Uzbekistan Journal of Mathematics and Computer Science
Volume 1 No. 1 Page 64–70 (2025)
DOI: https://doi.org/10.56143/10.56143/ujmcs.v1i1.10
Research article

Technical diagnostics of diesel locomotive units and assemblies using mathematical modeling

Kasimov Sh. A.* Kendjayev R.Kh. and Kudratov Sh.I.

Abstract

The operational efficiency of diesel locomotives is largely determined by their reliability. The problem of ensuring the reliable operation of diesel locomotives has always been considered as one of the priority tasks for railway transport.
Reliability management of diesel locomotives consists in establishing, ensuring and maintaining its level standardized by technical conditions at all stages of creating diesel locomotives and using them for their intended purpose.
The effective use of diesel locomotives provides, in particular, their high reliability in operation, minimum maintenance and repair costs, maximum use of resource and energy potential. In this regard, a special role is given to the technical diagnosis of components and assemblies of a diesel locomotive.
The current reliability of a diesel locomotive at each given moment of its use depends on a number of factors acting in the period of time preceding this moment. For example, the reliability of a newly built locomotive depends on the level of research and development, the quality of the manufacture of components and parts, as well as their assembly and adjustment.

Keywords: *Crankshaft, thermal index, reliability, performance, diesel locomotives, thermal strength, design.*

AMS Subject Classification (2020): *Primary: 34A25 ; Secondary: 34C07;*

1. Introduction

The reliability of a locomotive in operation is determined by the conditions in which it operates (climate, dust content of air, track plan and profile, mass of trains, etc.), as well as the organization of its maintenance and repair (method of servicing the locomotive by crews, qualification of locomotive crews, frequency of inspections and repairs, scope of repair work performed during these inspections and repairs, quality of repair work, etc.).

Thus, the reliability of locomotives, their assembly units and parts depends on a large number of different factors, which can be divided into three main groups:

- design and engineering;
- production and process;
- operational and repair.

Received : *05–January–2025,* ***Accepted :*** *27–march–2025*
**** Corresponding author***

To assess the level of reliability of a technical object, a system of special numerical characteristics – reliability indicators is used. Depending on the properties of the object characterized by these indicators, single and complex indicators are distinguished [1-2].

One of the main single indicators of reliability is the failure flow parameter ω, which is the average number of failures of the repaired product per unit of time and characterizes the reliability of the locomotive. Complex indicators quantitatively characterize at least two properties that make up reliability. An example of a complex indicator is the availability factor, which simultaneously characterizes two different reliability properties of diesel locomotives - reliability and maintainability. Normalization and reliable assessment of the reliability level should be carried out using complex indicators. The use of single indicators for these purposes (the most popular among specialists is the failure flow parameter) can distort the true picture of the state of reliability of diesel locomotives.

2. Problem statement.

Technical dagnostics in order to ensure the required level of reliability and strength of such a complex object as a diesel locomotive is associated with comprehensive analytical and numerical studies on mathematical modeling of its components and parts. At the same time, an integrated approach involves solving the problems of assessing the stress-strain state, as well as studying the operating modes of the crankshaft systems of a diesel locomotive.

One of the main diesel engine systems for which the solution of such tasks is necessary is the most important and responsible system of an internal combustion engine - a crank mechanism, since it is with the help of the units of this mechanism that the thermal energy of the working gases is converted into mechanical energy of rotation of the crankshaft. The reliability of the crank mechanism directly determines the reliability and durability of the entire diesel engine of the diesel locomotive as a whole, which imposes strict requirements on the design, manufacture, installation, operation, maintenance and repair of the mechanism components, as well as on the quality of materials used in the manufacture of these components, which should ultimately ensure the required engine life.

In a diesel locomotive, steady-state torsional vibrations are forced. Under conditions of resonance of angular displacements of sections, a malfunction occurs in the area of ? ? the crankshaft. The shaft revolutions at which these resonant phenomena occur are called *critical*. The occurrence of critical crankshaft conditions leads to destruction. The task of the thermal monitoring diagnostic complex is to timely determine the malfunction of the facility:

- diagnostics during operation of critical speeds;
- determination of resonance amplitudes;
- calculation of high dynamic stresses occurring on the diesel engine crankshaft of a diesel locomotive [3 - 4].

