Peculiarities of the Influence of hydraulic vibration damper failures upon the dynamics of a passenger car

L.V. Martynenko[1*]

[1] Irkutsk State Transport University, 664074 Irkutsk, Russia

Abstract. When the car is moving along periodic irregularities of the track at a speed when the frequencies of forced and natural oscillations are close in magnitude, large amplitudes of vibrations of the body on the springs may occur, if there are no or small resistance forces in the spring suspension system. To dampen resonant vibrations, special dampers are introduced into the spring suspension system, which make it possible to reduce the amplitudes and accelerations of the driving motion, and, consequently, to reduce the impact of dynamic forces on the elements of the bogie car with different load capacity (passenger, mail and baggage cars and restaurant cars). Hydraulic vibration dampers of viscous resistance, which, despite the complication of manufacturing, repair and maintenance, are used in the bogies of passenger cars, elastic elements that do not have internal friction are used. Vertical and inclined hydraulic vibration dampers used in wagon bogies have a telescopic piston design. They are easy to operate and have a low weight.

1 Introduction

The increase in the speed limit of the rolling stock is accompanied by changes in the design of the passenger car. This is primarily due to the necessity of working out more intensively the mechanical part of the bogie and the vibration damping system, especially in the non-traction passenger rolling stock, since the design features of the track of the eastern polygon (ascents of a large slope and curves of a small radius) create an external force of a periodic nature, which, at certain speeds of movement, causes resonance phenomena that reduce the functionality and safety of the train.

Thus, a relevant direction in the development of high-speed abilities of rolling stock is the development of a set of measures and devices to reduce the level of vibrations of the mechanical system "track irregularities - wheel - bogie suspension - bogie - car body suspension - car body" in modes of increased high-speed traffic with the possibility of developing a system for controlling their characteristics depending on changes in external influence. The Irkutsk Passenger Carriage Depot of the East Siberian Branch of Federal Passenger Company JSC has revealed a number of significant deviations in the operation of

* Corresponding author: liuba.martinenko@yandex.ru

KVZ-TsNII bogies during operation (the most common in passenger rolling stock, compared to other bogie models), cracks and ruptures often occur on the bogie frame.

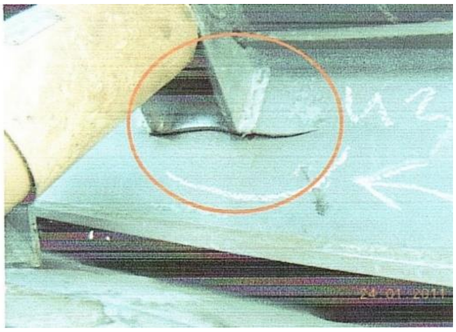

Fig. 1. Crack in the frame of a passenger trolley when the hydraulic vibration damper is not working properly

The main cause of these malfunctions is considered to be the improper operation of hydraulic vibration dampers when small chips are detected in the valve of the hydraulic vibration damper, as well as the effect of negative temperatures on the overall technical condition of this unit. The oil in the hydraulic damper thickens and the damper acts as a rigid thrust, not absorbing vibrations, but amplifying their impact. Hence, the impossibility of using them at low negative temperatures, as well as the complete lack of the possibility of dynamic control of vibration damping characteristics. As a result, there is a lack of adaptability of the system to external influences. Also, their specific disadvantages include increased wear of the damper elements due to constant friction and the need for their periodic replacement as well as contamination of the working fluid during operation, resulting in the extinguisher losing its performance due to clogging of the throttle holes. Under the influence of high temperatures resulting from the friction of the parts of the lubricated units, an active process of oxidation of hydrocarbons, which form the basis of engine oils, begins. As a result, their performance can be significantly reduced, and during long-term operation, hydraulic oil can partially dissolve rubber seals and collars.

