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REQUIREMENTS FOR THE STRENGTH OF LOAD-BEARING STRUCTURES OF LOCOMOTIVES

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Abstract– This article presents a brief analysis of the requirements for the strength of load-bearing structures of locomotives according to the newly adopted international standard GOST 34939-2023 “Locomotives. Requirements for bearing structure strength and dynamic properties”. This standard was adopted by the Eurasian Standardization, Metrology and Certification Council on January 20, 2023 and was also implemented in the Republic of Uzbekistan. This normative-technical document regulates the requirements for strength and dynamic qualities of locomotives in the CIS countries.

Key words– load-bearing structure, body, frame structure, bogie frame, main frame, lifetime, assigned lifetime, residual lifetime, extended lifetime.

I INTRODUCTION

In transportation engineering, the load-bearing system is understood as a sequence of metal structures of the object united by kinematic connections and perceiving the gravity forces of all equipment and its own gravity forces balanced by reactions in the spots of contact interaction "wheel-rail". Thus, the entire sequence of force elements from the body (cab, main frame, bogie frames, support and return devices, leashes, springs and other elements) to the wheelset is a load-bearing system, and the constituent parts interacting on the force flow of weight loads are its elements [7].

The body and main frame of the locomotive are designed to provide working conditions for the locomotive crew, locating power and auxiliary equipment, locomotive control devices. Designs of the main frame and body are determined by the type of locomotive service, equipment layout, method of load perception and transfer, production and technical conditions of locomotive manufacture and operation. Therefore, high demands are placed on bodies and main frames in terms of stiffness, strength and reliability [7].

The lifetime of the locomotive as a whole is determined by the life of its basic parts (bogie frame, body frame, load-bearing body elements) [7, 23].

Upon expiration of the lifetime of the locomotive, established by the normative and technical documentation, its lifetime can be extended, which requires a number of works and scientific justification in accordance with the established normative documents [4-9, 13-18, 21-25]. These requirements also apply to industrial locomotives. To date, more than 70 units of traction units of PE2M, PE2U, MPE2U types are in operation at industrial enterprises of the Republic of Uzbekistan, and more than 50% of them have already worked out their lifetime, specified in the regulatory documentation, and require urgent measures to extend their useful life [2].

According to the technical documentation, the lifetime of traction units PE2M, PE2U and MPE2U is not less than 24 years [2, 3].

The residual lifetime is assessed by the strength of the frame structures, which are an integral part of the locomotive that determines its lifetime. The main supporting parts of the locomotive are its main frame and bogie frame [2-19, 21-25].

To assess the residual lifetime of locomotives, technical diagnostics of its load-bearing structures, assessment of mechanical properties of its material through laboratory tests and analysis of its stress-strain state are carried out. The stress-strain state can be analyzed by the strain measurement method or the finite element method (FEM) using modern software [20, 21, 23]. In this process, a 3D model of the frame structure is created, taking into account all features of the structure (material, geometric parameters). When analyzing the stress-strain state of the frame structure and during design work, static and dynamic forces acting in all modes throughout its use are taken into account.

II THE METHODOLOGY

1. Requirements for strength and stiffness of load-bearing structures

The tasks of ensuring strength and reliability, creation of more advanced rolling stock structures with minimum metal consumption and long operating lifetime require the choice of geometrical parameters and properties of materials of parts with their maximum adaptation to the operating conditions and loading of structures. At the same time, the accumulation of damage in the structural materials used must not lead to sudden failures causing damage to people, the environment and the products themselves. This largely depends on the perfection and completeness of the current regulatory requirements, which are realized by calculations and tests of structures during their design [7].

The load-bearing capacity of the structure is evaluated under the action of design loads according to permissible values:

- stresses;
- strains;
- fatigue reserve factors;
- stability margin factors.

The strength of the main frame when subjected to the standard longitudinal force applied along the coupling axes should be confirmed by impact testing, as well as by calculation or the results of bench static tests with double-sided compression and tensile tests. The strength conditions of the main frame are:

- under impact test: $\sigma \leq \sigma_{0,2}$;
- under static loading: $\sigma \leq 0,9\sigma_{0,2}$.

$\sigma_{0,2}$ — *yield strength;*

σ — *stress corresponding to the standard longitudinal force.*

Fatigue reserve factors of load-bearing structures shall be not less than:

- 2,0 — for steel structures;
- 2,2 — for structures of aluminium alloys.

The fulfilment of this requirement at the design stage is verified by calculation results, and if a prototype is available, it is confirmed by test results.

The fatigue resistance of bogie frames and intermediate frames of the second stage of spring suspension should be confirmed by the absence of fatigue cracks after 10 million cycles of loading on a vibration test bench.

