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ISSN 0543-5846
METABK 61(1) 269-272 (2022)
UDC / UDK 622.3 - 621.86/87: 621 - 59: 620 -16 /539.374: 539.43: 620.18 = 111

STRENGTHENING ELEMENTS TO INCREASE FATIGUE STRENGTH OF MINE HOISTING MACHINE STEEL STRUCTURES

Received – Primljeno: 2021-06-24
Accepted – Prihvaćeno: 2021-09-10
Preliminary Note – Prethodno priopćenje

The article deals with the issues of reliable operation of metal structures of mine hoisting machines. A method has been developed that makes it possible to increase the brake device steel beam structures strength, which will further prevent the formation and growth of cracks in the body of the metal structure. It is proposed to strengthen the «weak points» in the structure to increase strength and resistance to fatigue failure with the complete rejection of using expensive high-strength alloys. To study the stress-strain state and fatigue failure of steel structures, the method of computer simulation was used. The article presents the results of studying metal structures of mine hoisting machines by non-destructive testing methods; the percentage of various damages is determined. The article discusses a method for combating fatigue failure of steel structures through the use of elements that strengthen the structure in the places of its fatigue failure.

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

INTRODUCTION

This article is a logical continuation of the previously published results of scientific work aimed at improving reliability of electromechanical equipment of the ArcelorMittal Mining-and-metallurgical Company [1, 2]. The problem of fatigue failure of metal structures of mine hoisting machines (MHM) is acute. One of the ways to solve the problem of fatigue failure of metal structures in long-term operation is developing methods of their strengthening and restoration of strength.

The developed method is based on the use of reinforcement elements that are places in the places where mechanical stress concentrators arise during structural loading, where fatigue cracks develop later on [1, 2]. Indeed, these are “accidental-hazardous destruction zones” that are to be eliminated since they can lead to complete destruction of the structure and create an emergency situation [1, 2]. The method of dealing with fatigue cracks is described in detail in [1, 2], and there are also given the main results of practical experiments of using strengthening elements. A scientific justification for the use of strengthening elements has been developed, and positive practical experience of their use has been accumulated within 6 years.

In 2021, there was carried out an annual survey of 56 mine MHMs of the ArcelorMittal Company, most of which had already been in operation for more than 30-40 years, and some of them had already worked for more than 50 years [1, 2]. The survey was carried out by non-destructive testing methods including the use of an ultrasonic flaw detector. The results of the survey showed that out of 56 mine hoisting machines, damage was found in 11. It was found that wear and damage to hinge joints made the share of 39 %, and 61 % was the share associated with fatigue failure of steel structures (beams, rods, drums), as well as the share of welded joints destruction. The new results turned out to be almost identical to the results obtained earlier, during examination of the MHMs in 2019 and 2020 [1, 2]. It should be noted that metal structures with strengthening elements placed on them did not have fatigue fracture centers and were recognized as fit for operation. This allows concluding that the efficiency of using strengthening elements is high. It can also be noted that the share of fatigue failure of metal structures is significant and increases with the aging of electromechanical equipment.

When preparing the article, the results of previously published studies were used, aimed at developing methods of combating fatigue failure of steel structures of electromechanical equipment [1, 2]. The world experience was also analyzed, and scientific work carried out in different years was considered.

There were analyzed the structural failure features of various steel alloys having fatigue cracks [3, 4]. The causes and nature of the appearance of cracks and the diagram of stress (S) and the number (N) of cycles before failure (S-N) characteristics for various steels and the behavior of the S-N curves [5], especially in the mode with a high fatigue cycle [6] were considered. There were ana-

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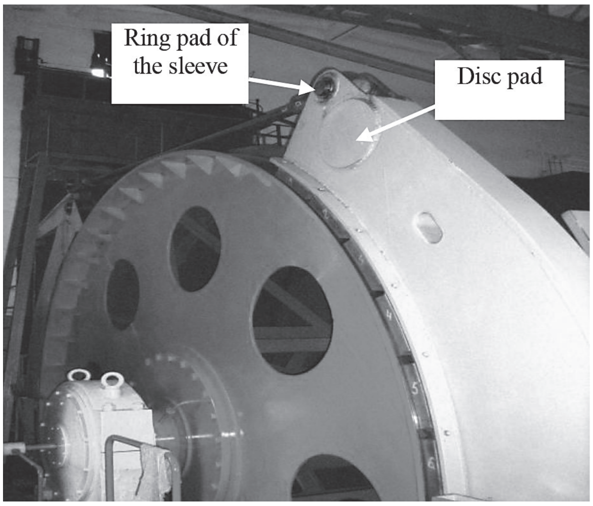

Figure 1 Example of placing strengthening elements during the repair and strengthening the structure of the 2C - 6 x 2,4 MHM brake beams

lyzed the causes and factors affecting the mechanism of fatigue failure of steel structures [7, 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 development of a fatigue crack depends on a set of conditions, for example, the material, the medium, the loading mode, has been described in detail [11].