Local excavation of the cylinder working surface does not have a significant impact on the performance of the hydraulic vibration damper, since the elasticity of the piston rings always ensures their pressure against the cylinder walls. However, its significant value contributes to rapid failure of piston rings due to intensive wear. In addition, during the operation of the extinguisher, the rings lose elasticity and sometimes burst. These defects reduce the compression between the piston and piston cavities of the cylinder. At the same time, the oil additionally flows through the gap between the cylinder walls and the piston during the tensile stroke, which causes a decrease in the drag force developed by the damper during tension. With faulty vibration dampers, the car body swings for a longer time on spring suspension, pushes and shocks are dampened harshly, which creates conditions for more serious malfunctions in the bogie units. In the process of operation of vibration dampers, its parts wear out and are damaged. The rod and the inner surface of the cylinder receive local workings, as well as the oil seal frames associated with them. As the wear of the rod and its guide increases, the annular gap between these parts increases too. To determine the type of increase in this gap, the rods and guides of the dampers that came to the wagon depot for inspection were periodically measured. Below are the fault drawings of the hydraulic vibration damper parts.

The oil pressure in the piston cavity of the cylinder during compression and tension is increased. Therefore, the oil is forced out of the cylinder into the reservoir through the annular gap between the rod and its guide at both strokes.

Fig. 2. The wear of the axle box of the hydraulic vibration damper, the piston rod and its guide

Increasing this gap will lower the damper's resistance parameter. An intense parameter drop starts at a gap of 0.08 mm or more.

Fig. 3. Hydraulic vibration damper ring

During the operation of the hydraulic vibration damper, the piston rings lose elasticity and sometimes burst. These defects reduce the compression between the piston and piston cavities of the cylinder. At the same time, the oil additionally flows through the gap between the cylinder walls and the piston during the tensile stroke, which causes a decrease in the drag force developed by the damper during tension.

2 Methods and materials

The analysis of hydraulic vibration dampers failures for 2015-2022 is presented in Table 1.

Table 1. Fault Analysis of Hydraulic Vibration Dampers

Faults/Years	2015	2016	2017	2018	2019	2020	2021	2022
Ice formation under the casing, pieces	336	440	337	441	443	445	337	443
Discrepancy in test diagrams, pieces	1156	1160	1163	1165	1163	1166	1165	1162
Wear of bushings, pieces	224	227	223	224	222	224	227	223
Wear of piston rings, pieces	1139	1133	1152	1134	1119	1108	1123	1135
Discrepancy in valve adjustment, pieces	--	--	--	--	--	--	--	--

Casing deformation, pieces	112	112	113	113	111	112	111	113
Wear of the guide rod, pieces	112	111	111	112	111	114	112	111
Fluid leakage, pieces	1155	1159	1162	1164	1162	1165	1164	1161
Damage to the stem seal, pieces	996	998	997	998	994	996	998	997
Cylinder damage/wear, pieces	-	-	-	-	-	-	-	-
Damage to the bottom, pieces	-	-	-	-	-	-	-	-
Damage to the bellows on the MGK, pieces	114	112	112	116	115	117	113	114
Total faults, pieces	5517 1100%	5532 ++3%	5533 ++0,3 %	5546 ++2,4 %	5532 --2,5%	5549 ++3,2 %	5539 --1,9%	5537 --0,4%

According to the analysis carried out from 2015 to 2022, among the malfunctions of hydraulic vibration dampers model 45.30.045 prevail:

- fluid leakage
- damage to the stem seal;
- piston ring fracture;
- Inconsistencies in test diagrams.

When calculating the loads acting on the hydraulic vibration damper during operation, the hydraulic vibration damper experiences a load of 110 kg/cm Calculation of the effective loads on the hydraulic vibration damper in a static state when the rolling stock is not in motion.

The calculation of the vibration damper load can be determined by formulas (1) and (2)

KVZ-TsN type I $$P_{st} = \frac{Pbr - P_h}{m},$$

$$P_{st} = \frac{588.6 - 0.2}{4} = 147.1kN \tag{1}$$

KVZ-TsNII type II $$P_{st} = \frac{Pbr - P_h}{m},$$

$$P_{st} = \frac{706.32 - 0.2}{8} = 88.3kN \tag{2}$$

where P_{br} is the mass of the wagon;
P_h is the mass of a single part;
m is the number of parts under the wagon.