The stability margin factor for body elements (main frame) must be at least 1.10 for design modes I and IV.

The maximum calculated value of the deflection of the lower chord of the body (main frame), referred to its full length, shall not exceed:

- from the vertical gross load: for the load-bearing body - 0.4 mm/m, for the load-bearing (main) frame - 0.6 mm/m;
- under simultaneous action of vertical gross load and calculated longitudinal force: for load-bearing body - 1.5 mm/m, for load-bearing frame - 2.2 mm/m.

2. Calculation of strength indicators

2.1 General requirements

After selecting materials when designing load-bearing structures of the underframe for the given loading parameters, the following is performed by calculation:

- selection of dimensions and structural shapes of load-bearing elements for given loading parameters;
- analyses of the stress-strain state in the most loaded zones for different design loads;
- estimation of strength and fatigue resistance;
- estimation of expected lifetime.

The strength calculations are subject to: body (main frame), bogie frames, intermediate frames of the second stage of spring suspension, elements of connection of the body (main frame) with bogies, spring suspension springs, axle box housings, equipment fastening units.

2.2 Calculation modes for strength assessment

Locomotive underframe elements are calculated for the most unfavourable possible combination of simultaneously acting load groups in accordance with the established calculation modes [8]. Calculation modes I–IV are used to evaluate strength by allowable stresses in relation to the yield strength of the material [1, 7].

Design mode III is used to evaluate fatigue resistance.

Mode I includes:

- mode *Ia* to account for maximum longitudinal quasi-static forces;
- mode *Ib* to account the maximum longitudinal impact forces on the coupling device (collisions).

Mode II includes:

- mode *IIa* to account for forces acting in curved sections of track with maximum permitted unmitigated acceleration;

- mode *IIb* to take into account the forces acting upon starting;
- mode *IIv* for emergency braking forces.

Mode III takes into account the forces acting at various speeds, up to design speeds, along a straight section of track.

Mode IV is designed to take into account the forces due to the repair technology and emergency recovery operations and arising:

- when lifting the body (main frame) on two diagonally placed jacks;
- when lifting the locomotive by the coupling unit;
- when rolling out the wheelset.

3. Strength assessment

3.1 General provisions

Strength assessments are carried out:

- during design;
- during prototype testing;
- when introducing design or technological changes affecting strength;
- when changing the load.

Strength assessment is carried out according to the following limit states:

- appearance of residual deformations under static loading resulting from exceeding the yield strength of the material;
- occurrence of macro-cracks under cyclic (high-cycle and low-cycle) loading;
- loss of stability (failure to preserve the original shape of a structure or its element due to its insufficient stiffness);
- inadmissible change of geometry and dimensions of parts due to accumulation of plastic deformations.

3.2 Methods of calculation and assessment of strength

Strength assessment methods are determined depending on the operating conditions of the element in question and the achievement of its limit state.

Bodies (main frames), bogie frames, intermediate frames of the second stage of spring suspension, spring suspension springs, connection assemblies and traction and braking force transmission assemblies are evaluated for both allowable stresses and fatigue resistance.

Strength assessment by allowable stresses is carried out for cases of the most unfavourable possible combination of simultaneously acting normative loads in accordance with design modes.

The total stresses obtained as a result of the calculation must not exceed the permissible values set out in table 1 for the relevant design modes.

<table>
<tr><th colspan="2" rowspan="2">Calculation mode</th><th colspan="2">Permissible stress for elements</th></tr>
<tr><th>body (main frame)</th><th>bogie</th></tr>
<tr><td rowspan="2">Mode I</td><td>Ia</td><td colspan="2">$0,9\sigma_{0,2}$</td></tr>
<tr><td>Ib</td><td>$0,9\sigma_{0,2}$*</td><td>$0,9\sigma_{0,2}$</td></tr>
<tr><td colspan="2">Mode II</td><td colspan="2" rowspan="2">$0,6\sigma_{0,2}$</td></tr>
<tr><td colspan="2">Mode III</td></tr>
<tr><td colspan="2">Mode IV</td><td colspan="2">$0,9\sigma_{0,2}$</td></tr>
<tr><td colspan="4">* The value of $\sigma_{0,2}$ is used in the tests</td></tr>
</table>

TABLE 1: PERMISSIBLE STRESSES FOR BODY ELEMENTS (MAIN FRAME) AND BOGIES.

III CONCLUSION

These requirements are considered to be a basic and mandatory condition for ensuring the safety and reliability of passenger and freight traffic when using locomotives. Compliance with these requirements is required from the locomotive design process, through modifications during modernisation, operation and lifetime extension.

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