used, which allows simulating the stress-strain state of the MHM elements and to exclude cumbersome full-scale tests of experimental samples. By modeling, it is possible to find the best option for the strengthened structure with higher strength and reliability parameters, as well as to develop practical recommendations for restoring strength by carrying out repair and restoration work. Using computer visualization of the stress-strain state of the steel structure and the practical results of defectoscopy, an adequate model of the structural element of the brake system was developed in the ANSYS program. This allows increasing the accuracy of computer simulation to identify weak places in the structure and to identify the occurrence of emergency-dangerous zones of the fatigue failure. The results of computer modeling make it possible to achieve the optimal shape of the structural strengthening element and its dislocation, used to eliminate the concentration zone of mechanical stresses and the place of fatigue failure and crack development.

The use of the metal magnetic memory method in searching for fatigue cracks allows determining the places of their dislocation at early stages. Accordingly, it is necessary to mount strengthening elements that impede fatigue failure. The parameters of the structural strengthening element are determined by studying computer models in the ANSYS program. Adequate computer models developed must have a correlation in terms of mechanical stresses arising in real structures and take into account the results of practical measurements. Without this factor, it is impossible to avoid errors in calculating the parameters of the gain elements and their location on the structure using computer simulation. It is also necessary to achieve a real coincidence of the zones of stress concentration of the MHM real designs and the developed computer models. Considerable attention must be paid to the selected type and size of the finite element, since this factor affects the accuracy of the simulation results.

COMPUTER MODELING OF THE STRESS-STRAIN STATE OF A STEEL STRUCTURE

The obtained adequate computer model is used to search for solutions to strengthen the structure in the place of its fatigue failure, as well as when designing a new structure with reduced metal consumption and predetermined properties that reduce the risk of cracking. Using the computer model, it is possible to design a lighter structure with a beam wall thickness of 40% less in the unloaded zone and strengthened in the loaded zones, this will reduce the wall thickness of the brake beam from 30 mm to 20 mm without losing its strength, since the design provides a triple margin of safety which greatly increased the unnecessary metal consumption of structures. Using computer simulation allows obtaining more accurate results in the design. Visualization of the distribution of mechanical stresses under its loading, modeled in the program in the ANSYS program, is shown in Figure 2.

Solid lines with an arrow indicate places with stress concentrators in which fatigue cracks can develop leading to the destruction of the body of the steel beam and welds. The dashed line shows the area of load application. The computer model was developed taking into account all the technical parameters and loads of the real steel beam of the MHM braking mechanism [6].

Under operational loads, decreasing the fatigue strength was noted in the beam structure, not only in the hazardous area marked by lines with solid arrows but also in the area of welds of the upper and lateral edges of the beam [6]. The analysis of the fatigue failure of the beam metal performed in the ANSYS program taking into account the cyclic load factor shows that the main