The calculation data showed that the load on the hydraulic vibration damper depends on the gross wagon, the number of hydraulic vibration dampers and the technical condition in theagon.

The transfer of dynamic forces to the hydraulic vibration damper during the movement of the car from the contact of the wheels with the rails occurs with a small radius of the curve, galloping, unevenness of the track, uneven seating of passengers in the car, skew of the car of more than 50 mm, as well as other units of undercarriage equipment that carry a weight load, both from its own weight and from the weight of the payload.

Taking into account that the most common bogies of the passenger car are "KVZ-TsNII I and II types", the KVZ-TsNII-I bogie is typical and rolls under the bodies of passenger cars with a gross weight of up to 60 tons. The KVZ-TsNII-II bogie rolls under the bodies of cars with a gross weight of 60 to 72 tons.

Such a weight is available for dining cars, baggage cars, postal cars, mail and baggage cars, power station cars and other specialized passenger cars. KVZ-TsNII bogies of types I and II have the same design, but externally they can be distinguished by the number of hydraulic vibration dampers: KVZ-TsNII-I has one vibration damper on each side, and KVZ-TsNII-II has two. In accordance with this, the arrangement of brackets for attaching vibration dampers on the frame and bolster beam of the trolley is different. The main frame elements of the type II bogie are reinforced compared to the type I bogie. The KVZ-TsNII-II bogie has a more rigid spring suspension. The operation principle of these dampers is to sequentially transfer the viscous fluid by the piston through narrow channels (throttle holes) and suck it back through a single-acting valve. When passing through the viscous friction occurs through the throttle channels, resulting in transformation of the movement energy of the car into heat, which is then dissipated into the environment.

This vibration damper (Fig. 2) consists of a slave cylinder 7 with diameter d_c piston 10 with a rod 6 of diameter $d_ш$ reservoir 9, an upper valve 15 and a lower valve 14, a body 18 and a guide sleeve 21. The vibration damper is filled with a viscous liquid. As the piston moves downwards (compression stroke), the upper valve 15 rises and the fluid in the piston cavity of the slave cylinder flows freely into the piston cavity. However, due to the fact that the piston occupies part of the volume in the slave cylinder as it moves downward, there is an increase in pressure in the piston and piston cavities. Therefore, the bottom valve 14 closes and a portion of the fluid with high hydrodynamic resistance flows through its throttle port into the reservoir 9. The schematic diagram of the hydraulic vibration damper is shown in Figure 2.

As the piston moves upwards (stroke, tension), the upper valve 15 closes, the fluid pressure in the piston cavity of the cylinder increases, and the liquid again flows through the throttle port of the upper valve 15 into the piston cavity of the slave cylinder with great hydrodynamic resistance. At the same time, a vacuum occurs in this cavity, since the volume of fluid flowing through the throttle port of the upper valve 15 from the piston cavity is less than the volume of the piston cavity. As a result, the lower valve 14 is lifted and some of the liquid is sucked into the piston cavity from the reservoir 9, filling the space vacated by the rod. The vibration damper reservoir 9 serves not only as a reservoir for the fluid displaced by the rod from the slave cylinder, but also as a collector for the fluid seeping through the annular gap between the guide sleeve and the rod. In this cycle of the extinguisher, the fluid in the piston cavity of the working cylinderis under high pressure during the tension and compression strokes is under high pressure. Therefore, for its normal operation, a reliable seal of the rod outlet from the slave cylinder must be ensured.

