PASSENGER CAR PASSED ITS WAY SMOOTHLY

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ABSTRACT

This article continues the theme of passenger car building (see Mir Transporta [World of Transport and Transportation] Journal, 2006, Iss.2 and Iss.3 [4]). It provides a retrospective analysis (1865–2000) of ways of improvement of bogies, describes major historical and technical stages and types of modernization, outlines the story of creation of devices to ensure the movement smoothness of bogies. The representatives of scientific schools are named, who were involved in the development of units of non-automatic coupler without side buffers, as well as of two-axle bogies with single and triple suspension. A special role is given to the participation of employees of MIIT in the justification of rational installation angle of inclined hydraulic dampers in the central spring suspension, replacing the wedge friction dampers in the pedestal level with rubber gaskets.

ENGLISH SUMMARY

Background. *Passenger coach is an integral part of a passenger railway complex, providing an increasing demand for maintenance services, comfort and smooth movement of a train.*

Rail passenger coach building in Russia has a long history of development since the middle of the XIX century to the present. Features of design solutions and parameters of cars were determined by growing requirements for transportation quality and depended on climatic and social conditions, prevailing traditions of transport services.

Not everything in life of coaches was smooth. There were always reasons to talk about human fatigue in transit. Primarily there were coach's body oscillations which affected the position of parts of the human body. Coach's oscillations relate to bouncing, longitudinal pitching, parallel lateral oscillation, lateral pitching, rolling motion, shuttle motion.

Improvement of technical means, ensuring movement smoothness, goes in the direction of transmission and mitigation of actions of tensile (traction) and compression (shock) forces, speeding up their presence during the movement of a train.

Objective. *The objective of the authors is to investigate issues related to movement smoothness of passenger coaches in historical retrospective.*

Methods. *The authors use historical method, comparison, analysis and description.*

Results. *Passenger coaches' bogies are classified by purpose, number of axles, spring suspension devices and pedestal connection, a method of transmitting the load from the body and its components on the chassis, type of frame construction.*

Spring suspension reduces the dynamic impact of a track on a coach and of a coach on a track. It consists of elastic elements, returning devices and dampers. Elastic elements soften (absorb) shocks and blows on a moving coach in a vertical plane, and in conjunction with a returning device – in a horizontal plane. Dampers reduce the oscillations' amplitude, sprung weight.

Under the action of dynamic forces from a wheel set when a car is moving, elastic elements deform and provide a smooth oscillatory motion of sprung weight. Coiled springs were mainly used as elastic elements. In comparison with bolster springs they provided necessary elastic characteristics at lower weight and dimensions, and in combination with vibration dampers made movement of a train smoother. In addition, they softened horizontal thrusts and blows, were easier and cheaper to be manufactured and maintained, than bolster springs. Later railways used pneumatic, rubber, torsion and other types of springs.

Graduates of St. Petersburg Railway Engineers School were at the origin of the domestic passenger coach building. Passenger coaches, which were first built in Russia, had a central non-automatic coupling without side buffers, hand-operated brake and brake pads of aspen. With further improvement of a model designers' attention was primarily drawn to reduce tossing and shaking, for which springs were made more elastic.

Passenger coaches of Alexander mechanical plant obtained two-axle bogies with a single suspension. In 1865, engineer Rekhnevsky developed a new structure in which double spring suspension was applied, giving better smoothness than had a coach with a single suspension. In 1884, at the Russian-Baltic plant a bogie with Fette double suspension was designed. This type of a model, a prototype of which was produced only after almost three decades, was manufactured until 1936, with the replacement of wooden and metal structures with metal welded units.

The first design of bogies of a triple suspension appeared in 1897 in passenger long-distance coaches. Three years later, blacksmith master of main workshops of Petersburg-Warsaw railway I. O. Braun offered a more promising design of elliptical spring.

Two-axle bogies, which were most often present in the design of passenger coaches of the early XX century, were characterized by improved performance of spring suspension, side buffers and central towing hitch. By 1917, all domestic passenger cars had a through draft with a screw coupling and side buffers.

In the USSR, due to emergence of new types of cars and increasing speed bogies were significantly improved. Selection of spring suspension schemes was determined by requirements to ensure movement smoothness, stability and dynamic characteristics of a coach. In cradle suspension a body rested on the bolster and this bolster through a set of elastic elements rested on a cradle connected to the bogie frame with suspension links.

In 1937 bogies were tested, each of which had a system of springs' connection and the properties to mitigate vertical strokes. Bogies were compared in magnitude of amplitude and frequency of vertical and horizontal vibrations, the magnitude of acceleration and dynamic overload of chassis. Three models were recognized as the best in smoothness: bogies with a triple Fette suspension with single longitudinal balancers, bogies without balancers designed at

Egorov plant, and Khanin systems having conical springs in a central spring suspension.

Since the late 1940s to the 1980s passenger coaches used two-axle bogies CVM, KVZ-5, KVZ -TSNII, KVZ -TSNIIM and bogies with dimensions RIC. They provided a stable direction of movement along the track, the distribution and transfer of all loads from the body on a track, perception of traction and braking forces, the movement of a coach with minimal resistance and required level of smoothness.

In the 1940s, a renowned expert in the field of dynamics and design of cars M. V. Vinokourov, who headed the department of car facilities and also headed the department of cars in MEMIIT, explored natural and forced vibrations of a passenger coach. Considering the analysis of differential equations, he recommended reasonable gradual stiffness ratio of spring suspension, evaluated the impact of nonlinearity of suspension on smooth movement of a car.

