To the diagnostic technique of support-returning devices and of the spring suspension of diesel locomotives

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Abstract. The developed dynamic calculation schemes for the horizontal and vertical dynamics of the bogie carriages of the *TEP*70 *BS* passenger diesel locomotive under an impulsive load on its body are presented. Equations of oscillations of the components of the undercarriage of the specified diesel locomotive are obtained, describing the energy state of the diagnosed system with the subsequent substantiation of the equations of coupled mass oscillations in the horizontal and vertical planes of the diagnosed diesel locomotive using Lagrange equations of the 2nd kind.

1 Introduction

One of the main locomotives carrying out passenger transportation and operating on the Uzbek railway network is the *TEP*70 *BS* passenger diesel locomotive.

Given the relatively high overall operational reliability of the said diesel locomotive, individual components of its crew part do not withstand the planned time between repairs, which leads to a significant number of unscheduled repairs.

Among the main individual components, systems and assemblies of the undercarriage, which determine possible insufficient operational reliability in the conditions of railway passenger transportation, the following can be distinguished: support-returning devices of bogie frame structures, axlebox units (axleboxes) of wheel-motor units, spring suspension elements, as well as , to a lesser extent, the sand system and auto-braking equipment.

Excluding the latter systems, the main malfunctions and defects that arise during the route of rolling stock and the implementation of its (their) repair productions are:

- supporting-returning devices: cracks, wear of supports, pins and parts of the returning device - a crack in the body of the supports, general or local wear of the support plates and working surfaces of the rollers of the returning device supports;
- spring suspension: breaks and cracks in leaf springs and coils of springs, their subsidence. In addition, with leaf springs there is a shift of the sheets and a weakening of the clamp; crushing or shearing of the mounting pin of the clamp, and unevenness of the support coils in the springs and their falling out of their seats;

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- axlebox assemblies on rolling bearings: increased heating of the axlebox, disruption of the bearings on the axle; cracks and ruptures of the inner rings; weakening the tension of the inner ring; breakage or bending of the locking bar; wear and fracture of separators; loosening the nut or the thread; watering of the lubricant;
- hydraulic vibration dampers: cracks, breaks and bends in the damper mounting brackets; damper jamming; disconnecting the protective casing or rod from the upper head; cracks, crushing or fractures of the protective casing or vibrations damper housing.

Timely elimination of these malfunctions and defects in the undercarriage of diesel locomotives by diagnosing the technical condition of support-returning devices and spring suspension in specialized diagnostic points at locomotive depots will undoubtedly increase the efficiency of their use in areas where locomotives and locomotive crews circulate.

Thus, the development of methods and ways for diagnosing the technical condition of the undercarriage of locomotives, including diesel traction, is one of the primary and urgent tasks of the specialists of the locomotive complex of «Uzbekistan Temir Yollari» JSC.

2 Objects and methods of research

To implement the above, a significant contribution is made by the employees of the department of "Locomotives and Locomotive Facilities" of the Tashkent State Transport University, who are diligently engaged in research in the field of development and creation of diagnostic complexes to substantiate the level of technical condition and quality of repair production of the operated locomotive fleet of «Uzbekistan Railways» JSC.

The above applies to support-returning devices and spring suspension, which are critical components of the undercarriage of locomotives, including *TEP*70 *BS* passenger diesel locomotives. According to statistical data from the locomotive complex of the Uzbek Railway, approximately seventy percent of the total number of failures of components of *TEP*70 *BS* diesel locomotives are due to leaf springs, springs and hydraulic vibration dampers of both stages of the spring suspension and on support-returning devices.

The author of this article analyzed a large number of scientific studies by foreign [1-13] and domestic scientists [14-17], which are directly related and aimed at developing recommendations and measures related to increasing the efficiency of using locomotives by electric and diesel tractions in the operational conditions of railways.

However, the conclusions formulated (obtained) in the above-mentioned studies by the authors [1–17] and their results, which have a certain scientific interest and high practical significance, are not at all interconnected with issues devoted to the study of the horizontal and vertical dynamics of bogie carriages of rolling stock (locomotives and cars) railway transport along the route, taking into account the behavior of the masses of their crews, caused by impulsive moment loading of the body.

