FAILURE ANALYSIS OF LOAD-BEARING STRUCTURES OF INDUSTRIAL LOCOMOTIVES

Parvinabonu Vohidova
Master of Tashkent State transport University
Abdulaziz Yusufov
Doctoral student PhD of Tashkent State transport University
Sherzamin Abdurasulov
Doctoral student PhD of Tashkent State transport University
Shuxrat Jamilov
Senior teacher of Tashkent State transport University

ABSTRACT

In this article, the analysis of the failures occurring in the load-bearing structures of the industrial locomotives in use in the territory of the Republic of Uzbekistan is considered. It is known that various types of industrial locomotives are used in industrial works in the Republic of Uzbekistan today. Currently, locomotives such as TGM3, TGM4, TGK-2, pulverizing aggregates such as PE2M, PE2U are used in various industrial enterprises, mining and metallurgical combines, coal mines. This article analyzes the failures occurring in the load-bearing constructions of PE2U traction units.

Keywords: *industrial locomotives, traction unit, PE2U, load-bearing structure, Solidworks Simulation, FEM, state of stress.*

АНАЛИЗ НЕИСПРАВНОСТЕЙ НЕСУЩИХ КОНСТРУКЦИЙ ПРОМЫШЛЕННЫХ ЛОКОМОТИВОВ

АННОТАЦИЯ

В данной статье рассмотрен анализ отказов, возникающих в несущих конструкциях промышленных локомотивов, эксплуатируемых на территории Республики Узбекистан. Известно, что сегодня в Республике Узбекистан на промышленных работах используются различные типы промышленных локомотивов. В настоящее время тепловозы типа ТГМ3, ТГМ4, ТГК-2, тяговые агрегаты типа ПЭ2М, ПЭ2У используются на различных промышленных предприятиях, горно-металлургических комбинатах, угольных шахтах. В данной статье проведен анализ отказов, возникающих в несущих конструкциях тяговых агрегатов ПЭ2У.

Ключевые слова: *промышленные локомотивы, тяговый агрегат, ПЭ2У, несущий конструкция, Solidworks Simulation, МКЭ, напряженное состояние.*

INTRODUCTION

Load-bearing constructions of traction rolling stock structure are subject to frequent and long-term and rapid effects of cyclic loads during use. The operation of load-bearing structures in such working conditions causes the formation of fatigue cracks and a decrease in load- bearing capacity. Fatigue cracks are one of the main reasons for the failure of load-bearing structures, and as a result affect the safety and reliability of the movement [1-2].

Traction rolling stock load-bearing structures are made by welding from standard rolled low-carbon, low-alloy steels. According to their function, they can be in the form of frame (bogie frame, locomotive main frame), truss (body), plate and shell [1].

The main sources of fatigue from all the impact loads are the cyclic loads that appear when the rolling stock moves along the uneven part of the road. These dynamic loads depend on a number of factors (unevenness of the rails, wheel wear, changes in road properties, etc.), and as a result, they show a random character. Therefore, the loading mode of the load-bearing constructions of the tortuous movement structure during movement is not stable, and the process of changing the dynamic stresses generated in the constructions is not constant [1-2, 3-5].

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 fatigue life assessment methods of load-bearing structures usually do not take into account weld residual stresses. At the same time, residual weld stresses significantly affect the fatigue life of load-bearing welded structures under high cyclic loading [1-2].