In this work, mathematical modeling of torsional vibrations of crankshafts of diesel locomotives was carried out, taking into account the impact of operational loads. A mathematical model has been developed, an algorithm and a program have been drawn up, numerical studies have been performed in the MATHCAD 15 programming environment.

3. Method of solution

This paragraph presents a mathematical model for numerical studies of the torsional vibrations of the crankshafts of diesel locomotives, taking into account the impact of operational loads, based on the Gauss method and the iteration method.

The mathematical model for dynamic modeling is based on the assumption of calculating the crankshaft of a diesel locomotive as an eight mass discrete system consisting of a shaft of main journals with torsional stiffnesses $K_{12} - K_{78}$, as well as connecting rods mounted on it with mass moments of inertia $J_1 - J_8$.

At that, rear output part of crankshaft is connected to flywheel (flywheel flange FW), and through it - to transmission, and front part of crankshaft (FR), to which sprocket is attached, is connected to pulley of gas distributing mechanism drive and auxiliary systems.

The design diagram for this eight mass discrete system is shown in Figure 1.

Figure 1 shows the following symbols:

1 – 9 — numbers of main journals (shaft segments located on its axis of rotation) (see Figure 1);

I – VIII — numbers of crankpins (shaft segments offset from its axis of rotation and main crankpins), at $i = 1,\ 2,\ \ldots,\ 8$;

$K_{12} - K_{78}$ — torsional stiffnesses of the main journals (stiffness of the adjacent section of the shaft between masses) in $(n \cdot m)/rad$;

$J_1 - J_8$ — mass moments of inertia CR (crank pins) relative to axis OX in $kg \cdot m^2$.

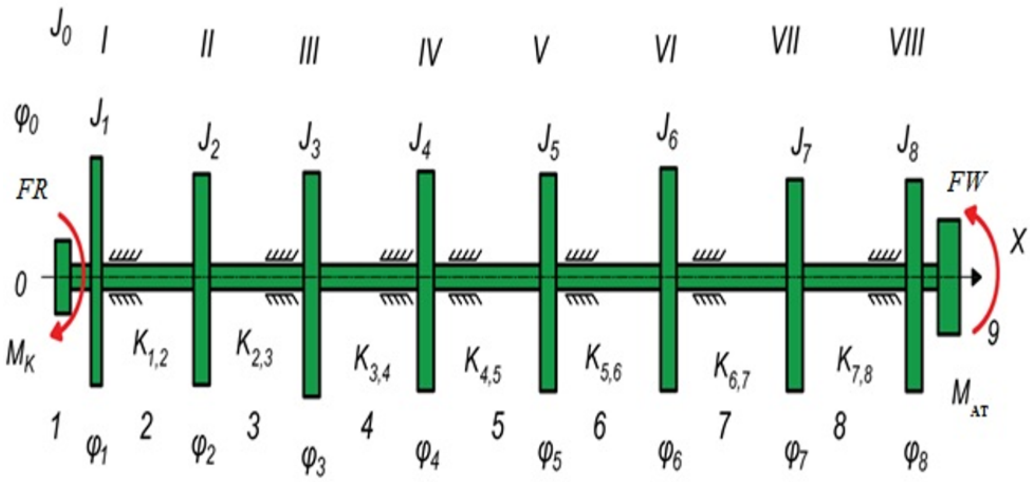

Fig. 1. Design scheme for analysis of torsional vibrations of diesel engine crankshaft in the form of eight-weight discrete system

FW — flywheel flange (shaft end) – the rear output part of the crankshaft, connected to the flywheel, and through it – to the transmission.

FR — the front part of the crankshaft (nose), to which the sprocket is attached, the drive pulley of the gas distribution mechanism and auxiliary systems.

The crankshaft of a diesel locomotive is modeled in the form of a rod with a piecewise continuous distribution of mass along the length, taking into account eight mass systems.

The calculation of the torsional oscillations of the crankshaft of a diesel locomotive with a piecewise continuous distribution of mass along the length can be represented in matrix form and "transition matrices" for sections of the rod.

We will justify the model of torsional vibrations of the masses of the crankshaft of a diesel locomotive in the form of a discrete system in the following sequence:

1. Secured crank pins rotate on crankshaft axle OX . Note here that their number for diesel generator 1A – 9 DG diesel locomotive UzTE16M [4] equals eight, i.e. $i = 1, 2, \ldots, 8$.