This work was carried out with the aim of substantiating the diagnostic methodology for support-returning devices and spring suspension of *TEP*70 *BS* diesel locomotives when they are impulsively loaded according to the parameters of damped oscillations of the masses of the diesel locomotive.

To solve this problem, vibrations equations are needed that describe the behavior of the masses of the crew of the diesel locomotive being diagnosed. For this purpose, based on design features [18] and research [19-22], dynamic of calculations schemes were developed, presented in fig. 1 - fig. 3 taking into account the associated vibrations of wagtion, of transverse movement, of lateral rolling and vertical vibrations of the *TEP*70 *BS* passenger diesel locomotive

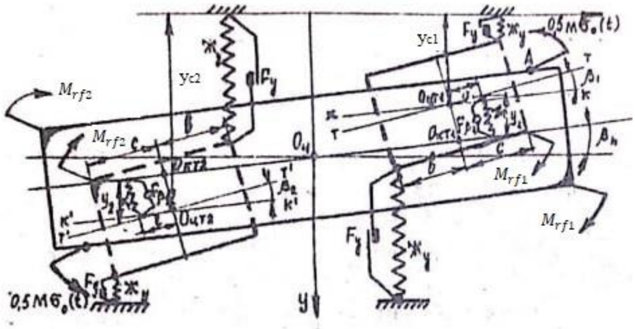

Fig. 1. Dynamic of calculation scheme of coupled oscillations of wagtion and of support masses of the diagnosed system in the horizontal longitudinal plane

Source: «Compiled by the author».

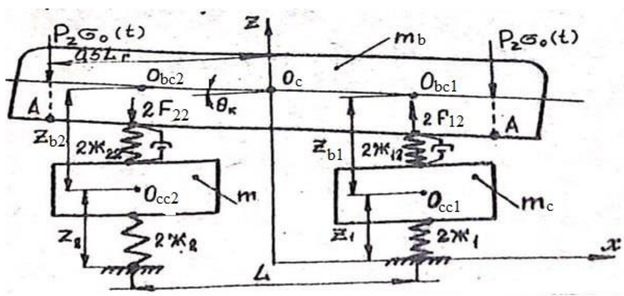

Fig. 2. Dynamic of calculation scheme of coupled vertical oscillations and lateral rolling masses of the diagnosed system in the vertical longitudinal plane

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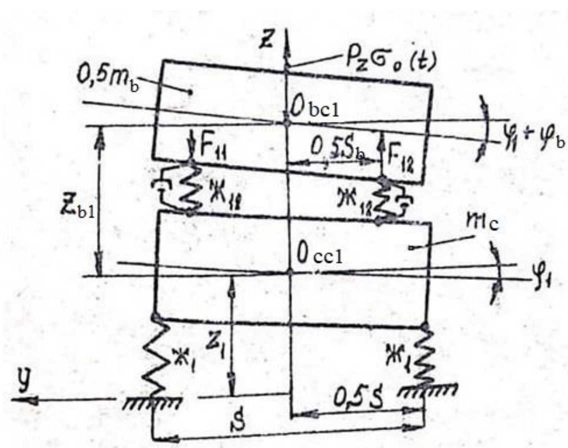

Fig. 3. Dynamic calculation scheme of coupled vertical oscillations and lateral rolling masses roll of the diagnosed system in the vertical transverse plane

Source: «Compiled by the author».

The following assumptions were used for these schemes and the derivation of mass oscillation equations.

