ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 9, Issue 10 , October 2022

Mathematical model and algorithm for calculating the durability indicators of electric locomotive bogie elements

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ABSTRACT: The article presents a mathematical model and an algorithm for calculating the durability indicators of the elements of the VL80s electric locomotive bogie. Based on the results of the research, a numerical method for calculating the durability indicators of an electric locomotive wheelset based on information on instrumental and non-destructive testing is proposed.

KEY WORDS: Electric locomotive, bogie, durability of bogie, reliability, bogie resource, mathematical model, algorithm, program, methodology for calculating durability indicators.

RELATED WORK: Russian scientists as I.P. Kiselev [4], E.S. Oganyan [5], I.S. Biryukov [6], A.N. Savoskin [7], A.V. Gorsky [8], V.A. Chetvergov, V.I. Kiselev [9] and others carried out similar research. In Uzbekistan the problem of optimizing the operation of the wheel and rail by reducing contact stresses during the dynamic interaction of wheel sets of rolling stock, the development of methods for calculating the dynamic strength of frame structures of locomotives of complex configuration for transport engineering, are being studied by professors Faizibaev Sh.S. and Khromova G.A., [10,11,12,13,14,15].

I. INTRODUCTION

The issues of developing methods for calculating and analyzing indicators of reliability and durability, determining the resource of equipment for electric rolling stock of railways are given great attention in the research of scientists around the world. [1,2,3].

The article sets scientific and practical tasks for assessing the reliability and durability of rolling stock equipment. The studies were carried out on the example of calculating the reliability and durability indicators of the elements of the electric locomotives bogie according to operational tests based on information on instrumental and non-destructive testing, as well as experimental studies conducted by the authors of this article.

II. MATERIALS AND METHODS

The methodology of theoretical research includes the compilation of mathematical models to study the reliability and durability of traction electric rolling stock equipment based on the results of diagnosing the bogie of the VL80s electric locomotive, standard methods of material resistance, elasticity theory, vibration theory, dynamics and strength of machines were used for research, numerical studies were carried out in the programming environment using approximation methods and spline interpolation.

The methodology of experimental research was determined by a set of rules for the application of standard principles for the implementation of full-scale tests, which consisted in the research of external influences, the use of appropriate equipment and vibration sensors and strain gauges, the use of an automated complex for recording and processing experimental data by probabilistic and statistical methods (Analyzer 2020). In addition, the test procedure we

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 9, Issue 10 , October 2022

propose is based on the methodology of conducting full-scale tests of electric locomotives, adopted the same for all CIS countries

III. EXPERIMENTAL RESULTS

Data on experimental studies are presented for the first time for upgraded bogie frames of VL80s electric locomotives with the installation of reinforcing pads on them [11].

During experiments and analysis of operational data, the main attention is paid to the development of a fundamental database of damage to electric locomotive bogies, which is used in modeling their dynamic characteristics [1,2,5,7,11].

The modeling was carried out on the basis of the characteristics of the bogies of the VL80s electric locomotive, obtained during tests on the bench [13,14] and during measuring trips [11]. During these trips, information is collected on the real loads that occur in the bogie frames and the main frame of the body of the VL80s electric locomotive, as well as data to test the developed on-board diagnostics algorithm under conditions of real rolling stock fluctuations.

The signals (possible diagnostic parameters) obtained during the measurements were evaluated using various algorithms as a function of time and frequency. In the first case, the statistical parameters were calculated and divided into classes; in the second case, the frequency spectra were analyzed and the transfer function was calculated. Only some of the evaluation algorithms turned out to be suitable for diagnostics.

Full-scale experimental studies on dynamic vibrations of the main body frame and bogie frames were carried out on VL80s electric locomotives.

The objectives of the experimental studies were:

1. Analysis of dynamic vibrations of the main body frame and bogie frames of the VL80s electric locomotive under operating conditions at “Uzbekistan Temir Yullari” JSC, taking into account the installation of reinforcing pads on it.

2. Determination of the prevailing frequency spectrum of oscillations and the construction of amplitude-frequency characteristics (AFC) according to the sections of the main frame of the body and frames of electric locomotive bogies. Comparison of the obtained results with theoretical calculations and known experimental studies [1,2,5,7].

3. Analysis of the stress-strained main frame of the body and bogie frames of the VL80s electric locomotive under various loading conditions and comparison of experimental data with theoretical data.

