

The Development of Technical Solutions for the Transverse Arrangement of Wheelsets of the Triaxial Non-Pedestal Bogies for Locomotives

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Abstract

This article presents the materials related to the development of a forward-looking design of the device intended to increase the reliability of running gears of locomotives in overcoming the curved segments of track due to the transverse arrangement of wheelsets. The substantiation is provided for the goals and objectives of the study. Based on the analysis of numerous domestic and foreign sources of literature and patents devoted to this issue, the said design of the device has been developed to the level of an invention. The calculation methodologies have been proposed, and the physical and mathematical models have been developed to substantiate the major design parameters of such a device. The study results are recommended to research, industrial, and operational entities of both domestic and foreign railway transport for the purpose of their further study and possible practical implementation.

Keywords: Bogie, Box, Frame, Gear, Hydraulic Spring Suspension, Wheelset

1. Introduction

Currently, the Bryansk Machine Building Plant (BMBP) has commercialized the batch production of the two-unit mainline freight locomotive 2TE25A with the power of 2x2500 kW (2x3400 hp) with the AC/AC electric transmission with the axial adjustment of the traction effect. The locomotive is designed to drive freight trains on the railways of the Russian Federation along the 1520 mm track and can be successfully operated throughout the CIS countries and abroad.

The locomotive consists of two units. Each unit is equipped as follows: A V-shaped diesel of D49 type; an AC electric transmission; an electric dynamic brake; triaxial bogies with the two-stage spring suspension; a microprocessor system of control, monitoring, and diagnostics; an Integrated Locomotive Protection System (ILPS-U); and a Driver Vigilance Telemetric Control System (DVTCS).

The purpose for developing the locomotive of the 2TE25A model was the creation of an advanced domestic mainline freight locomotive of the new generation that meets the modern requirements of the railways operation, and is not inferior to its analogues produced by the world's leading manufacturers of locomotives.

According to its characteristics, "Vitiaz" can be compared to the freight locomotive "Blue Tiger" (one of the best examples of the foreign locomotive engineering), which was constructed by the ADTranz, Bombardier, and general electric companies. But the 2TE25A model surpasses the "Blue Tiger" in power and many other characteristics. "Vitiaz" is the first Russian two-unit mainline locomotive with the asynchronous motor drive. The avoidance of commutator motors in the mainline locomotives can be considered the revolutionary process. This makes the traction units virtually perpetual. The asynchronous motor drives make it possible to increase many times the traction capacity of the locomotive and

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to remove a set of heavyweight and energy-intensive equipment from the configuration. The new locomotive is equipped with bogies providing for better implementation of the traction effect. The design is absolutely original and allows for providing the new locomotive with smooth running as well as with the ability to drive the heavyweight trains along the segments with an extremely hard track grading. The aggregate power of the two units of the new locomotive is 5,000 kilowatts. The locomotive is able to drive trains weighing more than 6,500 tons. The design speed is 120 km/h. The monitoring, control, and protection system, which is made on the basis of microprocessor hardware and software package, ensures control, monitoring, protection, and adjustment in the automatic mode. The design of the new locomotive is based on the following modern engineering solutions: the electronic fuel supply system of diesels; the tractive power transmission with the asynchronous traction electric motors and the system of axial adjustment of the traction effect; a bogie with the two-stage spring suspension and with the mechanism of transverse arrangement of wheelsets; the screw oil-filled compressor of increased productivity, etc¹.

The objective of the study includes an analysis of the design of this locomotive shows that despite the integrated therein advanced and modern design elements, one of its units, in particular the mechanism for providing the angular turn of wheelsets, positioning the latter in the traverse direction with respect to the center of the path of the railway track curve, in our opinion is complicated, metal-intensive, and insufficiently reliable in practice due to the presence therein of a large number of rotational kinematic pairs comprising the sliding supports. At the same time, all locomotives, both domestic and mainly

foreign ones, unlike the 2TE25A locomotive, have no devices ensuring radial angular rotation of wheel sets during their movement in the curved sections of rail tracks, and therefore similar structures used on the 2TE25A locomotive may find a wide use, which enables significantly to reduce the wear of wheel flanges of wheel sets and thereby enhance the durability of locomotive undercarriage in operating conditions²⁻⁶.