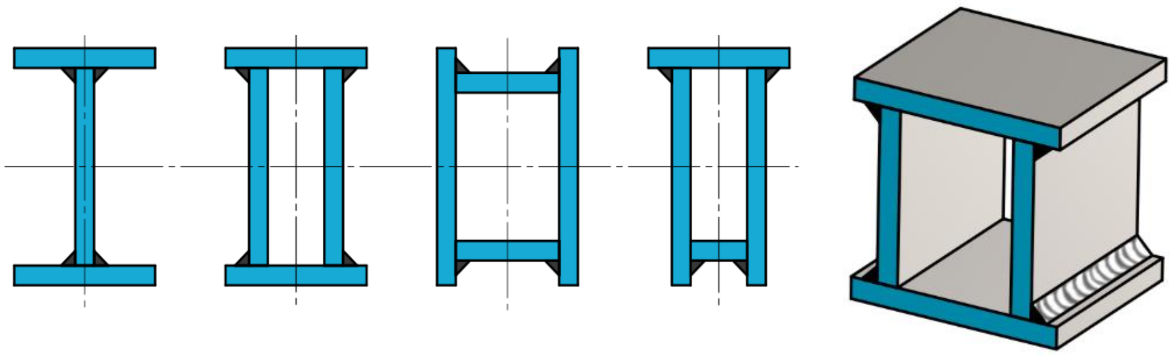
In this regard, the main frame of the traction rolling stock, the bogie frame, and their elements are the main nodes that receive strong variable loads during operation. Cyclic experimental testing of frame constructions by testing samples requires the creation of new constructions, the time of testing existing constructions is significantly long and does not always guarantee the choice of a reliable option from the point of view of strength and construction. In addition, it reduces competitiveness in the modern market economy in a period of transition to innovative development. As a solution to this problem, it is possible to introduce into practice the methods of assessing the service life of load-bearing structures, including complex welded joints, as well as to use software tools and computer technologies that allow choosing a reasonable structural or technological option [3-5, 8].

According to the experience of using the rolling stock, most of the cracks start in the area of the welds. The main reason for the reduction of metal properties in the weld area is wear due to the concentration of thermoplastic welding deformations. These deformations, which accumulate in the area near the weld or in the vicinity of defects similar to technological cracks located in one of the weld layers, cause embrittlement of the material. Such embrittlement of metal in defective areas, combined with residual stress and elongation, reaches the yield point of the material and causes a decrease in the load-bearing capacity of welded structures. Tensile residual stresses and embrittlement of metal in the failure zone lead to failure of metal structures.

Research shows that the main part of the failure of welded joints is due to metal fatigue. During the use of rolling stock, variable loads such as tensile, compressive, tensile, torsional and bending moments affect the welded joints of various 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 locomotive bogie frames welded from sheet elements is shown in Fig. 1 [1].



a) b)

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

Method. Today, TGM3, TGM4, TGK-2 diesel locomotives and PE2M, PE2U traction units are used in industrial enterprises in the territory of the Republic of Uzbekistan. In this article, we analyze the failures that occur in the load-bearing structures of PE2U traction units.

Load-bearing structures of PE2U traction units are made of 09G2 low-alloyed manganese steel by welding [6-11].

Fatigue cracks are the most common failure of PE2U traction unit electric locomotive main frame and motor-dumpcar main frame. According to diagnostic data, fatigue cracks occur mainly in the area of welding seams. The cracks are mainly in the weld areas connected to the ridge beam of the buffer beam (Fig. 2, a), in the weld areas connected to the ridge beam of the conical support bracket (Fig. 2, b),