2. From front part of crankshaft – LE flap (FR), to which sprocket is attached, pulley of gas distributing mechanism drive and auxiliary systems, power from fuel combustion is transmitted to crankshaft and then rear output part of crankshaft, which is connected to flywheel (FW), and through it – to transmission, transmits mechanical power required for diesel locomotive movement.

3. Design scheme for analysis of torsional vibrations of diesel locomotive crankshaft in the form of eight-weight discrete system, on which the following are highlighted:

- $\varphi_j(t)$ – angles of rotation of main journals together with connecting rods on crankshaft ($j = 0, 1, \ldots, 8$) in radians, which take into account functions of rotary (kinematic) movement of each of nine masses;
- rotational moment of inertia of i-th weight of connecting rod journal J_i relative to axis OX in $kg \cdot m^2$;
- driving moment M_K at a point O, wherein the angle of rotation of the journal $\varphi_0(t)$, and the mass moment of inertia is J_0;
- antitorque moment M_{AT} is applied to the flywheel flange FW.

4. To derive the equations of oscillations of mass moments of inertia, the Lagrange method and functions were used:

4.1. kinematic energy:

$$T = \frac{1}{2}\left\{J_0(\varphi_0)^2 + (J_0 + J_1)(\varphi_0 + \varphi_1)^2 + \ldots + \left(J_0 + J_j\right)\left(\varphi_0 + \varphi_1 + \ldots + \varphi_j\right)^2\right\}, \tag{3.1}$$

4.2. potential energy:

$$P = \frac{1}{2}\left\{K_{12}(\varphi_1 - \varphi_2) + K_{23}(\varphi_2 - \varphi_3) + \ldots + K_{(j-1)j}\left(\varphi_{j-1} - \varphi_j\right)\right\}, \tag{3.2}$$

4.3. operation of external forces (torque and resistance moment in the system):

$$dA = M_K \delta\varphi_0 - M_{AT}\left(\delta\varphi_0 + \delta\varphi_1 + \delta\varphi_2 + \ldots + \delta\varphi_j\right), \tag{3.3}$$

4.4. The Lagrange equation for each j-th coordinate φ_j ($j = 0, 1, \ldots, 8$) to describe the rotation of each i-th mass ($i = 1, 2, \ldots, 8$) of a given discrete eight mass system for the crankshaft of a diesel locomotive can be written as:

$$\frac{\partial}{\partial t}\left[\frac{\partial T}{\partial \varphi_j}\right] + \frac{\partial P}{\partial \varphi_j} = \frac{\partial A}{\partial \varphi_j}, \tag{3.4}$$

for φ_0:

$$\varphi_0\left(J_0 + J_1 + J_2 + \ldots + J_j\right) + \varphi_1(J_0 + J_1) + \ldots + \varphi_j\left(J_0 + J_j\right) = M_K - M_{AT}, \tag{3.5}$$

for φ_1:

$$\varphi_0(J_0 + J_1) + \varphi_1(J_0 + J_1) + K_{12}(\varphi_1 - \varphi_2) = -M_1, \tag{3.6}$$

for φ_2:

$$\varphi_0(J_0 + J_2) + \varphi_2(J_0 + J_2) + K_{23}(\varphi_2 - \varphi_3) = -M_2, \tag{3.7}$$

for φ_i ($i = 1, 2, \ldots, 8$):

$$\varphi_0(J_0 + J_i) + \varphi_J(J_0 + J_i) + K_{(i-1)i}(\varphi_{i-1} - \varphi_i) = -M_i. \tag{3.8}$$

5. The resulting system of differential equations:

- at $M_i = 0$ and $\ddot{\varphi}_0(t) = 0$ is a system of homogeneous equations;
- at $\ddot{\varphi}_0(t) \neq 0$ shows variable rotation;
- at $M_i \neq 0$ shows the action of variable loads.

6. Solving the system of differential equations (3.5) - (3.8) for the first case. The condition in this case refers to the uneven rotation of the crankshaft of the diesel locomotive:

$$\varphi_0(t) = \varphi_0 \cos(\omega t), \tag{3.9}$$

where φ_0 is the amplitude of the circular frequency.

6.1. For system solutions,

$$\varphi_1(t) = \varphi_1 \cos(\omega t), \varphi_2(t) = \varphi_2 \cos(\omega t), \varphi_j(t) = \varphi_j \cos(\omega t), \tag{3.10}$$

where φ_j – amplitudes of model mass fluctuations as per Figure 1.