Taking into account this disadvantage, the experts of the Department of Mechanics and Technological Processes of the Yelets State Bunin University together with the Department of Locomotives and Locomotive Facilities of the MIIT under the order of the Yelets Center of the Belgorod Region of the South Eastern Railways Branch of the Joint Stock Company "Russian Railways" for several years have been carrying out the research and development aimed at improving the design of the triaxial locomotive bogies that exclude the sharp wear of flanges of wheelsets, wherein the latter are protected by 12 patents of the Russian Federation for the inventions. This article is devoted to one of such designs⁷⁻¹⁰.

2. Materials and Methods

Let us consider the promising design of a triaxial locomotive bogie shown in Figure 1, which is a recognized invention¹¹.

Thus, Figure 1 shows the top view of the part of the locomotive bogie, its lateral view along arrows AA, and the lateral view along arrow B.

The locomotive bogie comprises frame 1, on which with the help of boxes 2 and a spring suspension made in the form of coiled compression springs 3, the wheelsets

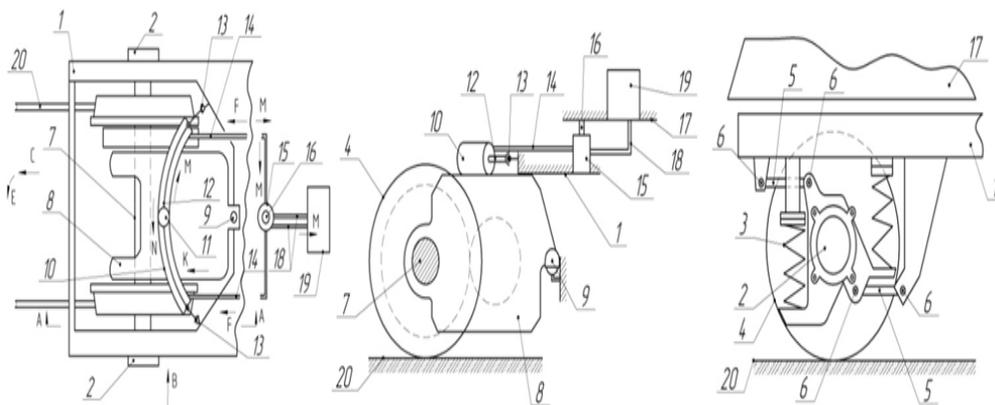


Figure 1. Design of the device of the transverse arrangement of wheelsets.

are mounted; wherein boxes 2 by means of locking studs 5 equipped with ball joints 6 are connected to frame 1 of the bogie. Traction electric motor 8 is hung on axle 7 of wheelset 4, wherein the second end of traction electric motor 8 is fixed on frame 1 of the bogie with the help of ball joint 9. On traction electric motor 8, there is rigidly fixed circular curvilinear hollow shell 10 of annular cross-section, in which rolling element 11 is movably arranged, being rigidly connected with curved rod 12 via ball joints 13 to frame 1 of the bogie. Circular curvilinear hollow shell 10 of annular cross-section by means of pipelines 14 is connected to the hydraulic directional valve 15, which is rigidly mounted on frame 1 of the bogie, and its slide valve 16 is also rigidly connected with locomotive body 17. Hydraulic directional valve 15 also with the help of pipeline 18 is connected with hydraulic unit 19 mounted in locomotive body 17. Wheelsets 4 move along railway track 20