In works [1, 2] there were considered not all the possible strengthening elements used in the repair of steel beams of mine hoisting machines; these sources do not describe the ring pad of the pivot sleeve mechanism (SRP) that are also subject to fatigue damage. These strengthening elements are also placed on the side surfaces of the brake beam steel structure of the 2 C - 6 x 2,4 MHM (Figure 1).

One of the solutions is increasing the diameter of the pad and its thickness, which can reduce mechanical stresses and increase structural strength, as well as increase the ability to resist fatigue failure. Initially, in the factory version, the diameter of the ring pad of the pivot sleeve mechanism was 85 mm, its thickness was 4 mm but that appeared to be not sufficient. Over time, fatigue fracture centers began to form in the area of the sleeve.

Figure 1 shows that two strengthening elements are used: a “ring pad of the sleeve” and a “disc pad”. In order to understand how the destruction of the SRP occurs, it is necessary to develop a computer model of the hoisting machine brake beam steel structure and to simulate its stress-strain state taking into account the operational loads.

RESEARCH METHODS USED AND COMPUTER SIMULATION

Computer simulation of the stress-strain state (SSS) of the beam steel structure was performed using the ANSYS program. This program has already been used earlier in [1, 2], it allows simulating the stress-strain state of the elements of the hoisting machine, as well as

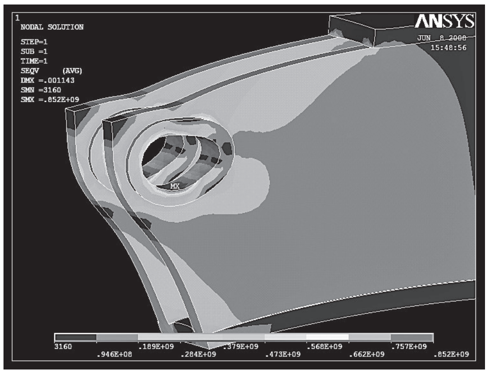

Figure 2 Fragment of a computer model of the mine hoisting machine brake beam steel structure

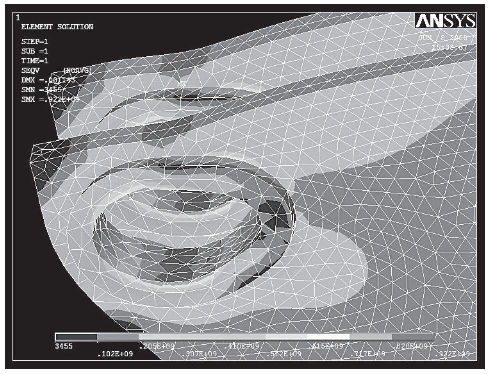

Figure 3 Mechanical stress concentration Zone

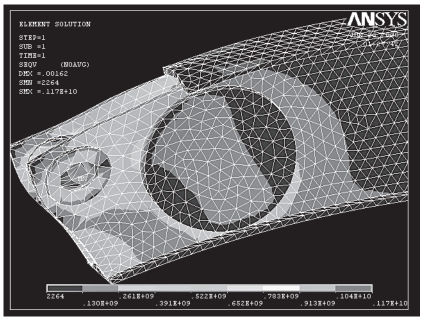

Figure 4 Fragment of the computer model of the mine hoisting machine brake beam steel structure with the SRP and “disc pad” strengthening

excluding cumbersome field tests of experimental samples. Using a computer model, it is possible to determine the optimal structural strengthening elements, their shape and location on the body of the steel beam. Figure 2 shows a fragment of a computer model Hoisting machine brake beam steel structure, which shows the deformation of the SRP under loading and visualization of the stress-strain state.

Figure 3 shows a fragment of a computer model of the brake beam steel structure, where there is indicated the division of the model into finite elements.

In Figure 3, the arrow shows the zone of concentration of maximum mechanical stresses. The pressure on the specified zone varied from 10 to 100 MPa. The pressure change step is equal to 1 MPa. The maximum pressure value was 100 MPa.

To check the results of computer simulation, there were used the results of field measurements of mechanical stresses using the metal magnetic memory method with the TSC - 1M device. This device allows establishing the exact values of the stress-strain state and to determine the location of fatigue cracks in a real structure. Fatigue cracks were also identified using the ultrasonic flaw detection method. An integrated approach to determining the real stress-strain state of the brake beam steel structure of the hoisting machine made it possible to achieve sufficiently high accuracy, in contrast to the classical methods of calculating the mechanics of the solid fracture. Figure 4 shows a fragment of a computer model of the brake beam steel structure of the mine hoisting machine, which shows the places where the SRP and "disc pad" are located.