6.2. After calculating the time derivatives from (3.10) in the system of differential equations (3.5) - (3.8), a system of algebraic equations is obtained to determine the amplitudes φ_j:

$$-\varphi_1\omega^2(J_0+J_1) - \varphi_2\omega^2(J_0+J_2) - \dots - \varphi_j\omega^2(J_0+J_j) = \frac{M_K - M_{AT}}{\varphi_0\omega^2(J_0+J_1+\dots+J_j)} = B_0 \tag{3.11}$$

$$-\varphi_1\omega^2(J_0+J_1) + K_{12}(\varphi_1-\varphi_2) = \frac{-M_1}{\varphi_0\omega^2(J_0+J_1)} = B_1, \tag{3.12}$$

$$-\varphi_2\omega^2(J_0+J_2) + K_{23}(\varphi_2-\varphi_3) = \frac{-M_2}{\varphi_0\omega^2(J_0+J_2)} = B_2, \tag{3.13}$$

$$-\varphi_i\omega^2(J_0+J_i) + K_{(i-1)i}(\varphi_{i-1}-\varphi_i) = \frac{-M_j}{\varphi_0\omega^2(J_0+J_i)} = B_i(i=1,\ 2,\ \dots,\ 8). \tag{3.14}$$

6.3. We introduce the designations of the coefficients A_{ij} and B_j for φ_j in the system of algebraic equations (3.11) - (3.14):

$$A_{11}\varphi_1 + A_{12}\varphi_2 + A_{13}\varphi_3 + \dots + A_{1j}\varphi_j = B_1, \tag{3.15}$$

$$A_{21}\varphi_1 + A_{22}\varphi_2 + A_{23}\varphi_3 + \dots + A_{2j}\varphi_j = B_2, \tag{3.16}$$

$$A_{31}\varphi_1 + A_{32}\varphi_2 + A_{33}\varphi_3 + \dots + A_{3j}\varphi_j = B_3, \tag{3.17}$$

$$A_{i1}\varphi_1 + A_{i2}\varphi_2 + A_{i3}\varphi_3 + \dots + A_{ij}\varphi_i = B_i(i=1,\ 2,\ \dots,\ 8). \tag{3.18}$$

4. Discussion of results.

The resulting system of equations can be solved by the numerical Gauss method [5-8] in the MATHCAD 15 programming environment. To do this, at the beginning, a determinant is obtained from the coefficients at φ_j

$$\Delta = \begin{vmatrix} A_{11} & A_{12} & A_{13} & A_{14}\dots & A_{18} \\ A_{21} & A_{22} & A_{23} & A_{24}\dots & A_{28} \\ A_{31} & A_{32} & A_{33} & A_{34}\dots & A_{38} \\ A_{41} & A_{42} & A_{43} & A_{44}\dots & A_{48} \\ A_{51} & A_{52} & A_{53} & A_{54}\dots & A_{58} \\ A_{61} & A_{62} & A_{63} & A_{64}\dots & A_{68} \\ A_{71} & A_{72} & A_{73} & A_{74}\dots & A_{78} \\ A_{81} & A_{82} & A_{83} & A_{84}\dots & A_{88} \end{vmatrix}, \tag{4.1}$$

After that, according to Cramer's rule, the formulas for φ_j

$$\varphi_1 = \frac{1}{\Delta}\begin{vmatrix} B_1 & A_{12} & A_{13} & A_{14}\ldots & A_{18} \\ B_2 & A_{22} & A_{23} & A_{24}\ldots & A_{28} \\ B_3 & A_{32} & A_{33} & A_{34}\ldots & A_{38} \\ B_4 & A_{42} & A_{43} & A_{44}\ldots & A_{48} \\ B_5 & A_{52} & A_{53} & A_{54}\ldots & A_{58} \\ B_6 & A_{62} & A_{63} & A_{64}\ldots & A_{68} \\ B_7 & A_{72} & A_{73} & A_{74}\ldots & A_{78} \\ B_8 & A_{82} & A_{83} & A_{84}\ldots & A_{88} \end{vmatrix}, \tag{4.2}$$

$$\varphi_2 = \frac{1}{\Delta}\begin{vmatrix} A_{11} & B_1 & A_{13} & A_{14}\ldots & A_{18} \\ A_{21} & B_2 & A_{23} & A_{24}\ldots & A_{28} \\ A_{31} & B_3 & A_{33} & A_{34}\ldots & A_{38} \\ A_{41} & B_4 & A_{43} & A_{44}\ldots & A_{48} \\ A_{51} & B_5 & A_{53} & A_{54}\ldots & A_{58} \\ A_{61} & B_6 & A_{63} & A_{64}\ldots & A_{68} \\ A_{71} & B_7 & A_{73} & A_{74}\ldots & A_{78} \\ A_{81} & B_8 & A_{83} & A_{84}\ldots & A_{88} \end{vmatrix}, \tag{4.3}$$

