Study of strength characteristics of the long wheelbase flat cars

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Abstract. Transportation of goods in large containers with loading length of 80 feet is one of the promising directions of railway transport development. However, despite considerable experience in construction of long-wheelbase flat cars, occasionally problems with the strength of load-bearing elements arise at the calculation, design and manufacture of such products. The article presents the technical characteristics of a long wheelbase flat car, as well as the results of experimental studies of fatigue tests of its load-bearing elements. The optimization of the design of the long wheelbase flat car was achieved both by increasing the sizes and shapes, and by using materials of increased strength. An analysis of the study’s results of an improved design showed the compliance of the values of the safety factor of fatigue strength and the service life of the flat car with regulatory and technical documentation. The conducted studies allow us to make recommendations regarding the design, rebuilding and testing of long wheelbase flat cars. The primary results of fatigue tests of the main load-bearing structural elements within the scope of experimental studies turned out to be mostly below acceptable values. This article contains facts confirming it. The results of experimental studies to determine the fatigue strength proved that the design elements require improvement and strengthening.

1. The first paragraph after a heading is Analysis of research and publications

Problems of the dynamics and strength of the rolling stock, as well as the possibility of using mathematical modeling to solve this problem were considered in the works of M.B. Kelrich [1-3], S.V. Myamlin [4-7], O.V. Fomin [8-11], A.V. Donchenko [12], V.M. Ishchenko [8, 13], L. Neduzha [6, 7, 14] and other scientists. The research papers of M.B Kelrich, A.V. Donchenko and V.M Ishchenko address the issues of experimental and computational studies of the strength qualities of long wheelbase flat car designs. The studies of O.V. Fomin focus on scientific and practical basis for construction and improvement of long wheelbase flat cars design and also technical solutions to improvement of existing flat car models and other type of freight rolling stock. Research and simulation of spatial oscillations of the railway rolling stock are dealt with in papers by S.V. Myamlin
and L. O. Neduzha. However, nowadays, design and experimental study of the structural strength of new models of long wheelbase flat cars raise a lot of questions regarding their dynamic and strength properties.

2. The purpose of the work

Is to study the stress-strain state of the long wheelbase flat car and increase its strength characteristics. One of the railcar-building factories in Ukraine completed works on the development, conducting a set of relevant tests and serial production set-up of a new model of a long wheelbase flat car. The frame of the long wheelbase flat car is shown in Figure 1, the main parameters and dimensions of the flat car are shown in Table 1.

![Figure 1. The frame of the long wheelbase flat car.](image)

Table 1. The main parameters and dimensions of the long wheelbase flat car.

| Name and dimension of the parameter | Normal value |
|------------------------------------|--------------|
| 1 Payload, t, not more than         | 69.6         |
| 2 Weight (tare), t                 | 23.9 ± 0.5   |
| 3 Design static load of the wheelset on the rails, kN (tf) | 230.5 (23.5) |
| 4 Length along the automatic coupling axle, mm | 25620±11 |
| 5 Design speed, km/h               | 120          |
| 6 Dimension in accordance with GOST 9238 (DSTU B V.2.3-29 *) | 1-T          |
| 7 Height above top of the rail up to automatic coupler axle (empty platform), mm | 1040-1080 |
| 8 The distance between the internal axles of the wheelsets (long-wheelbase), mm | 16650 |
| 9 Two two-axial bogies:             | model 18-7055 |
| 10 Minimum weight (tare) during operation, t | 22.124 |

These products are intended for the transportation of large capacity universal containers according to DSTU ISO 668 [15] or tank containers (for non-hazardous goods) according to DSTU ISO 668 types 1A (1AA, 1AX), 1B (1BB, 1BX), 1C (1CC, 1CX), 1EE on the 1520 mm gauge railways.

The loading scheme shown in Figure 2 was selected for the tests. Such a loading scheme is considered less favorable and, when operating long wheelbase flat cars, causes the most
damaging effect to the structural members, which is confirmed by the results of calculations at the design stage.

Figure 2. Disposition of four containers or tank containers of standard size 1C (1CC, 1CX).

However, at the stage of the full complex of preliminary experimental studies, negative results of fatigue tests were obtained. The obtained values of fatigue strength coefficient in several sections of the frame are below the permissible value.

For testing, a prototype flat car was loaded with four container simulators up to a gross weight of 101.26 tons, with an overload of 8.32 tons, which corresponds to 12% of the maximum wagon loading capacity. To increase the load in dangerous sections, according to the results of static tests, 8.32 tons of cargos were loaded into two containers located closer to the central section. An increase in cargo weight was necessary to increase the stress level in the central section up to the level of operational stresses obtained from the results of running strength tests. Permissible increase in static load is not more than 30% of the payload capacity. While performing a set of tests for a long wheelbase flat car the calculation of the main indicators of fatigue strength is calculated from equations (1) - (4).

