Reliability increase of running gears elements of mining traction locomotives using finite–element analysis package

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Abstract. The article is devoted to the problem of reliability augmentation of running gears elements of mining traction locomotives. Conducted studies consist of determination of convergence of calculation results and the experiment, as well as the estimate of reliability increase of the mining traction locomotives axle-box. The calculation error between calculation results and the experiment for the bracket of the axle-box hydrodamper is on average 3.39%, which is admissible for engineering calculations. The total value of the fatigue resistance stock coefficient considerably exceeds the maximum permissible fatigue resistance stock coefficient (2.83>2.0), which creates a safety margin of the axle-box of the mining traction locomotive.

1. Introduction

The serial production of electric locomotives, including traction units, begins from design, including a number of calculations in accordance with Russian regulatory documents: for electric locomotives (GOST R 55364-2012), for mining units (GOST R 55737-2013), for wheel pairs (GOST R 51775-2001), for axis wheel couple (OST 32.93-97), for tooth gear (OST 24/149/03-89).

In most cases, it is possible with the use of the instruments of mathematics, physics, theoretical mechanics and resistance of materials (for calculation of an axis of an electric locomotive, for example). But for difficult spatial designs, this method gives a big error.

To eliminate discrepancies, engineers used earlier bench tests and a method of analogies. Bench tests are expensive and labor-consuming, and the method of analogies is not always applicable. In this regard, the third way of calculation of details using finite-element analysis package, including Ansys, was widely adopted. This approach allows calculating details in deadlines with a fine precision. Using this approach, it is possible to avoid an excessive consumption of material or to increase the actual load of a detail.

The use of finite element models in Ansys program is widespread in design of mechanical elements of electric locomotives, mountain traction units, agricultural machinery, cars. S. I. Yevtushenko, M. N. Shutova et al. calculated the axle beam of the combine harvester [1], and proved the incorrect design of this element (stress in the axle beam from usual loading exceeding maximum permissible).

S. R. Abulkhanov, D. S. Goryainov provided calculation of upgraded railway front searchlight by vibrations with resonance frequencies [2]; they used Ansys to find out an optional headlight structure with light emitting diodes (LEDs) for the electric locomotive (VL series) [3].
Manea I. et al presents practical methodology for design and structural verification of the locomotive bogie frames for the LEMA electric locomotive using a modern software package for designing an application [4].

K. D. Vo et al. researched the influence of high temperature due to high adhesion condition on rail damage, and had established that after six wheel passes, the temperature due to the high adhesion condition was sufficiently high (723. °C) to be associated to the rolling contact fatigue (RCF) on the rail surface [5].

Y. Yuan et al considered engineering practices of EMI/EMC in railway vehicles, proposed a 'Bottom-Up' simulation flow, based on ANSYS electromagnetics CAE tools, to solve the EMI/EMC problems in railway vehicles form component level [6].

I. Sebesan and Y.Zakaria made comparative analysis of calculation results of the bogie frame, which is used on LDE 060-DA locomotives using Ansys and SolidWorks [7], and identified the high convergence of results for this electric locomotive.

The research of finite element modeling for the locomotive traction gears was done by X. C. Shi, W. D. He, J. H. Bao for gear tooth curves and their parameters [8]. Authors build by Ansys Parametric Design Language the simulation of the involute tooth curves and tooth root transition curves of the traction gears.

A. Rahmani et al described the modal analysis of a first stage blade in ALSTOM gas turbine, investigated the natural frequencies, and vibration modes of blade are found in various conditions [9].

2. Analysis of convergence of calculation results and experiment

The main problem of engineering calculations is a convergence of calculation results and the experiment.

The analysis of convergence of calculation results and experiment is carried out for the bracket of the axle-box hydrodamper to a bogie frame of an electric locomotive of EP1 [10]. When carrying out dynamic-strength tests of an electric locomotive EP1 by means of strain gauges, tension in bracket was defined. Comparison of settlement and experimental data is made for point A and B (fig. 1, a). In this points, the authors fixed the largest stresses. For determination of settlement stress, the authors created the finite-element model (fig. 1, b), consisting of the bracket, the axle-box spring, the basic platform of the axle-box bracket and the bonding roller of the hydrodamper. The loading from the hydrodamper (Fr) is applied to the bonding roller, the static loading (P) is applied to spring. A large number of elements provide high accuracy of calculation.