The experiments were carried out in series with repetitions over several days. During the tests, the total time, data on the speed mode of the electric locomotive were recorded, vibrations and deformations were also recorded on the main frame of the electric locomotive body (Figure 1).

Figure 2 shows an example of a vibrogram and an oscillogram obtained in the middle of the span of the body frame, and Table 1 provides generalized information about the values of vibration accelerations at various control points during the tests. Based on the interpretation of the obtained vibrograms, the main active vibration accelerations at the control points were determined.

To determine the prevailing frequencies at the control points and to analyze the vibration spectrum of the main body frame and bogie frames of the VL80 electric locomotive, standard software for personal computers in the form of “Analyzer 2020” and “Analysis Center” packages was used.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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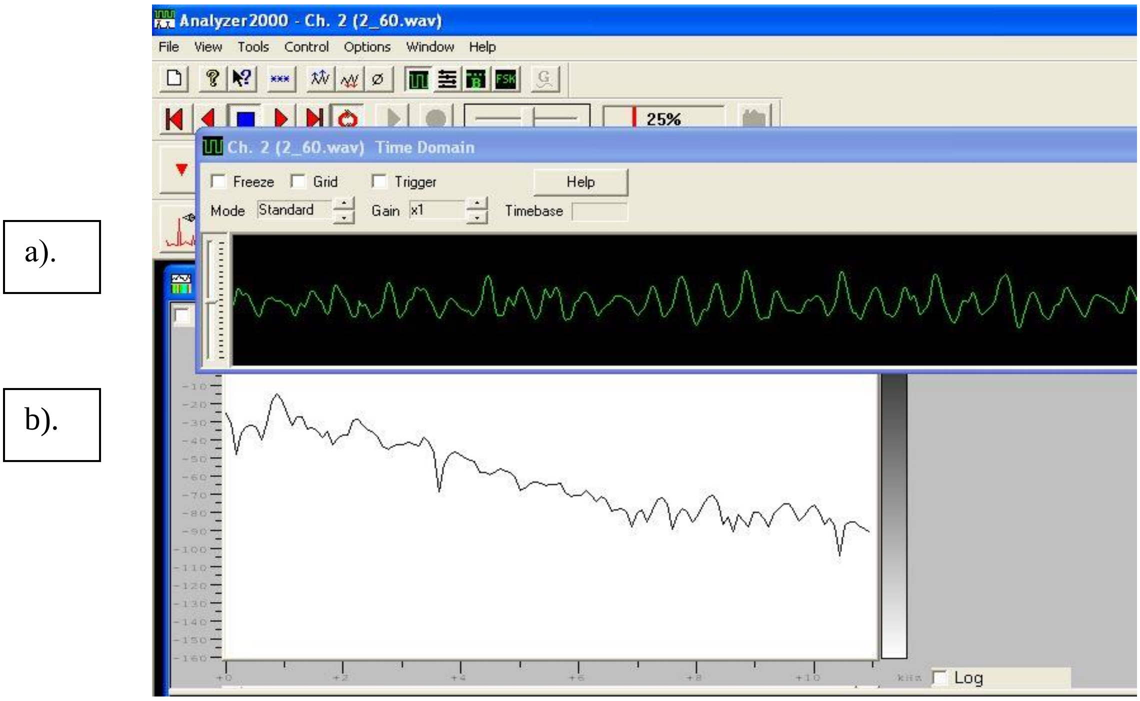

Figure 1. Sample of experimental record:
a). longitudinal stresses in the frame of the VL80s electric locomotive bogie;
b). processing of the total frequency spectrum