And so on . . .

$$\varphi_8 = \frac{1}{\Delta}\begin{vmatrix} A_{11} & A_{12} & A_{13} & A_{14}\ldots & B_1 \\ A_{21} & A_{22} & A_{23} & A_{24}\ldots & B_2 \\ A_{31} & A_{32} & A_{33} & A_{34}\ldots & B_3 \\ A_{41} & A_{42} & A_{43} & A_{44}\ldots & B_4 \\ A_{51} & A_{52} & A_{53} & A_{54}\ldots & B_5 \\ A_{61} & A_{62} & A_{63} & A_{64}\ldots & B_6 \\ A_{71} & A_{72} & A_{73} & A_{74}\ldots & B_7 \\ A_{81} & A_{82} & A_{83} & A_{84}\ldots & B_8 \end{vmatrix}, \tag{4.4}$$

The system of equations (3.15) - (3.18) for calculating torsional oscillations of the crankshaft of a diesel locomotive with piecewise continuous distribution of mass along the length is presented in matrix form using concentrated mass matrices and «transition matrices» for sections of the rod according to the Gauss method and the Kramer rule. An algorithm was developed and a program was compiled based on the Gauss method and the iteration method. Numerical studies are performed in the MATHCAD 15 programming environment.

Author's contributions

All authors contributed equally to the writing of this paper. All authors read and approved the final manuscript.

References

[1] Chesnokov A.L. Heat engineering and heat exchange in internal combustion engines. - M.: 2002.
[2] Kamenev V.M. Numerical Methods of Heat Transfer Modelling. - Moscow state technical university, 2009.
[3] Nazarenko A.S., Nazarenko, O.S. Mathematical Modelling of Heat Transfer in Technical Systems. - M.: Mashinostroenie, 2011.
[4] Chetvergov V.A. Reliability of the locomotives / V.A. Chetvergov, V.D. Puzankov. - Moscow: Marshrut, 2003. – 415 p.
[5] Krivorudchenko, V.F. Modern methods of the technical diagnostics and non-destructive control of the parts and units of the rolling stock of the railway transport: Textbook for the universities of the railway transport / R.A. Akhmedjanov, V.F. Krivorudchenko. - Moscow: Marshrut, 2005. - 436 p.
[6] Kasimov Sh.A., Sulliev A. and Eshkabilov A.A. Tashkent State Transport University, Tashkent, Uzbekistan. Optimizing Pulse Combustion Systems for Enhanced Efficiency and Sustainability in Thermal Power Engineering. E3S Web of Conferences 449, 06006 (2023). pp. 5 -16, November 2023.

[7] Khamidov O., Yusufov A., Kudratov Sh., Yusupov A. (2023). Evaluation of the technical condition of locomotives using modern methods and tools. In E3S Web of Conferences (Vol. 365, p. 05004). EDP Sciences.

[8] Kasimov Sh.A., Kendjayev R.Kh. , Islomov Yo.A. Mathematical simulation of flow of gas liquid flow in improved devices in pump compressor tubing to increase oil production. AIP Conference Proceedings, Volume 3045, Issue 1, 050032 (2024), 11 March 2024. https://doi.org/10.1063/5.0197374, pp.7. Melville, New York, 2024.

Affiliations

Kasimov Shuhrat.
Address: Tashkent State Transport University, Dept. of Higher mathematics, Tashkent-Uzbekistan.
e-mail: shuxrat1812@mail.ru
ORCID ID: 0000-0003-2390-980X

Kendjayev Ravshan
Address: Tashkent State Transport University, Dept. of Higher mathematics, Tashkent-Uzbekistan.
e-mail: lovsan63@mail.ru
ORCID ID: 0000-0003-2390-980X

Kudratov Shohijakhon
Address: Tashkent State Transport University, Tashkent-Uzbekistan.
e-mail: lovsan63@mail.ru
ORCID ID: 0000-0003-2390-980X