1. The following values are accepted as constant: m_c, m_b - the masses of the bogies and the body; I_{cx}, I_{cz}, I_{bx}, I_{by}, I_{bz} - mass moment of inertia of the bogies and body relative to the axes passing through the center of gravity of the body and bogies; $Ж_y$, $Ж_c$ - the rigidity of the elastic axial stops in the axle boxes of the front and rear wheel pair of each bogie, as well as the support-return devices between the body and frame of each bogie; F_y - the reduced frictional forces of the sprung masses of the bogies when they move relative to the wheel pairs; $F_{\beta 1}$, $F_{\beta 1}$ – for reduced resistance forces of viscous friction of hydraulic vibration dampers of support-return devices; M_{rf1}, M_{rf2} - of reduced moments of the returning forces of the support-returning devices; $2Ж_1$, $2Ж_2$ - for reduced vertical stiffnesses of the spring suspension of the first stage between the frames and wheel pairs of each bogie; $2Ж_{12}$, $2Ж_{22}$ – for given vertical stiffnesses of support-return devices and second-stage spring suspension springs between the bogies and the locomotive body; $2F_{12}$, $2F_{22}$ - reduced viscous friction resistance forces of hydraulic vibration dampers of the second stage spring suspension between the bogies and the locomotive body.
2. The position of the masses at any time is determined by the coordinates: y_1, y_2, y_{c1}, y_{c2}, z_1, z_2, z_{b1}, z_{b2} - relative horizontal and vertical elastic movements reduced masses of the carts and body; β_1, β_2, β_b, φ_1, φ_2, φ_b - angles of relative elastic deformations of the reduced masses of the bogies and body.
3. The reverse form of specifying coordinates is used, taking into account relative mass movements from the reference axis, rather than absolute ones [23].
4. The energy state of the diagnosed system when deriving of the oscillation equations masses of dynamic calculation schemes is described on the basis of the Lagrange equations of the 2nd kind.

4.1. For the design scheme presented in fig. 1 we have:

$$\frac{d}{dt}\left[\frac{\partial T_1}{\partial K_i}\right]+\frac{\partial \Pi_1}{\partial K_1}+\frac{\partial \Phi_1}{\partial K_1}=\frac{\delta A_1}{\delta K_1} \tag{1}$$

4.2. For the design scheme presented in fig. 2 and fig. 3 will be:

$$\frac{d}{dt}\left[\frac{\partial T_2}{\partial K_i}\right]+\frac{\partial \Pi_2}{\partial K_i}+\frac{\partial \Phi_2}{\partial K_i}=\frac{\delta A_2}{\delta K_i} \tag{2}$$

where K_i – i-th coordinates of linear and angular elastic displacements of the reduced masses of the bogies and body of the diagnosed diesel locomotive;

T_1, T_2 и Π_1, Π_2 – respectively, the kinetic and potential energy of the system being diagnosed;

Φ_1, Φ_2 и A_1, A_2 – respectively, the energy of dissipative forces and the work of external forces on the virtual displacements of the system being diagnosed.

3 Results and discussion

Taking into account the introduced assumptions and according to dynamic calculation schemes (see fig. 1 - fig. 3.), we derive, using the Lagrange method [24], equations* of kinetic and potential energies, dissipative function and work of external forces on the virtual movements of the masses of the nodes of the diesel locomotive under study , determined by elastic linear displacements and angular deformations of the reduced masses of the system being diagnosed (*Values T, Π, Φ, A with index 1 refer to the design scheme according to fig. 1, and with index 2 - according to fig. 2 and fig. 3).

1. Kinetic energy of the system being diagnosed:

$$T_1 = \frac{1}{2}\Big\{m_c \cdot (\dot{y}_{c1}^2 + \dot{y}_{c2}^2) + \frac{1}{4}m_b\big[\dot{y}_{c1} + \dot{y}_1 - \big(\dot{\beta}_b + \dot{\beta}_1\big)\cdot l + \dot{\beta}_b \cdot l + \dot{y}_{c2} - \dot{y}_2 + \big(\dot{\beta}_b + \dot{\beta}_2\big)\cdot l + \dot{\beta}_b \cdot l\big] + I_{bz}\cdot \dot{\beta}_b^2 + I_{cz}\big[\big(\dot{\beta}_b + \dot{\beta}_1\big) + \big(\dot{\beta}_b + \dot{\beta}_2\big)\big]\Big\} \tag{3}$$