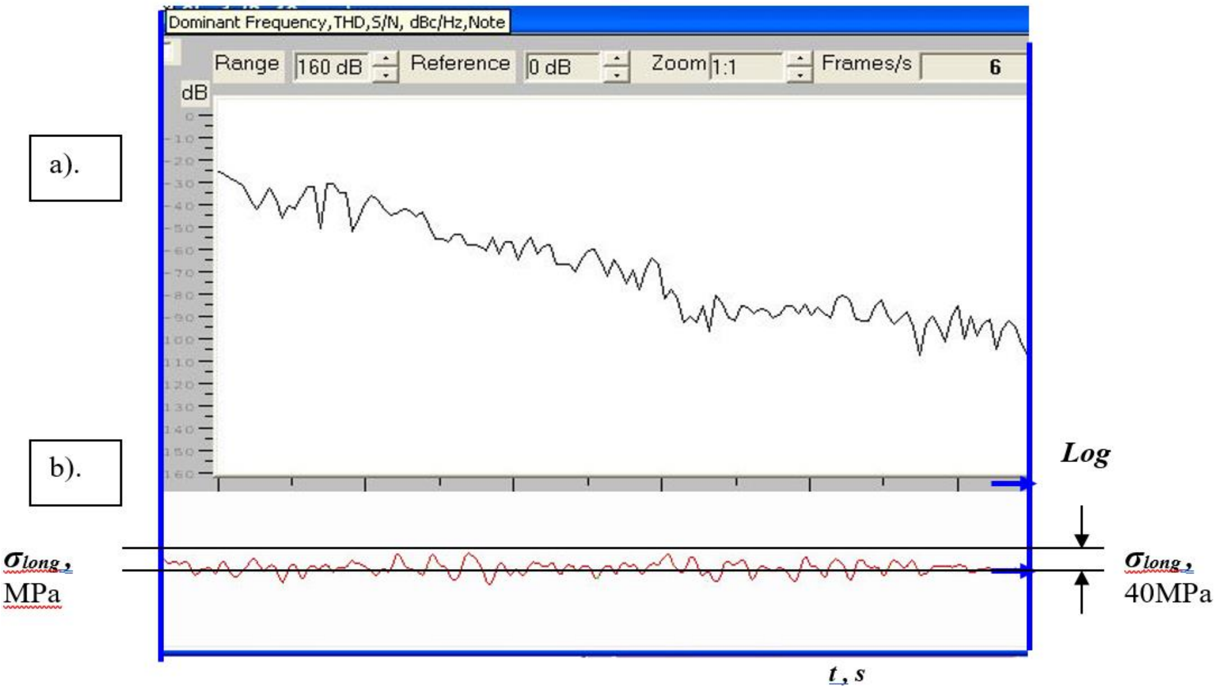

Figure 2. Oscillogram of change
a). the total frequency spectrum in the program;
a). longitudinal stresses in the frame of the electric locomotive bogie 3VL80s
(In the middle of the frame span) at a speed of movement
V = 100 km/h and the total weight of the train is 2000 tons

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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Table1.
Information about the conducted experimental measurements.

Check Point	Maximum amplitude per N338, мм	Maximum amplitude on the monitor, dB	Vibration acceleration, Гц	Stress, MPa
body frame vertical (middle span)	31	66,8	2,07	bending stresses 68MPa
body frame horizontally (mid span)	87,5	160	6,0	longitudinal stresses 38MPa

From the spectral analysis of the obtained experimental records, it can be seen that vibrations of the main body frame and bogie frames of the VL80s electric locomotive under the influence of a driving load that occurs when the electric locomotive moves along a track with periodic unevenness and in curves experience a wide frequency spectrum of dynamic loads (from 0.1 to 5000 Hz). Vibrations with higher frequencies are also present in the spectrum, but they are not characteristic of mechanical systems and are explained by the presence of harmonic components in the spectrum.

From the analysis of Figure 2, it is obvious that the total oscillation frequency in the middle of the frame span of the bogie frame of the 3VL80s electric locomotive is equal to 6 Hz in terms of the first harmonic, and the longitudinal stresses are sign-alternating and do not exceed 40 MPa at a speed of V = 100 km/h and a total train weight of 2000 t The experimental data are in good agreement with the theoretical ones, while the error was 5-8% for various train loading modes. With an increase in the speed of the electric locomotive, the error increases, but does not exceed 8%.

From the analysis of the obtained experimental results, it follows that the vibrations of the frame parts of the VL80s electric locomotive bogie correspond to known theoretical studies and practical measurements previously carried out by other researchers [1,2,5,7].

IV. RESULTS AND DISCUSSION

According to theoretical studies, it has been established that the movement of a railway vehicle is accompanied by vibrations of the body of an electric locomotive in a vertical plane with a natural frequency of usually 1 ... 2.5 Hz, while vibrations with acceleration (0.15 ... 0.3) g arise from track irregularities; therefore, on a jointless track, the oscillation amplitude is smaller, and on a track with joints (with a rail length of 25 m and 12.5 m) it is greater. An electric locomotive bogie also has its own oscillation frequency - usually about 4-15 Hz, while the acceleration reaches (2 ... 3) * g. As a result of system oscillations, dynamic stresses with an amplitude of up to 40 MPa arise in the bogie [11].

Due to the unevenness of the track in the horizontal plane and the taper of the bandages, the wobbling of the bogie and the body takes place. In this case, in the contact of the wheel with the rail, horizontal forces arise, reaching 60–90 kN in curved sections of the track [10].