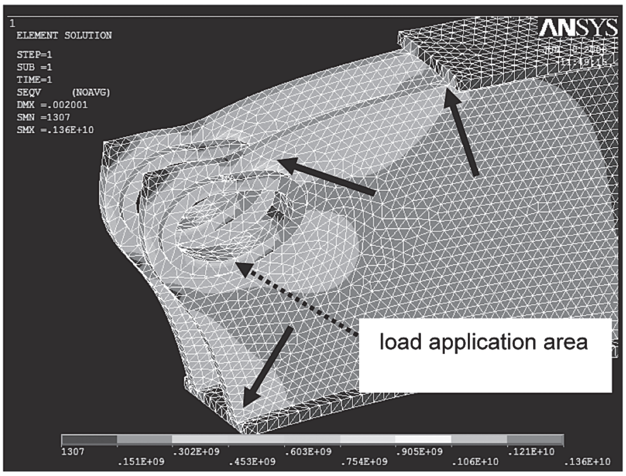

Figure 2 Computer model of the steel beam structure when loaded

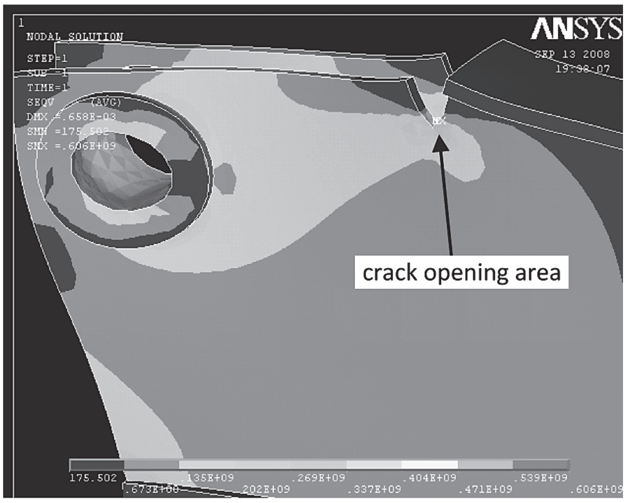

Figure 3 Computer model of the beam structure with displaying the process of development of a fatigue crack in the "emergency-dangerous zone

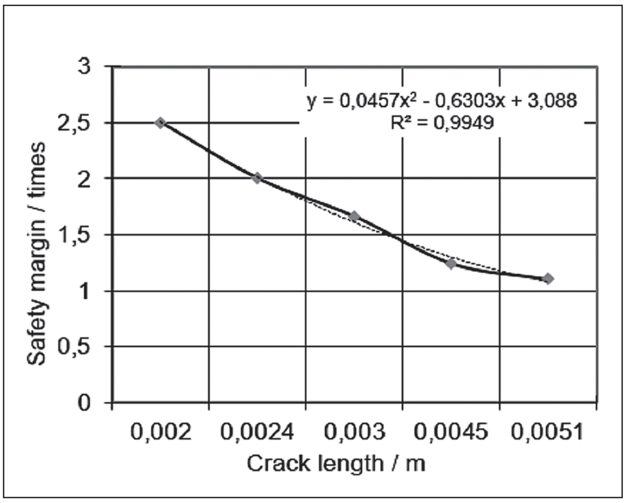

Figure 5 Safety margin dependence on the crack length

factors in the development of fatigue cracks are the amplitude of stresses and strains; the duration and number of cycles [6]. A crack develops in hazardous areas, where in the future a strengthening element is mounted to localize it. Visualization of the crack development process modeled in the ANSYS program is shown in Figure 3.

With increasing the length of the crack, the beam strength decreases, and the permissible load on it decreases; the results are shown in Figure 4.

In the process of the fracture development, a transition from a hidden (thin) to an external (wide) crack is observed, which is explained by metal fatigue, accompanied by accumulation of damage in the metal grain boundary region from cycle to cycle. In the event of a fatigue crack, the beam strength decreases sharply; the results are shown in Figure 5.

Figure 6 shows the options of strengthening elements for a steel beam structure. To strengthen the beam, the following elements are used: disk pad - 1; stiffener - 2; ring pad - 3. The use of a combination of strengthening elements significantly increases the structure strength.

In the process of research there were developed eleven computer models of the beam with various combinations of strengthening elements, as well as the location on the body of the beam and, based on the scientific analysis, one of the most effective options of its strengthening was selected with the "disk pad + stiffener + ring pad" combination.

Such a beam with the wall thickness of 20 mm has a margin of safety and is able to resist the fatigue failure, as well as a beam with the wall thickness of 30 mm, thereby saving metal up to 40%, without loss of strength at the same value of operational loading. Strengthening elements are made of the same steel grade as the beam, in our case it is low-carbon structural steel CT10 (Russia); there is its American analogue AISI C1010 or German one DIN C 10.

In the process of modeling, it is possible to establish the nature of changing the growth rate of the fatigue crack, which depends on the asymmetry coefficient of the stress intensity cycle. The use of structural strengthening elements allows reducing the value of

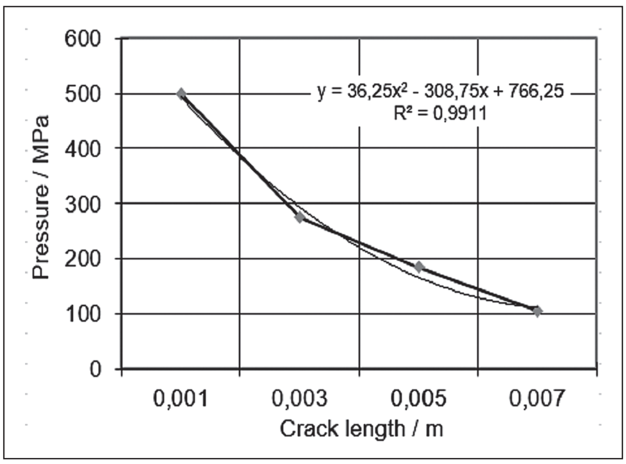

Figure 4 Reduction of permissible stress values during loading resulting in structural failure dependence on the length of the crack growing in it