The locomotive bogie operates as follows. During the straight-line motion of the locomotive along arrow C, when being in a train-connected or a single-unit configuration, it moves along railway track 20. Wherein the working fluid (it has no numeral reference in the Figures) from the hydraulic unit through pipeline 18 is fed to hydraulic directional valve 15, and therefrom it is transferred through pipeline 14 along arrows F to the both sub-cavities of rolling element 11. Since circular curvilinear hollow shell 10 of annular cross-section is rigidly connected with traction electric motor 8, which, in its turn, is fixed on axle 7 of the wheelset, the whole wheel-motor unit has no possibility of angular oscillations relative to the longitudinal axis of symmetry of railway track 20. When entering the curve of railway track 20, for example, with a direction of curvature along arrow E, slide valve 16 blocks one of pipelines 14, and therefore ensures the working fluid supply only to another pipeline 14, through which the latter flows along arrow K, whereas expelling from circular curvilinear hollow shell 10 of annular cross-section along arrow M and through hydraulic directional valve 15; as well as through another pipeline 18 along arrow M it is finally delivered to hydraulic unit 19. Such expelling of the working fluid occurs due to the fact that circular curvilinear hollow shell 10 of annular cross-section together with traction electric motor 8 and wheelset 4 will acquire an angular turn along arrow N (relative to ball joint 9), therefore efficiently fitting into the curve of railway track 20. After passing the curve of

railway track 20, slide valve 16 returns to its initial position (due to the fact that it is rigidly connected to locomotive body 17), and supplies hydraulic fluid pressure again to both pipelines 14 along arrows F. Then the wheel-motor unit occupies the position shown in Figure 1. It should be noted that the angular turn of the wheel-motor unit (it comprises wheelset 4 and traction electric motor 8) is of small value – no more than 6° , and since locking studs 5 and coiled compression springs 3 are made of an elastic material, for example, of the 65G graded steel, they do not prevent such movement, and after unloading, i.e., during the transition of the wheel-motor unit into the initial position, their deformation disappears. When the bogie negotiates the direction opposite of arrow E, the operation of the device is similar to that described above. It should be noted that the locomotive bogies are triaxial, and thus, as seen from the description, the described design and its operation refer not only to the turn of one axle 7, but also of another one, which, similar to the first axle, is located from the other end part of the bogie. Consequently, the angular turn is acquired only by two extreme axles 7, while the middle axle does not possess such a possibility, but this is not actually required, since its axis of symmetry coincides with the radius of the curve of railway track 20. Further, the processes described can be repeatedly performed^{10,12–17}.

3. Results and Discussion

To calculate the rational kinematic and geometrical parameters of the proposed device, the following methodology is adopted. The most important initial parameter for conducting such calculations is the force applied to curved rod 12 (see Figure 1.) that occurs during the working fluid pressure supply to curvilinear hollow shell 10, and the force of inertial resistance P_i , generated by the flux of the working fluid flowing through pipeline 14 with the diameter d_{k1} along arrow M through hydraulic directional valve 15 to hydraulic unit 19, wherein the latter can be determined from the known dependence^{3,18–19}:

$$P_i = \gamma \cdot \phi_\theta \cdot \lambda_\theta \ell_K \cdot F_b \quad (1)$$

The calculation of this force can be provided in the following sequence:

1. First, we determine the cross-sectional area of the ball m_b taking its diameter equal to 120 mm:

$$F_b = \frac{\pi \cdot D_b^2}{4} = \frac{3.14 \cdot 12^2}{4} = 113 \text{ cm}^2. \quad (2)$$

2. The pipeline area $d_{k1} = 40 \text{ mm}$ designed for removing the working fluid from curvilinear hollow shell 10 into the hydraulic directional valve makes:

$$f_{k1} = \frac{\pi \cdot d_{k1}^2}{4} = \frac{3.14 \cdot 4^2}{4} = 12.56 \text{ cm}^2. \quad (3)$$

3. Then we calculate the reduced area of section S:

$$S = F_b - f_{k1} = 113 - 12.56 = 100.44 \text{ cm}^2 \quad (4)$$

4. The working fluid pressure p before the pipeline d_{k1} at the angular turn of the wheel-motor unit to the value φ generated by the force $P_i = 6.0 \text{ m}$ providing for the given angular turn equals to:

$$p = \frac{P_i}{S} = \frac{6,000}{100.44} = 59.74 \text{ kgf / cm}^2 \quad (5)$$