We carried out a probabilistic-statistical processing of operational data on failures of the main body frames and frames of bogies of electric locomotives VL80 and 3VL80s according to the data of the locomotive depot "Uzbekistan" JSC "Uzbekiston temir yullari". The main causes of failures in the mechanical part are the structural inadequacy of the joint operation of the vertical box-section pivot beams of the body frame at the attachment point with the bogie frames, the imperfection of the design of the pivot assembly, the central supports of the body frame and the bogie frame, which creates large oscillations of bearing and wobbling.

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International Journal of Advanced Research in Science, Engineering and Technology
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In general, failures of VL80 and 3VL80s electric locomotives (in %) for 2017-2021 distributed as follows:

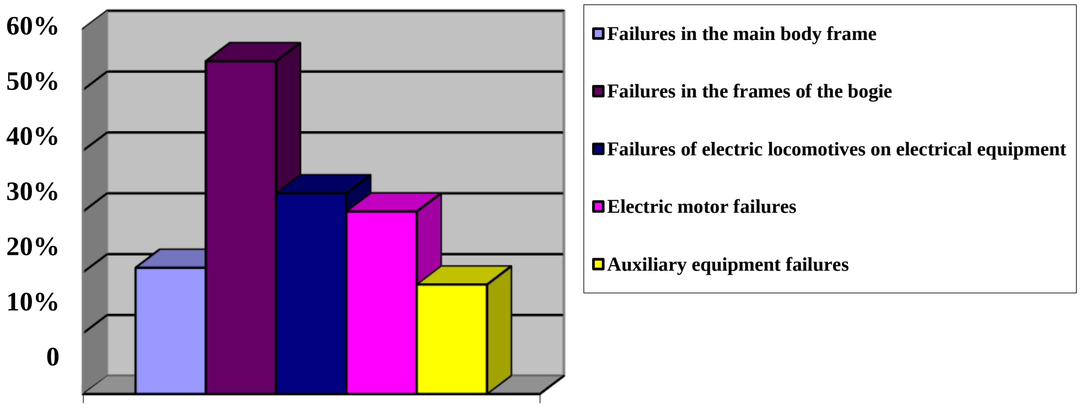

Figure 3. Distribution of failures of electric locomotives VL80 and 3VL80s for the period 2017-2021 according to the locomotive depot "Uzbekistan" JSC "Uzbekiston temir yullari"

When calculating the reliability of the rolling stock, the load is presented in the form of a random process, followed by the schematization of the loads, which is convenient for the calculation. To assess the reliability in the period of gradual failures (gradual failures in the literature are often called wear-out, and wear is understood in an extended sense), we will accept the normal distribution law, since it is the most universal, convenient and widely used for practical calculations.

The normal distribution is subject to the time to failure of many retrievable and non-repairable products, the dimensions and measurement errors of parts, etc. Distribution density

$$f(t) = \frac{1}{S\cdot\sqrt{2\pi}} \cdot e^{-\frac{(t-m_t)^2}{2\cdot S^2}}. \quad (1)$$

The distribution has two independent parameters: the mathematical expectation m_t and the standard deviation S. The values of the parameters m_t and S are estimated from the results of operational failure data using the formulas

$$m_t \approx \bar{t} = \sum t_i / N \ , \quad (2)$$

$$S \approx s = \sqrt{\frac{1}{N-1}\sum(t_i - \bar{t})^2}\ , \quad (3)$$

where t ̄ and S are estimates of the mathematical expectation and standard deviation. The convergence of parameters and their estimates increases with an increase in the number of operational data on failures [8].

In accordance with the data of the works of VNITI and VNIIZhT (Russia) [5,6,7], it is possible to evaluate the failure-free operation *P(t)* of an electric locomotive VL80c or 3VL80c for $t = 1{,}5 \cdot 10^4$ hours of a wearable movable joint (we mean the pivot assembly of the body frame and bogie frames - - the most susceptible to destruction), if the wear resource obeys a normal distribution with parameters $m_t = 4 \cdot 10^4$hours, S = 104 hours. Then the quantile for a new electric locomotive can be defined as:

$$U_P = \frac{1.5\cdot10^4 - 4\cdot10^4}{10^4} = -2.5\ . \quad (4)$$

The normative value of the probability of failure-free operation of the VL80c electric locomotive for one trip is 0.987...0.989, and for the overhaul period ≈0.70...0.75. The indicated probability value corresponds to the mileage between repairs of 13 thousand km. Figure 4 shows a graph obtained from the results of the operation of electric locomotives in the conditions of Uzbekistan, connecting the quantile U_P and the probability of failure-free operation *P(t)*