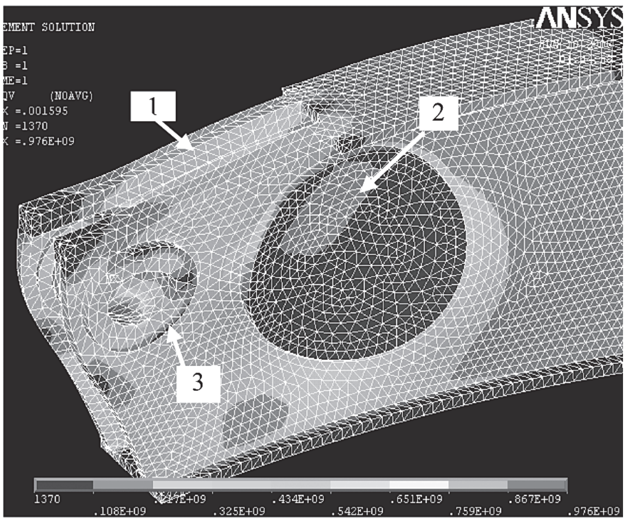

Figure 6 Various options of strengthening elements and their location

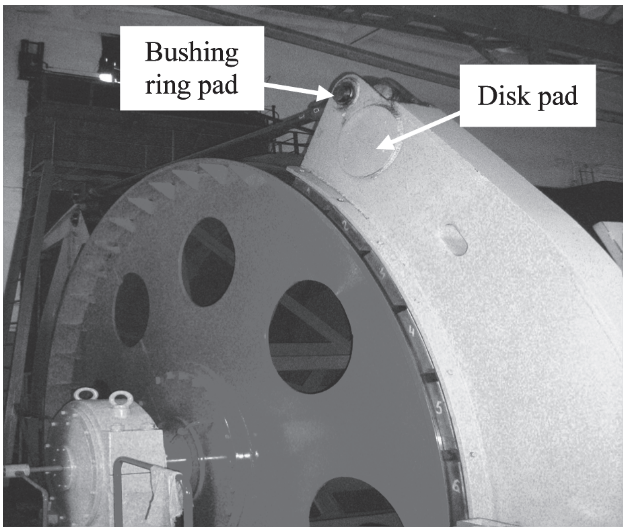

Figure 7 An example of mounting the strengthening elements during repair and strengthening of the MHM 2 C - 6 x 2,4 brake beams

the coefficient of asymmetry of the stress intensity cycle and significant reducing predisposition of crack closure to the state change at the threshold of fatigue and the asymmetry of the stress cycle, which ultimately reduces the likelihood of the fatigue crack growth. The conditions of the process of formation and growth of fatigue cracks in the structure directly depend on the parameters of the stress cycle (magnitude, asymmetry, frequency) and environmental impact (its chemical activity, humidity, temperature), as well as the nature of the stress-strain state at the top of the crack in the structural element, which is determined by their geometry and dimensions.

RESEARCH RESULTS, DISCUSSION AND CONCLUSIONS

The capabilities of the ANSYS program allow simulating the loads on the beam elements associated with the cyclic load and the asymmetry of the cycle, as well as establishing the exact geometric dimensions of the strengthening elements and their location on the beam body. The proposed method passed practical testing during the repair and reinforcement of the design of the MHM 2 C – 6 x 2,4 brake beams that are in operation at the ArcelorMittal mines (Figure 7); the disk and ring pads were used.

After the repair was carried out, the design of the MHM 2 C – 6 x 2,4 brake beam was carried out using ultrasonic flaw detection methods within 8 months of 2019. The observations showed the absence of zones with fatigue cracks.

The use of strengthening elements in the repair or design of the MHM steel structures of brake mechanism beams will increase strength and reliability of the steel structure, reduce the metal consumption of the structure, and increase resistance to the fatigue failure. The method allows quick repairing and restoring the steel structure without disassembling the brake mechanism. The strengthening elements can be used to increase the fatigue strength of any steel structures and are mounted in places of the identified zone of the fatigue failure.

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