The computer model has been repeatedly adjusted to achieve the greatest adequacy. It is also necessary to achieve a real coincidence of the stress concentration zones of the real structures of the mine hoisting machine and the developed computer models. The correct selection of the finite element type and its dimensions is very important, since the accuracy of calculating the stress-strain state depends on this. If selection is not correct, the error in the results obtained can reach 300 %.

With the help of computer simulation, the optimal shapes of the structural strengthening elements and their locations were established. It is possible to achieve the maximum discrepancies in the SSS parameters obtained using computer simulation in the ANSYS program and field measurements no more than 10 %. By modeling, it is possible to find the optimal variant of the ring pad diameter. Then in practice it is necessary to check the correctness of the decisions made.

COMPUTER SIMULATION RESULTS

It is possible to maximize the SRP diameter up to d=115 mm. The results of computer simulation shows that with increasing the diameter and thickness of the SRP, the values of mechanical stresses and deformations decrease within 20 %. The research results are shown in Figure 5, where the values of mechanical stresses decrease depending on the diameter of the SRP at the maximum pressure of 100 MPa.

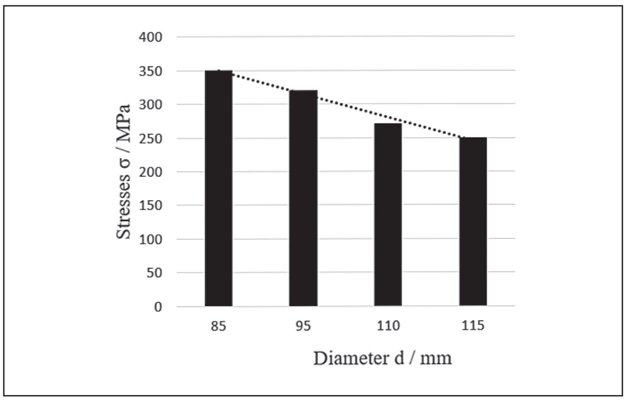

Figure 5 The value of maximum stresses depending on the SRP diameter

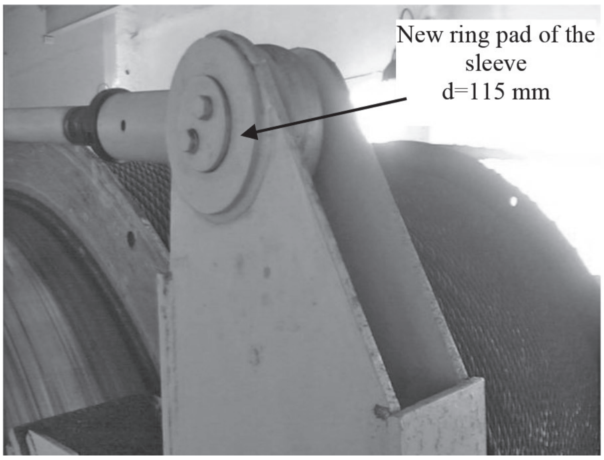

Figure 6 Placing a new SRP with an increased diameter d = 15 mm

In the process of modeling, the search for the most rational SRP diameter and its thickness was carried out. Initially, SRP with the diameter of 85 mm and the thickness of 4 mm was placed in the structure of the brake beams of the 2 C -6 x 2,4 mine hoisting machine. The operational practice has shown that the SRP is subject to fatigue failure and accordingly, it is necessary to take measures to strengthen it. In the experiment, the pressure on the working area of the SRP shown in Figure 3 by the arrow was set from 1 to 100 MPa. We investigated four models of the braking beam structure with a strengthening element "disc pad", while the diameter of the SRP varied from 85 to 115 mm. The best result was shown by the SRP with the diameter d=115 mm.

DISCUSSION AND CONCLUSIONS

There was developed a method of strengthening steel structures and practical recommendations for carrying out repairs aimed at restoring the brake beam of the hoisting machines. The results of the scientific work were used by the engineers of the ArcelorMittal Company when carrying out repair work aimed at localizing the centers of fatigue failure and restoring steel structures strength of 2 C – 4 x 2,3; 2 C – 5 x 2,3 and 2 C – 6 x 2,4 mine hoisting machines. Figure 6 shows the location of the strengthening element, that is using the SRP of d = 115 mm instead of the SRP of d = 85 mm that underwent fatigue growth and was dismantled. Additionally, the SRP thickness was increased to 6 mm.

This method makes it possible to extend the safe operation life of a structure in long-term operation, in particular, by extending the service life of the SRP. Increasing the radius of the SRP makes it possible to reduce the values of maximum stresses and strains up to 20 %.

Acknowledgements

The research is carried out according the project with s. Seifullin kazakh agrotechnical university and within the framework of tomsk polytechnic university competitiveness enhancement program grant.references.

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