$$U_P = \frac{\ell n\, t - \mu}{S}. \quad (5)$$

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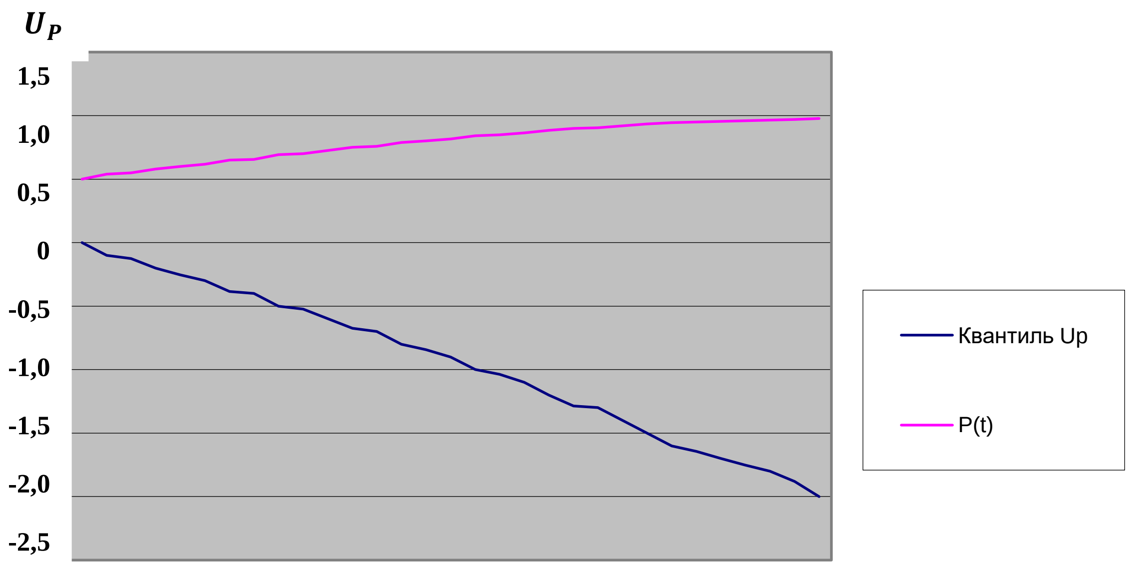

Figure 4. Dependence of U_P quantile on probability
no-failure operation P(t)

V. CONCLUSION

Based on the probabilistic-statistical processing of operational data on failures of body frames and bogie frames of electric locomotives of the VL80 and VL80s series for "Uzbekistan Temir Yollari" JSC, the following generalizing conclusions can be drawn:

1. The mechanical part accounts for about 50% of all damages, while the body frame, coupler and bogie frames account for 20.747%, 0.603% and 54.71% of all failures, respectively. In total, for the period from February 2, 2017 to October 11, 2021, 153 failures of the mechanical part (100%) were recorded for electric locomotives of the 3VL80s and VL80 types (according to the Uzbekistan depot). At the same time, a significant place is occupied by fatigue cracks that occur in the main body frame - the total percentage was - 20.747% (including body hinge beams - 9.43%; body longitudinal beams - 7.547%; central beam of the body frame - 3.77%) and in frames bogies - the total percentage was - 54.71% (cracks in the bogie frame pivot beam - 18.86%; bogie frame longitudinal beams - 24.53%; cracks along the bogie frame contour - 11.32%), in the bogie pivot bars (11.32%) and structural elements of the central support - the total percentage was - 11.32% (cracks in the area of the return device, linings and racks), etc.

2. The reason for the cracks is the structural inadequacy of the joint operation of the vertical pivot beams of the box section of the body frame at the attachment point with the bogie frames. Imperfection in the design of the pivot assembly, the central supports of the body frame and the bogie frame, which creates large oscillations of tilt and wobble, which leads to the occurrence of fatigue cracks.

3. Even after their welding (elimination) during modernization, new ones appear in their place. Therefore, it is now necessary to improve reliability during modernization due to the strengthening of dangerous sections of the bogie frame and body, thereby strengthening the design of the pivot beams of the body frames and the bogie frame and attachment points in the central support by installing curly reinforcing bars.

ISSN: 2350-0328

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Vol. 9, Issue 10 , October 2022

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