![Figure 1. A finite-element model of the bracket of the axle-box hydrodamper: a – points of experiment stress dimension; b – finite-element model with loading](image)

As a result of calculation of model, using the method of final elements, stresses in the bracket elements have been determined. The most loaded bracket model points are points A (37.05 MPa) and B (44.46 MPa), as well as in the experiment (point A – 36.3 MPa, point B – 43.0 MPa).

The calculation error is 3.39%, it is admissible for engineering calculations.
3. Reliability increase of axle-box of mining traction locomotive

The reliability increase of the axle-box of the mining traction locomotive, reached by using the adequate settlement model for calculating fatigue resistance.

Mining traction locomotive NPM2 was made at the Novocherkassk Electric Locomotive Plant (NEVZ), and now works at the Open Joint Stock Company «Magnitogorsk Iron & Steel Works». During designing the running gears elements (2001-2002 years), the fatigue resistance of the axle-box was not calculate, but now engineers have an opportunity to calculate details of difficult geometry with high convergence using the finite-elements analyses package, such as Ansys.

Calculation of the fatigue resistance is based on comparing the maximal and minimal stress value in the same point (\(\sigma_{\nu}\) – amplitudes of stresses, \(\sigma_{m}\) – mean value of stresses).

Fatigue resistance stock coefficient is:

\[
    n = \frac{\sigma_{1P}}{k_\sigma \cdot \psi \cdot \sigma_m}\geq [n],
\]

where:

- \(\sigma_{1P}\) – mean value of endurance strength (124.6 MPa)
- \(k_\sigma\) – coefficient transition from a standard sample (2.05)
- \(\psi\) – asymmetry coefficient (0.3),
- \([n]\) – maximum permissible fatigue resistance stock coefficient (2.0).

The finite-element model of the axle-box of mining locomotive NPM2 was created and calculated by means of finite-elements analyses package Ansys 17.2. The body of the axle-box is fixed on an internal radius, loading is applied in the spring attachment point.

Maximal and minimal stresses are recorded in the bracket of the axle-box. Figure 2 shows maximal and minimal principal stresses in the left bracket, figure 3 shows maximal and minimal principal stresses in the right bracket.

![Figure 2](image_url)

**Figure 2.** Principal stresses in the left bracket: a – maximum, MPa; b – minimal, MPa
Results of calculating are shown in table 1.

| Bracket | Maximal principal stress, MPa | Minimal principal stress, MPa | Amplitudes of stresses, $\sigma$, MPa | Mean value of stresses, $\sigma_m$, MPa | Fatigue resistance stock coefficient, $n$ |
|---------|-------------------------------|-------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Left    | 32.40                         | -7.19                         | 19.8                                | 12.61                               | 2.83                                |
| Right   | -1.68                         | -38.59                        | 18.46                               | -20.14                              | 2.84                                |

The total value of the fatigue resistance stock coefficient considerably exceeds the maximum permissible fatigue resistance stock coefficient ($2.83 > 2.0$); therefore reliability of long-term use of the axle-box of the mining traction locomotive increases, and the time of incident-free work is extended.

4. Conclusion

Conducted studies of work of running gears elements determine a high convergence of calculation results and experiment. The calculation error for bracket of the axle-box hydrodamper on average is $3.39\%$, it is admissible for engineering calculations. In the calculations the authors used a finite-element model, consisting of the bracket, the axle-box spring, the basic platform of axle-box bracket and the bonding roller of the hydrodamper.

During design of the axle-box of the mining traction locomotive, the fatigue resistance was not calculated, because of absence of calculating software for models with irregular shape. But in this paper, the authors have calculated the total value of the fatigue resistance stock coefficient in program package Ansys 17.2. Maximal and minimal stresses are recorded in the bracket of the axle-box. The total value of the fatigue resistance stock coefficient considerably exceeds the maximum permissible fatigue resistance stock coefficient ($2.83 > 2.0$), which creates a safety margin of the axle-box of the mining traction locomotive.

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