5. Now, we determine the speed of the working fluid flow V_{wf} in the pipeline d_{k1} by the following dependence:

$$V_{wf} = \frac{F_b \cdot V_B}{f_{k1}} = \frac{113 \cdot 50}{12.56} = 44.9 \text{ m/s}. \quad (6)$$

where, V_B is the ball's forward speed equal to 0.5 m/s

6. Next, we determine the Reynolds number Re :

$$Re = \frac{V_{wf} \cdot d_{k1}}{\nu} = \frac{44.9 \cdot 0.04}{14 \cdot 10^{-6}} = 128,285. \quad (7)$$

Since $Re_{(sp)} = 2,300$, and the value obtained $Re = 128,285 > Re_{(sp)}$, then the mode of the working fluid motion is turbulent, and the force of inertial resistance to the ball's motion makes:

$$P_i = y \cdot \varphi_\theta \cdot \lambda_\theta \cdot l_{k1} \cdot F_b = 860 \cdot 160 \cdot 10 \cdot 0.05 \cdot 0.04 = 2,752 \text{ kgf}. \quad (8)$$

where: φ_θ is the throttling coefficient, which takes into account the constructive feature of the curvilinear hollow shell 10, and is taken as equal to 160;

λ_θ is the dynamic factor, which is equal to 10;

l_{k1} is the given length d_{k1} , which can be set similar to its absolute value $l_{k1} = l_{k1} \cdot 0.05 \text{ m}$.

An analysis of the obtained value $P_i = 2,752 \text{ kgf}$ shows that it is by 2.18 times lower than the adopted circumferential force $P_i = 6,000 \text{ kgf}$, which is generated by the curvilinear push rod of the hydraulic cylinder, and which is considered to allow dampening the dynamic loads occurring on the flange of the wheelset riding on the rail at the moment when the locomotive enters into the curve of

the railway track. However, in this case, it is also necessary to note the negative effect of such a phenomenon, since it influences the smooth running of the locomotive when it turns. Therefore, it can be concluded that the choice of P_i in each specific case substantially depends on λ_θ , the value of which, in the cases of resonant oscillation of the bogie in a transverse plane of its motion, is usually within the range from 20 to 50, and if to take into account the run of the flange of the riding wheel over the projecting unevenness formed, for example, by the rail joints at a high speed, then the λ_θ value can exceed 50.

Let us conduct the calculation of the strength of a curved rod 12 (Figure 2.) that is also a critical part, which strength directly influences both the working performance and the reliability of the proposed technical solution in general¹⁸.

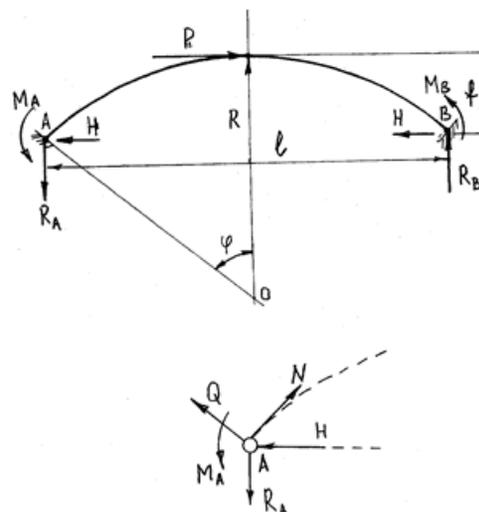


Figure 2. The analytical model of the curved rod.

Figure 2 shows the analytical model that is a curved rod with radius R fixed on supports A and B located relative to the vertical axis of symmetry of the rod at an angle φ . Supports A and B are separated by distance l . Due to the effect of external load P occurring at the angular turn of the wheel-motor unit (see Figure 2) in supports A and B , responses R_A , R_B , and H as well as moments M_A , M_B will occur. Consequently, in the rod support section, due to the effect of the given forces, the normal N and transverse Q forces will occur, which can be determined from the following formulas:

$$N = H \cos \varphi + R_A \sin \varphi, Q = H \sin \varphi - R_A \cos \varphi \quad (9)$$

