DURABILITY ANALYSIS OF LOCOMOTIVE LOAD BEARING WELDED STRUCTURES

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Abstract. *In this article, the causes of possible failures in the welds and near-weld structures of locomotives (main frame, bogie frame and body) and their elimination methods are considered. Analysis of welded joints and their optimization possibilities were studied using the Finite Element Method (FEM).*

Keywords: *finite element method (FEM), load-bearing structures, locomotive frame, bogie frame, SolidWorks Simulation, weld, fatigue cracks, cyclic loading.*

АНАЛИЗ ДОЛГОВЕЧНОСТИ СВАРНЫХ НЕСУЩИХ КОНСТРУКЦИЙ ЛОКОМОТИВОВ

Аннотация. *В данной статье рассмотрены причины возможных отказов сварных и околосварных конструкций локомотивов (главный рама, рама тележки и кузов) и методы их устранения. Анализ сварных соединений и возможности их оптимизации изучались с использованием метода конечных элементов (МКЭ).*

Ключевые слова: *метод конечных элементов (МКЭ), несущие конструкции, рама локомотива, рама тележки, SOLIDWORKS Simulation, сварной шов, усталостные трещины, циклическое нагружение.*

INTRODUCTION

Load-bearing structures of locomotives are exposed to long-term and intensive effects of cyclic loads during operation. The operation of frame structures in such conditions leads to the appearance of fatigue cracks and a decrease in load-carrying capacity. Fatigue damage is one of the main causes of failure of locomotive frame structures, which ultimately affects the safety of traffic [1-3].

Metal structures of locomotives are made by welding from standard rolled low-carbon, low-alloy steel. According to the functional aspect, they can be in the form of frame (bogie frame, locomotive frame), truss (cargo body), plate and shell [12-15].

Cyclic loads that occur when locomotives move along an uneven part of the track can be singled out as the main sources of fatigue from all the impacting loads. These dynamic loads depend on a number of random factors (micro and macro unevenness of the rail bed, wheel wear, changes in the elastic-dissipative properties of the road, etc.), as a result of which they themselves show a random character. Therefore, the loading mode of the load-bearing structures of locomotives during movement is not stable, and the process of changing the dynamic stresses in the structures is not constant [18-20].

It is recommended to evaluate the fatigue life of welded load-bearing structures operating under such loading conditions within the framework of the high-cycle fatigue model based on the generalized linear hypothesis of fatigue damage under unstable loading conditions. The currently used methods of assessing the fatigue life of load-bearing structures often do not take into account the residual stresses of welding. At the same time, residual welding stresses have a significant effect on the fatigue life of load-bearing welded structures under high cyclic loading.

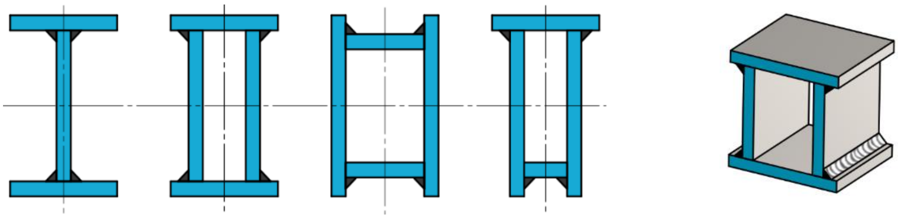
In this regard, the bogie frame is the main node of the locomotive, which is exposed to strong fluctuating loads during operation. Cyclic experimental testing of frame structures by testing samples leads to a significant increase in the time of creating new structures, testing existing structures, and does not always guarantee the choice of a reliable construction option that is reasonable from the point of view of strength and construction. In addition, it reduces competitiveness in the conditions of the modern market economy while moving towards innovative development. The solution to this problem can be achieved by introducing into practice uniform methods for estimating the service life of load-bearing structures, including complex welded joints, as well as by using software packages and computer technologies that allow choosing the most reasonable structural or technological solution [6].

It should also be taken into account that, according to the experience of using the rolling stock, most of the cracks start and develop in the zone of welded joints. The main reason for the sharp deterioration of the plastic properties of metal in the welding zone is dynamic wear due to the concentration of thermoplastic welding deformations. These deformations accumulated in the zone close to the weld or in the vicinity of defects similar to technological cracks located in one of the weld layers lead to embrittlement of the material. Such embrittlement of the metal in the defect zones, together with residual stress and elongation, reaches the yield point of the base material and leads to a very significant decrease in the load-carrying capacity of the welded structures. High tensile residual stresses and metal embrittlement at the failure site lead to failure of metal structures. Most often, they begin in the area of secondary parts, which are welded to the main load-bearing elements with longitudinal seams and have non-welded slots or narrow gaps. Elimination of such a failure is achieved by welding the attached element or by increasing the space between its separate parts.