The calculation of the fatigue safety factor was carried out as follows:

\[ n = \frac{\sigma_{a,N}}{\sigma_{a,e}} \]  

(1)

where:
- \( \sigma_{a,N} \) – is the endurance limit (in amplitude) for the check area with a symmetric cycle and steady-state loading mode with the base number of cycles \( N_0 = 10^7 \).
- \( \sigma_{a,e} \) – is the equivalent reduced amplitude of dynamic stresses in the studied section of the frame during the movement of the flat car in operation, is determined by the results of running strength tests or by calculation.

The endurance limit was determined as follows:

\[ \sigma_{a,N} = \left( \frac{N_{test}}{N_0} \right)^{\frac{1}{m}} \sigma_{a,test}^m \]  

(2)

- \( N_{test} \) – is the number of cycles passed during testing before the crack initiation.
- \( N_0 \) – is the base number of cycles, \( N_0 = 10^7 \).
- \( m \) – is the exponent in the equation of the fatigue curve \( m = 4 \).
- \( \sigma_{a,test}^m \) – is the stress amplitude during fatigue strength tests, MPa.

The equivalent reduced amplitude is determined by calculation, based on the results of throwing off of the flat car from the blocks.
\[ \sigma_{a,e} = \frac{\sigma_{a,b,\ell}}{\sigma_{a,b,\ell}^{\text{cent}}} \sigma_{a,e}^{\text{cent}}. \] (3)

- \( \sigma_{a,b,\ell} \) – the amplitude of the dynamic voltage recorded in the studied area of the frame during testing to throw off the flat car from the blocks.
- \( \sigma_{a,b,\ell}^{\text{cent}} \) – the amplitude of the dynamic voltage recorded in the central section of the frame during testing to throw off the flat car from the blocks.
- \( \sigma_{a,e}^{\text{cent}} \) – the calculated reduced amplitude of the dynamic voltage in the central section of the frame when the car is running in operation:

\[ \sigma_{a,e}^{\text{cent}} = \sigma_{\text{st}}^{\text{cent}} \cdot K_{d,e}. \] (4)

- \( \sigma_{\text{st}}^{\text{cent}} \) – static voltage in the central section of the frame.
- \( K_{d,e} \) – is the equivalent reduced coefficient of vertical dynamics of the car.

Figure 3-4 shows the installation locations of strain gages and the appearance of cracks in the central section.

**Figure 3.** Locations of strain gauges and the cracks initiation during fatigue tests.

**Figure 4.** Zones C, H, P of the crack’s initiation during fatigue tests.
The cracks started to appear on the flat car frame with the number of test cycles $N_{test} = 1198000$. The appearance of such a number of cracks indicates insufficient structural strength. The safety factor of fatigue resistance in these zones is $n = 0.57 - 0.59$ with an acceptable value $[n] \geq 1.15$.

Figure 5 and 6 show the characteristic fatigue cracks in the studied areas of the frame of a long wheelbase flat car.

![Figure 5](image-url)  
**Figure 5.** A crack with a length of 80 mm in zone D.

![Figure 6](image-url)  
**Figure 6.** Crack 110 mm long in zone D.
Various force application schemes were used to simulate vertical disturbances (one and two-sided force application schemes) during the tests. Realization of the same values of dynamic stresses by one and two-sided force application schemes allowed to obtain satisfactory convergence of the achieved values of the fatigue strength coefficient. Thus, the methodology for fatigue testing of long wheelbase flat cars structure concerning the improvement of research methods was further developed.

An analysis of the fatigue tests results showed the need to strengthen and modify certain structural elements. An additional strength calculation of the structure was performed, and adjustments were made taking into account the test results.

The main changes concern the following elements:

- center sill web and upper and lower plates;
- stub sill bottom and vertical plates;
- draft sill bottom plate.

The thickness of the centre sill web plate in the central part is increased from 8 to 10 mm. The upper and lower plates of the center sill are made solid, without 10-mm upper and lower inserts, of 09G2S material with a thickness of 16 mm. In addition, the diameter of the holes on the center sill was reduced from 600 to 500 mm, and the holes of a 600 mm diameter at the beginning of a variable section were removed.

After manufacturing of the advanced prototype, fatigue tests were continued. Before crack initiation in the new design of a long wheelbase flat car in the central section area, the number of cycles was 2128000, which corresponds to a fatigue strength coefficient of 1.196 with an allowable value of \( n \geq 1.15 \).