As the initial data, we take the following numerical

values of the force and geometrical characteristics with respect to full-scale bogie of the locomotive 2TE25A, and of the basic diagram shown in Figure 2: $R = 600 \text{ mm}$, $P = 6.0 \text{ tf}$, $\varphi = 45^\circ$, and rod's diameter $d = 40 \text{ mm}$. Let us determine the numerical values of the geometric parameters f and l (Figure 2) using the known dependences:

$$\begin{aligned} f &= P - R \cos \varphi = 600 - 600 \cdot 0,707 = 176 \text{ mm} \\ l &= 2 P \sin \varphi = 2 \cdot 600 \cdot 0,707 = 848 \text{ mm} \end{aligned} \quad (10)$$

Now, we will determine the geometric characteristics of the rod, such as cross-sectional area S , moment of resistance W , and the moment of section inertia J from the following dependences^{18,13}:

$$\begin{aligned} S &= \frac{\pi d^2}{4} = \frac{3.14 \cdot 4^2}{4} = 12.56 \text{ cm}^2, \quad W = \frac{\pi d^3}{32} = \frac{3.14 \cdot 4^3}{32} = 6.28 \text{ cm}^3 \\ J &= \frac{\pi d^4}{64} = \frac{3.14 \cdot 4^4}{64} = 12.56 \text{ cm}^4 \end{aligned} \quad (11)$$

Now, we determine the numerical values of responses R_A , R_B , and H , as well as of moments M_A , M_B respectively from the formulas:

$$\begin{aligned} R_A &= R_B = \frac{3}{4} \cdot \frac{Pf}{l} = \frac{3 \cdot 6 \cdot 0,176}{4 \cdot 0,848} = 934 \text{ kgf} \\ H &= \frac{P}{2} = \frac{6,0}{2} = 3000 \text{ kgf} \\ M_A &= M_B = \frac{Pf}{8} = \frac{6 \cdot 0,176}{8} = 132 \text{ kgf} \cdot \text{m} \end{aligned} \quad (12)$$

Using the following dependences, we will calculate the value of the normal N and transverse Q forces acting in the rod's support sections:

$$\begin{aligned} N &= H \cos \varphi + R_A \sin \varphi = 3 \cdot 0.707 + 0.934 \cdot 0.707 = 2,781 \text{ kgf} \\ Q &= H \sin \varphi - R_A \cos \varphi = 3 \cdot 0.707 - 0.934 \cdot 0.707 = 1,461 \text{ kgf} \end{aligned} \quad (13)$$

Using the numerical values of such force characteristics, we determine the normal and tangential stresses occurring in the rod from the following formulas:

$$\begin{aligned} \sigma_M &= \frac{M}{W} = \frac{13200}{6,28} = 2102 \text{ kgf/cm}^2 = 210 \text{ MPa} \\ \sigma_N &= \frac{N}{S} = \frac{2787}{12,56} = 222 \text{ kgf/cm}^2 = 22,2 \text{ MPa} \\ \tau &= \frac{4 Q}{3 S} = \frac{4 \cdot 1461}{3 \cdot 12,56} = 155 \text{ kgf/cm}^2 = 15,5 \text{ MPa} \end{aligned} \quad (14)$$

Then the stresses characterizing the combined stress state of the rod, which occurs therein and is applied in the above-mentioned technical solution providing for the angular turn of a triaxial non-pedestal bogie of a locomotive, can be determined from the following formula:

$$\sigma_{\text{eq}} = \sqrt{(\sigma_M + \sigma_N)^2 + 3\tau^2} = \sqrt{(2102 + 222)^2 + 3 \times 155^2} = 2329 \text{ kg/cm}^2 = 233 \text{ MPa} \quad (15)$$

For the rod production, we choose the material St60 according to GOST 8509-86 with $[\sigma] = 294 \text{ MPa}$. It is evident that in this case, the strength of the rod will be ensured, since $233 \text{ MPa} < [\sigma] = 294 \text{ MPa}$ ^{19,21-23}.

4. Conclusion

In analyzing the foregoing, it is clear that the proposed design of a triaxial non-pedestal bogie of a locomotive, which is a recognized invention and can be applied in domestic mainline locomotives, including the locomotive of the 2TE25A model, meets the modern requirements for improvement of the reliability of their running gears, demonstrates a simple structure, and meets the conditions.

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