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STRENGTHENING ELEMENTS OF STEEL STRUCTURES FOR CONTROLLING FATIGUE FRACTURE

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The article deals with the issues of reliable operation of steel structures of mine hoisting machines. It is proposed to strengthen the "weak points" of the braking device beam structure, which will further prevent the formation and growth of cracks in the body of the metal structure. The article presents the results of examining steel structures of mine hoisting machines by the methods of non-destructive testing and the percentage of various damages is determined. The article discusses the method for controlling fatigue failure of steel structures through the use of strengthening elements to reduce their metal consumption and increase resistance to fatigue failure, while completely eliminating the use of expensive high-strength alloys.

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

INTRODUCTION

The relevance of reliable operation of the mine hoisting machine (MHM) braking device throughout the entire service life is dictated by the Safety Rules and has already been considered earlier [1].

This article is a continuation of scientific work [1] and is aimed at solving the problem of the formation and growth of fatigue cracks in the steel beam of the brake device (BD). One of the solutions to the problem is to strengthen the "weak points" of the BD beam structure using strengthening elements.

Strengthening elements allow increasing the beam structure strength.

They are mounted on the lateral surfaces of the beam in places where mechanical stresses are concentrated and prevent the development of fatigue cracks.

Strengthening elements allow extending the structure service life, as well as providing the required strength and reliability of its operation.

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 [2, 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], especially in the mode with a high fatigue cycle [5, 6] were considered. The use of strengthening elements for controlling fatigue cracks is considered and the practical results of their application are given in [7]. There were analyzed the causes and factors affecting the mechanism of fatigue failure of steel structures [8]. The results of studying fatigue cracks in metal structures were also studied [9, 10]. The literature sources discussed above made it possible to obtain the information of the problem of fatigue failure of structures in long-term operation. The cause of the formation of cracks is the presence of stress concentrators in the "weak points of the structure". To confirm the idea put forward regarding the use of strengthening elements, in April 2 020 a comprehensive survey of 53 mine winders in operation at the Arcelor Mittal JSC was carried out using a USN 60 ultrasonic flaw detector from the Krautkramer Company. Based on the results of the survey, a list of identified defects was compiled: 40,3 % were wear or damage to the BD hinge joints and 59,7 % were fatigue cracks in steel structures of the BD (beams, rods, drum), which coincides with the results of surveys carried out earlier [1, 7]. The largest number of cracks was found in the BD beam, about 19 % of them. Figure 1 shows a photo of the location of a fatigue fracture with a fatigue crack in the body of a steel beam under a layer of protective paint.

The crack dislocation site was cleaned from the layer of protective paint for subsequent repairs and placing a reinforcement element on it. The repair was carried out according to the recommendations discussed in detail and given in articles [1, 7]. After the repair was completed, strengthening elements were mounted on the side surfaces of the BD beam, which completely eliminated the consequences of destruction and increased the structure strength as a whole [1, 7]. Fatigue

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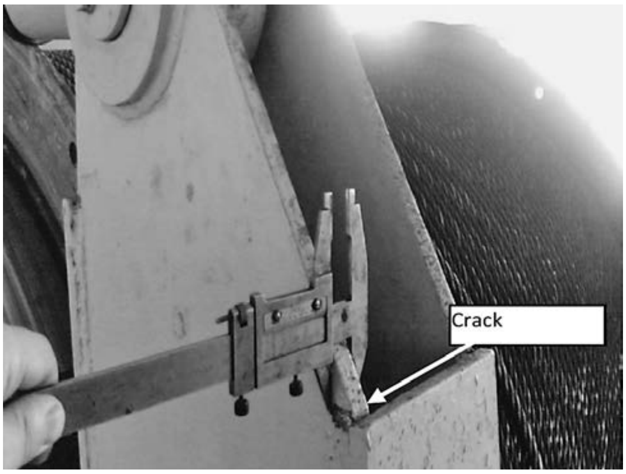

Figure 1 Location of the crack in the beam body

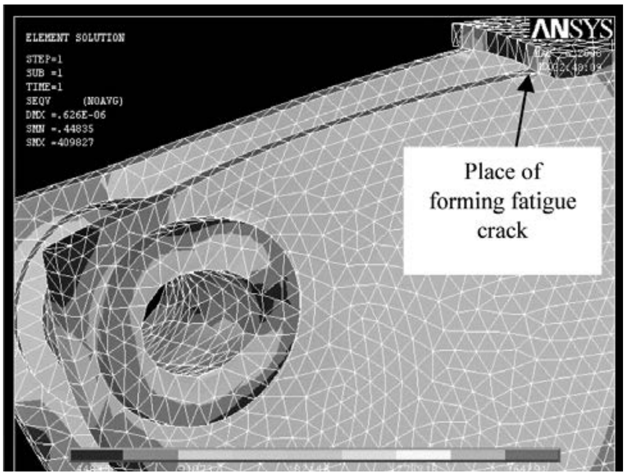

Figure 2 Computer model of the BD beam

failure of metal structures of mine hoisting machines (MHM) of the Arcelor Mittal JSC is a natural factor of ultimate wear of structures, since 48 out of 53 mine hoisting machines have a service life of the BD mechanism within 30 - 60 years. The company is working to replace the outdated mine hoisting machines fleet with new ones, but this is a very slow process in time, since its implementation requires serious financial costs. The causes of the conditional destruction of the BD steel structures are increasing the mechanical load on the elements of the MHM, since the volume of daily transportation of coking coal increases, as well as the speed of movement of the lifting vessel along the mine shaft. Thus, these factors cause increasing the dynamic loads on the elements of the braking device.