In the years 1995–1997 the scientists of the department of Cars and cars facilities of MIIT led by V. D. Husidov together with JSC «TVZ» and VNIIZhT (Tver rail car plant and Russian railway research institute respectively) conducted R&D work on the modernization of a bogie KVZ-TSNII of a passenger coach. Emphasis was placed on justification of rational installation angle of inclined hydraulic dampers in the central spring suspension, replacement of wedge friction dampers in the pedestal level with rubber gaskets of a certain rigidity.

Bogies KVZ-TSNII at a high speed range in the pedestal level of suspension worsened the parameters of movement smoothness. Hydraulic dampers of central spring suspension due to their characteristics and location angle in the bogie did not provide the optimal damping of vertical and lateral vibrations. Indicator of movement smoothness was 3,25, which was not consistent with the standards adopted by the Ministry of railways. Therefore, in order to modernize a bogie, critical coefficients of dampers' resistance were identified through calculations of vertical and lateral vibrations of a coach.

It was found that for vertical oscillations of the body critical value of the resistance coefficient of a damper was 2,0 tf / m, and for the side oscillation it was equal to 10 tf / m. The researchers used integration of a system of differential equations to set an initial lateral deviation of a body from the equilibrium position and chose the value through calculation, at which the process of the damped oscillations became aperiodic.

In case of forced spatial oscillations of a passenger coach on bogies of type KVZ-TSNII, required value of damping of vertical oscillations should be two times larger than for the lateral oscillations. This fact should be taken into account when determining the rational installation angle of a damper in a bogie for joint damping of vertical and lateral oscillations, as well as while choosing coefficients of resistance of vertical and lateral dampers involved in separate vibration damping.

At the preliminary discussion in JSC «TVZ» of options to upgrade bogies KVZ-TSNII it was suggested that the lateral oscillation damping may be performed by the friction in the joints of a cradle suspension without installation of additional damper.

Series of calculations analyzed the dynamic performance of a coach at the installation angles of 45º, 60º, 75º to the horizontal plane and the different coefficient of resistance of the liquid. Dynamic performance of a car was examined through maximum values of: integral vertical forces in the central suspension acting on bolster; vertical and lateral forces's impact on central suspension spring group; lateral forces' impact arising between wheel and rail; frame forces acting on wheel sets; vertical and lateral acceleration of the body and the bogie frames.

Comparison of results showed that the damper installation angle of 45º is disadvantaged as damping forces are larger in impact horizontally than vertically. Preliminary calculations of these values recorded that they differ by two times and hence for vertical vibrations at such an angle damping force is not enough, and for lateral vibrations it is excessive.

The best dynamic performance is marked with a coefficient of damper resistance of 6–8 tf / m and the installation angle of 60–75º. Acceleration on body amounts to 0,06–0,80 g, and on the frame it does not exceed 0,50–0,60 g at a speed range from 15 to 50 m / s (54–180 km / h). Such resistance coefficient of the damper and installation angles provides a required ratio of damping forces in vertical and transverse directions, and the resistance coefficients are close to 0,25.

A standard damper of a bogie KVZ-TSNII has a certain resistance coefficient of about 12 tf / m.

Cutoff of a chart with a safety valve is approximately 1,5 t. For those parameters of a damper calculations were conducted at four installation angles, equal respectively to 45º, 60º, 75º, 80º.

The effectiveness of measures to modernize central and pedestal steps of spring suspension is determined by indicators of movement smoothness in vertical and lateral directions. Indicators of movement smoothness were obtained by calculation in the integration of the system, which describes a dynamic state of a car. According to Sperling it was made by the formula:

$$W_{\ddot{i}} = 2{,}7K\sqrt[10]{Z_0^3\omega^5},$$

where w *is vibration frequency;* Z_0 *is an amplitude of vibrations; K is empirical coefficient.*

In order to proceed with calculations, values of the coefficient K were determined by a graph showing the change in its value as a function of frequency and direction of oscillation. At the same time lengths of vertical and horizontal irregularities of 25 m; amplitudes of vertical and horizontal irregularities of 0,02 m; track gauge of 1520mm were taken as the initial values of the state of the track.

A typical variant of a bogie had the inclination angle of the hydraulic damper equal to 45º, in the pedestal level of suspension friction dampers were located with the force of friction of 0,07 t, and the elastic gasket was missing. Upgraded version of the bogie got the inclination angle of the hydraulic damper 60º, in the pedestal level of suspension friction dampers were missing, but elastic gaskets were put with the following characteristics:

- *Compression stiffness of the gasket – 4000 t / m;*
- *Shear stiffness – 2500 t / m;*
- *Stiffness for crushing – 1500 t / m;*
- *Coefficients of inelastic resistance of gaskets with compression deformation, shear and crushing – respectively 0,4; 0,3 and 0,3 tf / m;*
- *The radial clearances between the gasket and chair of spring – 10 mm.*

The best smoothness of movement was shown by a variant with split vibration damping in the central stage and a modernized version of the *pedestal level. Indicators of movement smoothness of this trolley in vertical and lateral directions were 2,80 and 2,09 respectively at speeds of 30 and 45 m / s. Thus they exceeded by 25–30% a standard option.*

Conclusion. *Users of rail transport at each historical stage consistently demonstrated the need to improve the efficiency of passenger transport, and this was the most effective stimulus to improve the design of a passenger coach. Scientists of railway universities, including MIIT, conducted R&D work which permitted through modernization of bogies of passenger coaches to ensure the smoothness of movement. The historical review shows that they used the well advanced methods of their time and their persistent efforts permitted to create newer set of applied methods which were used for a long period for further researches.*

Keywords: *history, rail transport, passenger car, spring suspension, movement smoothness, bogie construction, body, scientific schools.*

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