$$T_2 = \frac{1}{2}\Big[m_c \cdot (\dot{z}_1^2 + \dot{z}_2^2) + \frac{1}{4}m_b \cdot (\dot{z}_1 + \dot{z}_{b1} + \dot{z}_2 + \dot{z}_{b2}) + \frac{I_{by}}{L^2}\cdot (\dot{z}_2 + \dot{z}_{b2} - \dot{z}_1 - \dot{z}_{b1}) + I_{cz} \cdot (\dot{\varphi}_1^2 + \dot{\varphi}_2^2) + I_{bx}\cdot\Big(\frac{\dot{\varphi}_1 + \dot{\varphi}_2}{2} + \dot{\varphi}_b\Big)\Big] \tag{4}$$

2. Potential energy of the system being diagnosed:

$$\Pi_1 = \frac{1}{2}\big\{Ж_c(y_1^2 + y_2^2) + Ж_y[2y_{c1}^2 + 2y_{c1}\cdot(\beta_b + \beta_1)\cdot(b - c) + (\beta_b + \beta_1)\cdot(c^2 + b^2) + 2y_{c2}^2 2 + 2y_{c2}(\beta_b + \beta_2)\cdot(c - b) + (\beta_b + \beta_2)\cdot(c^2 + b^2)]\big\} \tag{5}$$

$$\Pi_2 = \frac{1}{2}\Big[Ж_1\Big(2z_1^2 + \frac{S^2}{2}\cdot\varphi_1^2\Big) + Ж_2\Big(2z_2^2 + \frac{S^2}{2}\cdot\varphi_2^2\Big) + Ж_{12}\Big(2z_{b1}^2 + \frac{S_b^2}{2}\cdot\varphi_b^2\Big) + Ж_{22}\Big(2z_{b2}^2 + \frac{S_b^2}{2}\cdot\varphi_b^2\Big)\Big] \tag{6}$$

3. Dissipative function taking into account energy dissipation in the system:

$$\Phi_1 = K_{\beta 1}\cdot(\dot{y}_1^2 + \dot{y}_2^2) \tag{7}$$

$$\Phi_2 = K_{\beta 2}\cdot\big(2\dot{z}_{b1}^2 + 0{,}5\cdot S_b^2\cdot\dot{\varphi}_b^2 + 2\dot{z}_{b2}^2 + 0{,}5\cdot S_b^2\cdot\dot{\varphi}_b^2\big) \tag{8}$$

where $K_{\beta 1}$, $K_{\beta 2}$ – coefficients of “viscous” vibration resistance, determined according to recommendations [25].

4. Work of external forces on virtual displacements:

$$\delta A_1 = \big[M\sigma_0(t) - M_{rf1} - M_{rf2}\big]\cdot\delta\beta_b - M_{rf1}\cdot\delta\beta_1 - M_{rf2}\cdot\delta\beta_2 - F_y(\delta y_{c1}\cdot sign\dot{y}_{c1} + \delta y_{c2}\cdot sign\dot{y}_{c2}) \tag{9}$$

$$\delta A_2 = P_z\cdot\sigma_0(t)\cdot\delta\cdot\Big(\frac{z_1 + z_{b1} + z_2 + z_{b2}}{2}\Big) \tag{10}$$

Taking into account the ratios $y_{c1} = - y_{c2}$, $\dot{y}_{c1} = - \dot{y}_{c2}$, $y_1 = - y_2$, $\dot{y}_1 = - \dot{y}_2$, $\beta_1 = \beta_2$, $\dot{\beta}_1 = \dot{\beta}_2$, $Ж_1 = Ж_2$, $Ж_{12} = Ж_{22}$, $z_1 - z_2$, $z_{b1} = z_{b2} = z_b$, $\varphi_1 = - \varphi_1$, $F_{11} = -F_{12}$, $F_{21} = -F_{22}$, wich reflecting the symmetrical loading of the body and the identity of the parameters of the crew of both bogies, the author of this article were obtained equations for mass oscillations of the diagnosed system, namely:

– for coupled oscillations of the indicated masses in the horizontal plane we have

$$\Big(m_c + \frac{1}{4}m_b\Big)\cdot\ddot{y}_{c1} + \frac{1}{4}m_b\cdot\ddot{y}_1 + Ж_y\cdot y_1 - (c - b)\cdot Ж_y\cdot(\beta_b + \beta_1) - \frac{1}{4}m_b\cdot l\cdot\ddot{\beta}_1 = -F_y\cdot sign\dot{y}_{c1} \tag{11}$$

$$\frac{1}{2}m_b\cdot\ddot{y}_1 + 2Ж_y\cdot y_1 + 4K_{\beta 1}\cdot\dot{y}_1 - \frac{1}{42}m_b\cdot l\cdot\ddot{\beta}_1 \tag{12}$$

$$(I_{bz} + 2I_{cz})\cdot\ddot{\beta}_b + 2\cdot(c^2 + b^2)\cdot Ж_y\cdot\beta_b - 2\cdot(c - b)\cdot Ж_y\cdot y_{c1} = M\sigma_0(t) - 2M_{rf1}\cdot sign\dot{\beta}_1 \tag{13}$$

$$\left(I_{cz}+\frac{1}{2}I_{bz}\right)\cdot\ddot{\beta}_b+2\cdot(c^2+b^2)\cdot Ж_y\cdot\beta_b+I_{cz}\cdot\ddot{\beta}_1+(c^2+b^2)\cdot Ж_y\cdot\beta_1-2\cdot(c-b)\cdot Ж_y\cdot y_{c1}=-M_{rf1}\cdot sign\dot{\beta}_1 \quad (14)$$

– for coupled vertical oscillations and lateral rolling in the vertical plane will be

$$\frac{1}{2}m_b\cdot\ddot{z}_b+\left(2m_c+\frac{1}{2}m_b\right)\cdot\ddot{z}_1+4\cdot Ж_1\cdot z_1=P_z\sigma_0(t) \quad (15)$$

$$\frac{1}{2}m_b\cdot\ddot{z}_b+\left(2m_c+\frac{1}{2}m_b\right)\cdot\ddot{z}_1+4\cdot Ж_{12}\cdot z_b+8\cdot K_{\beta2}\cdot\dot{z}_b=P_z\sigma_0(t) \quad (16)$$

$$I_{bx}\cdot\ddot{\varphi}_{b+2}\cdot\left(I_{cx}+\frac{1}{2}I_{bx}\right)\cdot\ddot{\varphi}_1+Ж_{12}\cdot S_b^2\cdot\varphi_b+2\cdot K_{\beta2}\cdot \dot{S}_b^2\cdot\dot{\varphi}_b=0 \quad (17)$$

$$I_{bx}\cdot\ddot{\varphi}_{b+2}\cdot\left(I_{cx}+\frac{1}{2}I_{bx}\right)\cdot\ddot{\varphi}_1+Ж_1\cdot S^2\cdot\varphi_1 \quad (18)$$

The results of the preliminary solution of equations (11) - (18), obtained using the operational calculus method [24, 26], showed that in the case of impulsive loading of the diesel locomotive body, the diagnosed system performs damped oscillations with the natural oscillations frequencies of the masses of the body and both bogies.

4 Conclusion

1. Based on the above and the results of research [27], to diagnose the technical condition of the crew of *TEP*70 *BS* diesel locomotives, the following parameters of damped low-frequency oscillations were recommended as diagnostic signals: for bogies - of angular and offset, and for the body - vertical and angular.
2. A common sign indicating a malfunction of the support-return devices and spring suspension of both stages will be the appearance of asymmetry in the vertical oscillations of the bogies, lateral pitching and galloping of the body and bogies of the diagnosed diesel locomotive.
3. For substantiate the parameters of damped low-frequency oscillations of the masses of the diagnosed system and to determine the dynamics of changes in the values of the parameters of diagnostic signals when assessing the technical condition of support-return devices and spring suspension by the method of impulsive loading of the body of the diagnosed diesel locomotive, these studies need to be continued.

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