The main way to repair the beam in the case shown in Figure 1 is cleaning the place with the detected crack from paint, cutting the crack using electric arc welding to restore the integrity of the structure, treating the seam, and re-painting. As practice has shown, this method does not fully solve the problem. After the repair, the cracks develop again within 2 to 8 months. In this case, repeated repairs are required, and if it was multiple, the replacement of the entire beam. If to mount strengthening elements on the side faces of the beam, the problem of fatigue failure is completely removed. This has been proven by the given periodic visual observation within 6 months and repeated examination using an ultrasonic flaw detector. As a result, the fatigue crack is completely localized and its development is stopped. Similar results are presented in works [1, 7].

COMPUTER MODELING OF THE STRESS-STRAIN STATE OF A STEEL STRUCTURE OF THE BRAKE MECHANISM BEAM

The results of computer simulation of the stress-strain state (SSS) of the BD beam gave the results of a fundamental error in its design and determining the values of internal mechanical stresses arising under working loads. The design of the of the braking device elements of the MHM should be carried out using computer programs that provide visualization of the stress-strain rate, and allows determining the stress concentrators in the structure. To extend the service life of the mine hoisting machines, it is necessary to reduce mechanical stresses in the structure, which is achieved by using strengthening elements and optimizing its shape. Figure 2 shows a computer model of a BD beam, which allows accurate visualizing its stress-strain state under operational loading. Figure 2 shows the places with the maximum concentration of mechanical stresses, in which fatigue cracks are formed. The place of fatigue crack formation in Figure 2 completely coincides with the place of dislocation of a fatigue crack shown in Figure 1. Based on the results of studies of the stress-strain state of the BD beam, recommendations were developed for designers dealing with the problem of fatigue failure of MHM structures.

At the initial stage, it is required to develop an adequate computer model of the beam using the ANSYS program. The method of determining the parameters of the reinforcement of the technical unit structure requires preliminary simulation of a real beam of the MHM in exact accordance with its real geometric parameters and the full adequacy of the applied load. This will make it possible to determine the values of maximum stresses and strains that will occur in the beam during operation. The model makes it possible to identify “structural weaknesses” in which fatigue cracks can develop. The cause of the formation and growth of cracks is the presence of stress concentrators, which lead to fatigue failure of the beam structure. Elimination of stress concentrators will significantly increase the structural safety margin. The use of strengthening elements of the braking device beam structure will extend the service life and ensure the required reliability; the theoretical substantiation of these statements was given earlier in [1, 7].

In the process of searching for the optimal shape of the beam and placing strengthening elements on its edges, more than 40 different models were developed.

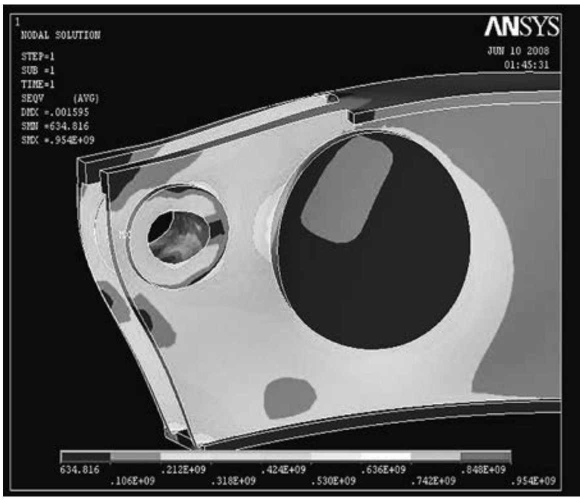

Figure 3 Computer model of the beam with strengthening elements

Among them, 11 models with the best performance were selected for further comparison and selecting the most optimal reinforcement option for this case. The most optimal in terms of its performance is model No. 26 with the wall thickness of 20 mm made of low-carbon structural steel CT10 (analogue of AISI C1 010 or DIN C 10).

This model performed the best when compared to the standard 20 mm beam structure of similar steel. The idea proposed by the designers to increase the thickness of the beam walls to 40 mm (ST10 steel) was tested. This would prevent fatigue failure of the beam in emergency-hazardous zones of cracking but it would significantly increase its metal consumption, which would negatively affect the operation of the entire brake mechanism of the MHM. The model of beam No. 26 with strengthening elements is shown in Figure 3.