Research shows that the majority of weld failure is due to fatigue. Loads that change over time during the use of the movement structure, for example, tensile-compressive stress, various combinations of twisting and bending moments in the vertical and horizontal planes, can affect their welded joints.

The most common of the welded frame constructions are open or closed-section welded beam constructions from sheets.

The box-shaped structure of the side beams of the locomotive bogie frames welded from welded beams and sheet elements is shown in Figure. 1.



а) б)

Figure 1. Constructions used for the locomotive bogie frame welded from sheets, a) open and closed beams; b) box section of frame structure

MATERIALS AND METHODS

It is not always possible to carry out an experimental study of the fatigue strength of welded load-bearing structures of locomotives at the stand. This is due to the large size of their geometric dimensions, the weight of their mass, as well as the high cost of their implementation. From this point of view, the assessment of the fatigue strength of welded load-bearing structures is an important factor that determines the resource of the rolling stock, scheduled maintenance and transport safety. Two types of failures, fatigue and brittleness, are observed during use in the welded constructions of the rolling stock [4-7].

Durability and reliability of welded constructions of the rolling stock are mainly determined by their resistance to fatigue. Residual weld tensile stresses significantly reduce the brittle fracture resistance and significantly affect the fatigue strength of welded joints. This is especially noticeable in the side beams and cross beams of the carriage frames, which are attached to additional parts of different hardness in the form of carriages, brackets, hangers and other forms [16-17].

In order to determine the weakest nodes in the stressed state, a finite element model of the frame of the electric locomotive was created (Fig. 2) and the most loaded parts of the structure were determined using the finite element method (Figure. 3).

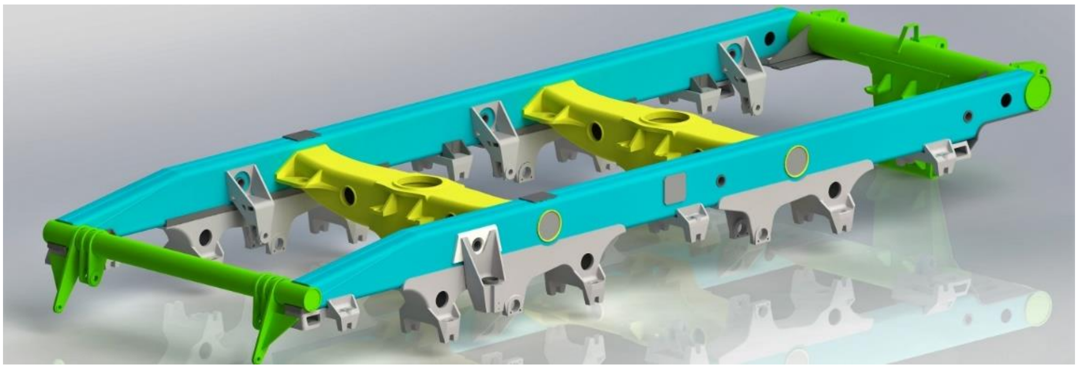


Figure 2. Finite element model of an electric locomotive bogie frame.

Welding in elements with a relatively small thickness of various large parts causes local plastic deformation, which causes a sharp concentration of stress [7]. During use, cracks appear along the borders of the transverse seams that connect these parts to the frame elements. Figure 4 shows the locations of fatigue cracks on the side of the bogie frame of the electric locomotive.