Before the loss of bearing capacity (structural survivability), the number of cycles was 2267000. In the remaining studied zones, the values of the fatigue strength coefficient exceed the value of the fatigue strength coefficient of the central section zone. Table 2 shows the data for calculating the coefficient of fatigue strength in the central section.

### Table 2. The source data for calculating the coefficient of fatigue strength.

| Section                  | \( \sigma_{a,e} \), MPa | \( \sigma_{a,N} \), MPa | \( N_{test} \) | \( \sigma_{a,test} \), MPa | \( \sigma_{a,N_{test}} \), MPa | \([n]\), MPa | n, MPa |
|--------------------------|--------------------------|--------------------------|----------------|--------------------------|--------------------------|-----------|-------|
| Crack in the central section area | 23.0 | 26.5 | 2128000 | 40.5 | 27.5 | 1.15 | 1.196 |

### 3. Conclusions

1. The original design of the long wheelbase flat car had insufficient strength properties, which is confirmed by experimental studies. The weakest zones are sections located in the middle of the flat car frame. An analysis of the experimental studies results of fatigue strength showed that the coefficient of fatigue strength in these zones is 49 - 52% of the permissible value.

2. The methodology of fatigue testing of long wheelbase flat cars concerning the improvement of test methods has been developed.

3. After improvement of the long wheelbase flat car design and performance of experimental studies, the minimum value of the fatigue strength coefficient in the central zones proved to be 1.196, that is higher than the allowable value \( [n] \geq 1.15 \).

### References

[1] Fedosov-Nikonov D, Kelrikh M 2016 Research on the Structural Strength of a Long Wheelbase Flat Car *Bulletin of Volodymyr Dahl East-Ukrain. Nat Univ. Sci. Journal* 1 pp 90–94
[2] Fedosov-Nikonov D, Kelrikh M 2016 Calculative experimental estimation method of the structural strength of a long wheelbase flat car Proc. of the Int. Sci. and Pract. Conf. Infrastructure innovations of transport and logistics systems Problems, experience, prospects (Truskavets: V. Dahl EUNU) pp 101
[3] Kelrikh M 2014 Perspective directions of planning carrying systems of gondolas Metallurgical and Mining Industry «Machine building» 6 pp 64–67
[4] Myamlin S 2001 Methodology for modeling spatial vibrations of a railway crew Railway transport of Ukraine 2 pp 2-5
[5] Myamlin S 2000 The program for modeling spatial vibrations of the rolling stock Railway transport of Ukraine 3 pp 52–54
[6] Myamlin S, Lunys O, Neduzha L and Kyryl’chuk O 2017 Mathematical Modeling of Dynamic Loading of Cassette Bearings for Freight Cars Proc. of 21st Int. Sci. Conf. Transport Means 2017 pt. III (Juodkrante, Lithuania: Kaunas Univ. of Technology) pp 973–976
[7] Myamlin S, Neduzha L and Urbutis Ž 2016 Research of Innovations of Diesel Locomotives and Bogies Proc. Eng. 134 (Vilnius, Lithuania: Vilnius Gediminas Techn. Univ.) pp 469–474
[8] Fomin O, Ishchenko V and Fedosov-Nikonov D 2018 Long wheelbase flat cars Problems of structural strength Metallurgical and mining industry (Dnipro: MPA) 2 pp 84–90
[9] Fomin A, Fedosov-Nikonov D 2018 Scientific and practical research of the structural strength of the long wheelbase flat car frame Scientific methodical Journal Bulletin of Science and Education 10 46 pp 8–15
[10] Fomin O, Fedosov-Nikonov D 2017 Research of the structural strength of the long wheelbase flat car Proc. of the State Univ. of Infr. and Techn. Transport Systems and Technologies 31 (Kyiv: DUIT) pp 140147
[11] Fomin O 2014 Modern requirements to carrying systems of railway general-purpose gondola cars Metallurgical and Mining Industry «Machine building» 5 pp 31–43
[12] Donchenko A, Fedosov-Nikonov D 2016 Methods of design and experimental studies of the long wheelbase flat car Col. of sci. papers of the State Econ.-Tech. Univ. of Transport Systems and Technologies 28 (Kyiv: DETUT) pp 53–60
[13] Ishchenko V, Fedosov-Nikonov D 2017 Long wheelbase flat cars: structural strength Metallurgical and Mining Industry «Machine building» 8 pp 18–23
[14] Lunys O, Neduzha L and Tatarinova V 2019 Stability research of the main-line locomotive movement Proc. of the 23rd Int. Sci. Conf. Transport Means 2019 pt III (Palanga, Lithuania: Kaunas Univ. of Techn.) pp 1341–1345
[15] Freight containers, series 1 Classification, sizes and nominal characteristics 2015 DSTU ISO 668: 2015 (ISO 668: 2013, IDT) p 25