It is visualization of the SSS pattern. Strengthening elements allow eliminating mechanical stress concentrators and «structural weaknesses» where cracks have formed in practice.

The elements of the type «rib» and «disc pad» are used, namely their combination. Their geometrical parameters were also established, according to the recommendations of [1, 7]. It was proposed to reinforce the beam with strengthening elements and form its profile according to the computer model shown in Figure 3.

For accuracy, the bearing capacity of all 11 variants of beam models with different reinforcement options was estimated, the features of the elements were discussed earlier in [1, 7]. To assess the load capacity of the strengthened, the gain Δ was determined, which characterizes increasing the bearing capacity of the structure.

$$\Delta = \frac{[\sigma'_{\max}]}{\sigma''_{\max}}$$

where $[\sigma'_{max}]$ is the value of maximum stresses occurring under mechanical loading in the standard structure, without strengthening elements, MPa; σ''_{max} is the value of maximum stresses occurring under mechanical loading in the strengthened structure, MPa.

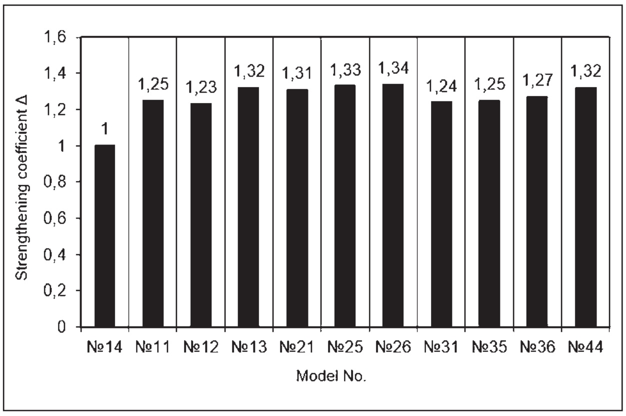

Figure 4 Results of calculating the coefficient of the structure reinforcement Δ for 11 computer models of the beam.

Using the research results, the calculation of the reinforcement showed its relationship with the bearing capacity of the beam structure. Increasing this parameter is noted when using strengthening elements. The conventional design has the coefficient Δ = 1, and the beam design No. 26 with strengthening elements has the coefficient Δ = 1,34; this is the best result. In this case, the thickness of the walls and the material of the beam are identical (Figure 4).

DISCUSSION AND CONCLUSIONS

It is possible to select the shape and geometrical parameters of the strengthening elements to increase the supporting structure. Analyzing the diagram in Figure 5, we can conclude that the shape-optimized strengthened structure No. 26, with the wall thickness of 20 mm, is capable of operating with the same margin of safety as design No. 44 without strengthening elements with the wall thickness of 40 mm.

The use of strengthening elements can significantly reduce the concentration of mechanical stresses in emergency-hazardous zones of cracking, it is also possible to increase the beam structure strength and its static strength margin. When designing, it is possible to optimize the shape of the structure to set the required properties. The use of strengthening elements ensures elimination of stress concentrators and centers of fatigue failure in the designed structures, and makes it possible to abandon expensive high-strength steels and to reduce the metal consumption of the structure as a whole.

Figure 5 shows the results of alculating the coefficient of static strength β for the BD beam structure. Analyzing the diagram, we can conclude that structures No. 26 and No. 44 have similar strength.

The use of reinforcing elements makes it possible to solve the problem of fatigue failure, to reduce the metal consumption of the structure and to increase brake beams steel structures resistance of the MHM for fatigue failure. Reinforcing elements can re-duce the values of maximum mechanical stresses in the zone of formation of fatigue cracks.

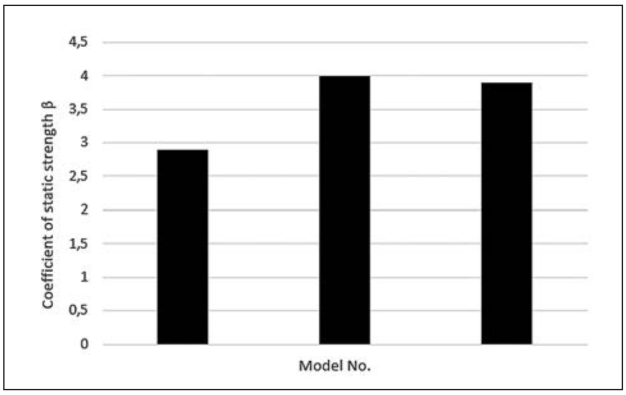

Figure 5 Results of calculating static strength of the BD bean structure: No. 14 is a standard structure with the wall thickness of 20 mm; No. 26 is a strengthened structure with the wall thickness of 20 mm; No. 44 is a structure without strengthening elements with the wall thickness of 40 mm.

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Note: Translated from Russian into English by N. Drak, translator of Karaganda Tech-nical University