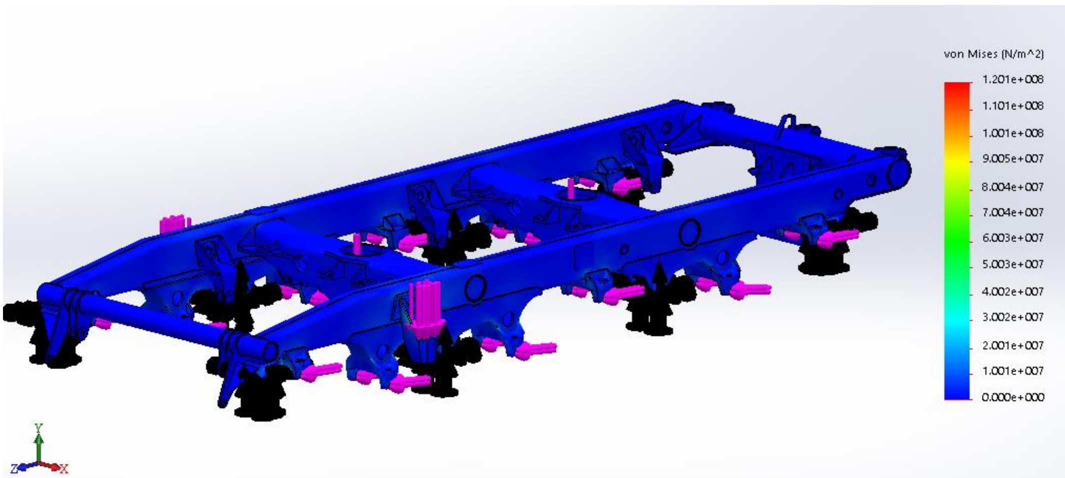


Figure 3. Results of calculating the strength of the bogie frame of the electric locomotive.

RESULTS

The analysis showed that one of the reasons for the failure is the welding of high-hardness cast thick-faced brackets with relatively thin sheets of the side beam. The thickness of the welded brackets and the side beam in the joint is 30 and 10 mm. This creates a significant stress concentration at the interface of the weld with the base metal. In welded frames, due to the short distance between the transverse seams, cracks also appear at the joints.

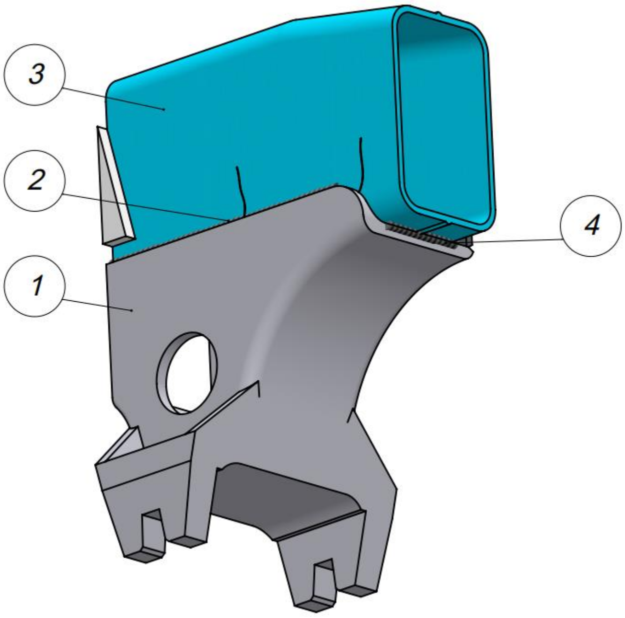


Figure 4. Places of occurrence of fatigue cracks on the side beam of the bogie frame the electric locomotive: 1 - bracket; 2 – longitudinal weld; 3 – side beam; 4 - transverse weld.

The reason for the decrease in the ductility of the metal in welded joints is the occurrence of plastic deformations in defect areas during natural wear in combination with various technological operations [8-10]. The same factor applies to cyclic loading. Material wear before cyclic strain accumulation and fatigue crack initiation can lead to early brittle fracture [11].

CONCLUSION

Finite element models of load-bearing constructions allow not only to analyze the static strength of a certain construction variant, but also to conduct research and choose optimal variants in the modernization of these constructions.

The created finite element model of the frame of the electric locomotive makes it possible to determine and analyze displacements, stresses and deformations calculated in this project, as well as to identify high stress areas in the structure and perform multidimensional calculations. The program allows you to fully study the stress-deformation state of the cart frame, evaluate possible changes that may occur during its modernization, determine effective methods of strengthening it during repair, and develop suggestions for extending its service life.

Locomotive repair is characterized by certain tolerances for welding modes, chemical composition of welding materials, unevenness of joining elements, etc. These factors also affect the welder's skills and individual abilities, and the spread of residual stresses and deformations. Butt welds are made with removable buttplates and after welding are removed and cleaned to eliminate stress concentrators. It is necessary to prevent the edges of the elements to be welded, as this leads to an increase in stress concentration. When the edges are shifted by 25% of the thickness of the welded elements, the stress concentration coefficient increases by 2 times, and when the edges are shifted by 50%, it increases almost 3 times. At the transition points of metal structures from welds to the base metal, there are always sharp changes in the geometric shape, which is characterized by the stress concentration factor.

Welding work should be carried out in specialized enterprises with the necessary equipment, specialists and technologies, taking into account the above requirements, during the period of factory repair.

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