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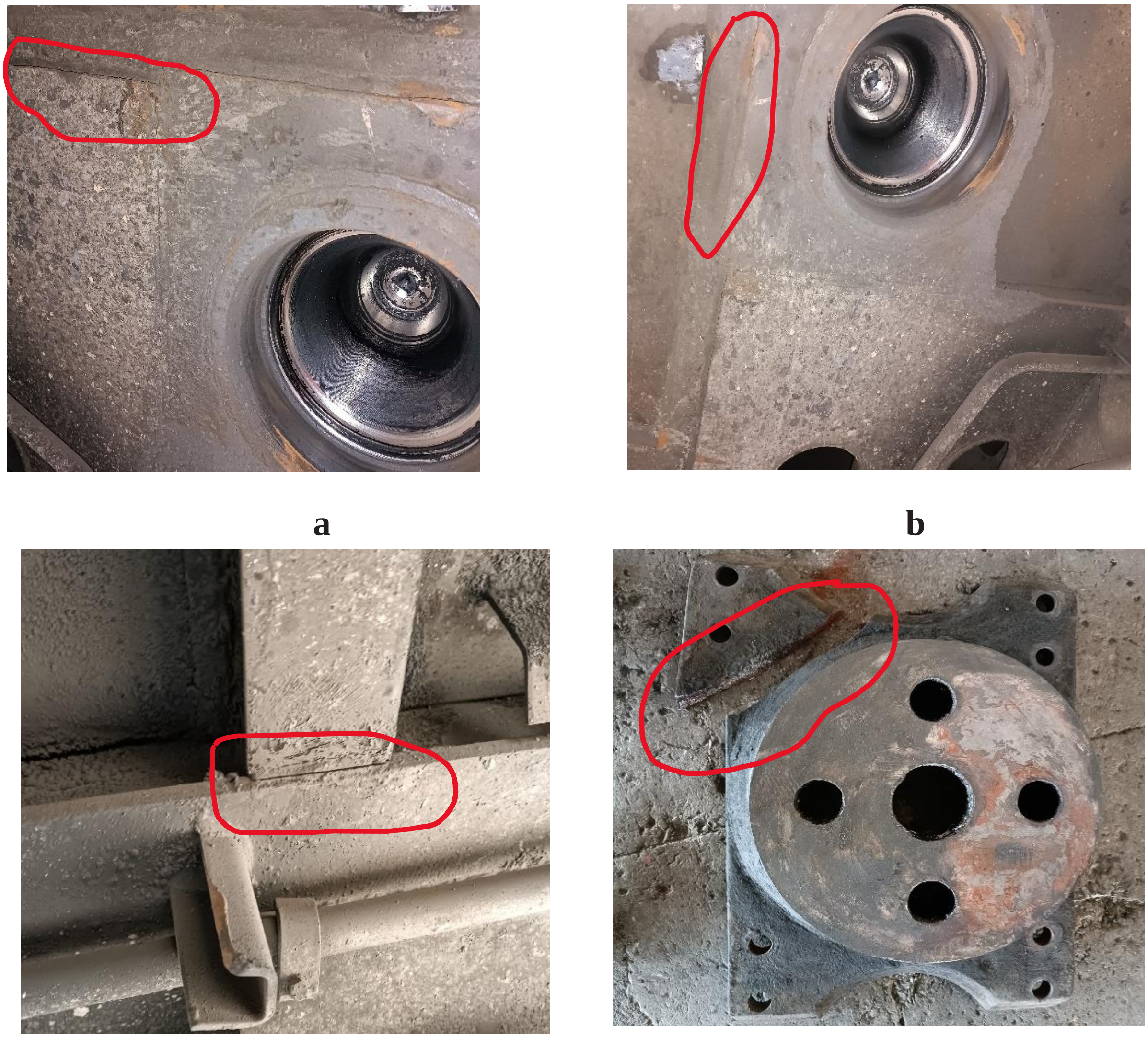
connected to the ridge beam of the transverse beams along with cracks in the weld areas (Fig. 2, c) and central support, fractures are also observed (Fig. 2, d).

To evaluate the stress-deformation state of the central support node, its model was created in Solidworks software (Fig. 3, a). To prevent such failures in the future, a slight change was made to the central support unit (Fig. 3b).

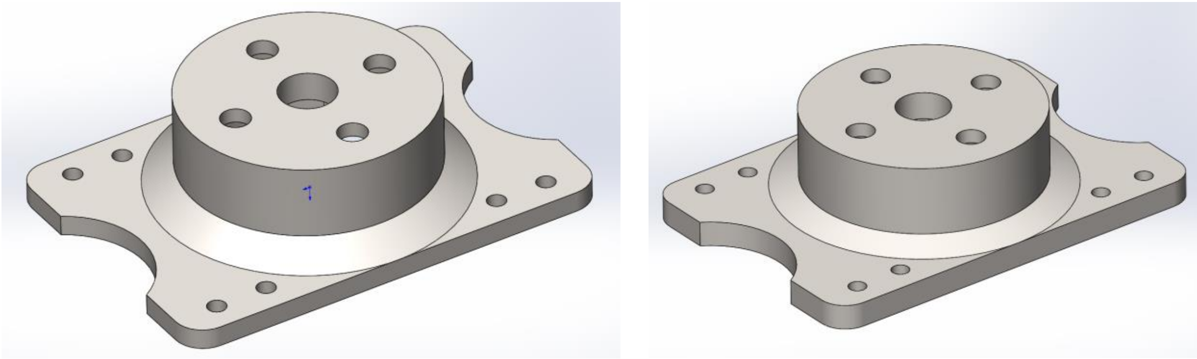
The change is that the thickness of the place where the central support joins the frame has been increased from 35 mm to 45 mm. Its installation limitations were taken into account.



a **b** **c** **d**

Figure 2. The main faults observed in the main frame of the electric locomotive of the PE2U traction unit.

The stress state analysis of these two different models using the finite element method is performed and compared using Solidworks Simulation software.



a b

Figure 3. Models of the central support.

Discussion. The fracture of the central support (Fig. 2, d) indicates a large load on this node. The central support is cast and cannot be repaired in this condition and must be recast [11-19]. It should also be said that the central support is not attached to the frame by welding. Fastening is done by 8 bolts and nuts. This assembly also accepts the traction, braking forces and body weight generated by the bogie.

The maximum traction force of PE2U traction units is $F_{mtf} = 1200$ kN, the weight of the electric locomotive section is $P_e = 120$. The electric locomotive section sits on 2 bogies. Each ava has a central support and 2 conical support plates for the location of the electric locomotive section. So, the vertical load on the central support is equal to:

$$P_{vl} = \frac{P_e}{6}, \quad t. \tag{1}$$

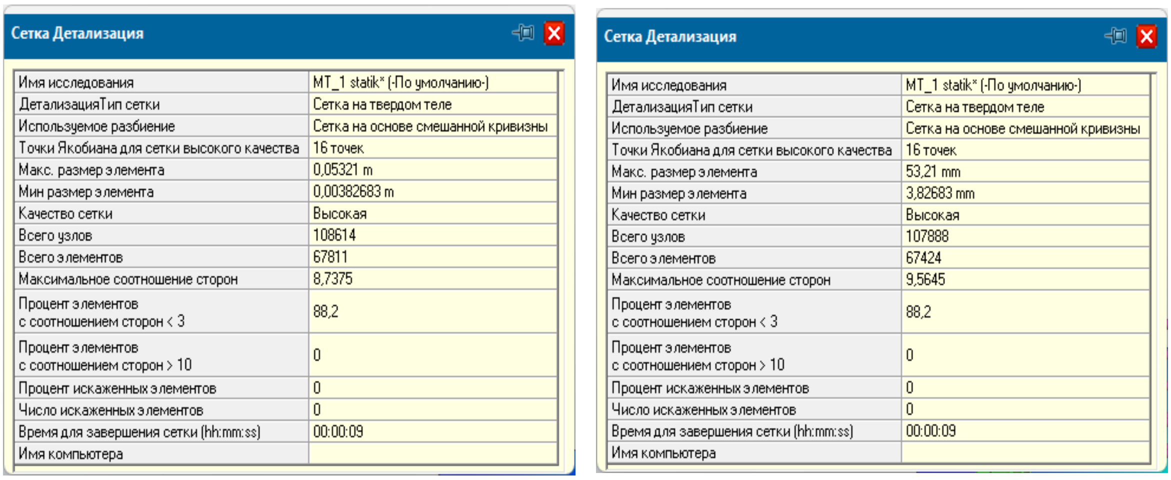
The maximum acting force is equal to:

$$F_{hl} = \frac{F_{mtf}}{2}, \quad kN. \tag{2}$$

Results. The calculation of the strength of the central support of the PE2U traction unit was performed using the finite element method (Fig. 5). For this, according to the formula (1), a vertical load of $P_{vl} = 20$ tons and a horizontal load of $F_{hy} = 600$ kN were given to it. Details of the unreinforced and reinforced states of the finite element model of the central support are presented in Figure 4.

Calculation of the strength of the central support was performed using the finite element method (Fig. 5). For this, according to the formula (1), a vertical load of

$P_{vl} = 20$ tons and a horizontal load of $F_{hy} = 600$ kN were given to it. The details of the first (previous model) and second (reinforced model) models of the [20-27] finite element model of the central support are shown in Figure 4.



Сетка Детализация

Имя исследования	MT_1 statik* (-По умолчанию-)
ДетализацияТип сетки	Сетка на твердом теле
Используемое разбиение	Сетка на основе смешанной кривизны
Точки Якобиана для сетки высокого качества	16 точек
Макс. размер элемента	0,05321 m
Мин размер элемента	0,00382683 m
Качество сетки	Высокая
Всего узлов	108614
Всего элементов	67811
Максимальное соотношение сторон	8,7375
Процент элементов с соотношением сторон < 3	88,2
Процент элементов с соотношением сторон > 10	0
Процент искаженных элементов	0
Число искаженных элементов	0
Время для завершения сетки (hh:mm:ss)	00:00:09
Имя компьютера	

Сетка Детализация

Имя исследования	MT_1 statik* (-По умолчанию-)
ДетализацияТип сетки	Сетка на твердом теле
Используемое разбиение	Сетка на основе смешанной кривизны
Точки Якобиана для сетки высокого качества	16 точек
Макс. размер элемента	53,21 mm
Мин размер элемента	3,82683 mm
Качество сетки	Высокая
Всего узлов	107888
Всего элементов	67424
Максимальное соотношение сторон	9,5645
Процент элементов с соотношением сторон < 3	88,2
Процент элементов с соотношением сторон > 10	0
Процент искаженных элементов	0
Число искаженных элементов	0
Время для завершения сетки (hh:mm:ss)	00:00:09
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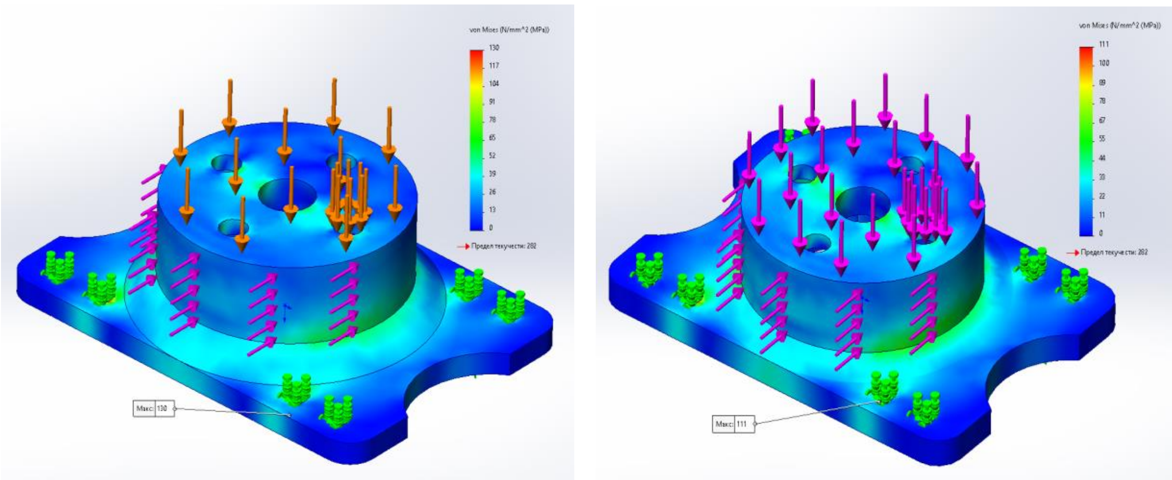
Previous model Reinforced model

Figure 4. Finite element model detailing of the central support.

Figure 5 shows the diagram of the stress state of the finite element model of the central support.



Previous model Reinforced model

Figure 5. Stress diagram of the central support part.

It is known from the above diagrams that the stress value in the first case was 130 MPa, and in the second case it was 111 Mpa [28-30].

CONCLUSION.

The proposed model of the central support increases the service life and ensures reliable operation between repairs.

Finite element models of load-bearing structures allow to carry out static stability calculations, conduct research, modernize these structures and choose optimal options.

The created finite element model of the central support allows to determine and analyze the calculated stresses, displacements and deformation quantities in this project, to identify high stress areas in the structure and to perform multidimensional calculations. The program allows to study the stressed-deformed state of the central support and evaluate the changes that occur during the modernization process, to determine the optimal methods of increasing the strength during the repair, and to develop proposals for extending the service life.

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