The main characteristics and resistance parameters of hydraulic vibration dampers used in passenger cars are as follows:

- Stroke, mm…………………………………………………………………… – 190
- Diameter of the working cylinder, mm……………………………………….. – 68
- Piston diameter, mm ……………………………………………………….. – 67.5
- Resistance parameter β , kgf-s/s……………………………………………… –110

- Amount of working fluid cm…………………………………………………….. – 3,900
- Damper weight, kg……………………………………………………………. – 19.8

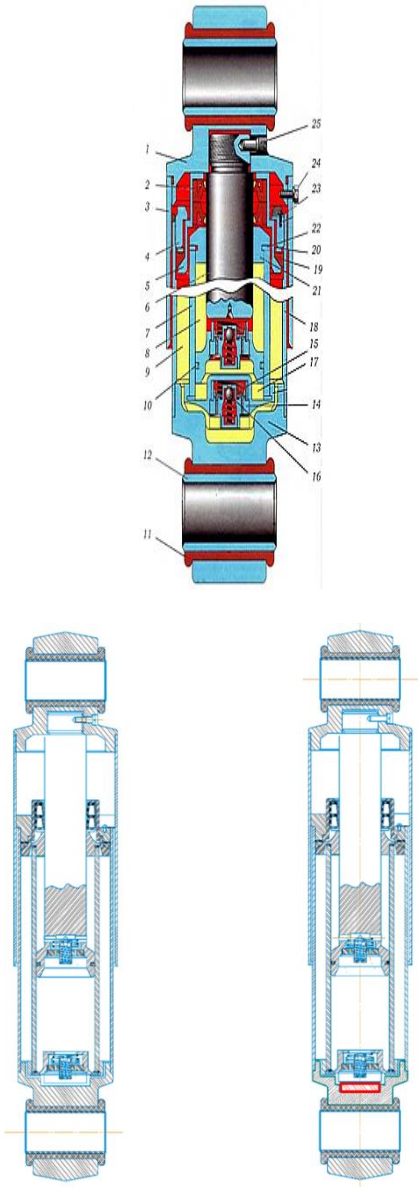

Fig. 4. Schematic diagrams of the hydraulic vibration dampers

In the system of joint damping of vibrations of the wagon on each side, the beds are installed obliquely with the angle of inclination $\alpha_{н} = 45 \div 55^{\circ}$ and the dampers are attached with their upper head to the bracket of the longitudinal beam of the bogie frame, and the lower one to the bracket of the bolster beam. With this installation, the dampers simultaneously dampen both vertical and horizontal vibrations of the body. Application of the appropriate working fluid in hydraulic dampers can significantly increase the durability of this device and ensure the stability of its characteristic - the parameter of resistance of the device. At present, low-viscosity lubricating oils containing synthetic additives are used for the working fluid of the car vibration damper, which contribute to giving this fluid the required physical and technical properties.

3 Results and discussion

In order to solve the problem of increasing the technical efficiency of the hydraulic vibration damper 45.30.045, a technical change was introduced to modernize the hydraulic vibration damper of the passenger trolley KVZ-TsNII type I, II. The main areas of modernization to improve the reliability and extend the service life of the hydraulic vibration damper are as follows:

- Significant reduction of clogging of the working fluid in the extinguisher cylinder.
- The modernized hydraulic vibration damper contains a body, in the lower part of the body, in the space between the bottom of the cylinder and the lower head, a round neodymium magnet is attached with dimensions:
- height 10 millimeters;
- diameter 20 millimeters.

Thus, when the liquid interacts with the magnet, it ensures the attraction of small chips and all kinds of inclusions in the liquid. The reliability and service life of the upgraded extinguisher is increased due to the elimination of clogging of the liquid, because suspended particles contained in the working fluid are deposited at the bottom.

In addition, no technical solution has been identified from the sources of information, in which there would be a magnet for pressing small particles and suspensions in the hydraulic vibration damper.

A number of tests were carried out with the hydraulic vibration damper 45.30.045 on the ENGA SIL 02-01 stand, which showed the damping parameters in accordance with the specifications.

4 Conclusion

In this article, it was proposed to drill a recess in the lower part of the body of the hydraulic vibration damper, then install a magnet into the drilled depression, for retention, collection of small chips and all kinds of inclusions, which will extend the life of the hydraulic vibration damper. The hydraulic vibration damper is used to play a huge role in the operation process and the disruption of dynamics leads to improper operation and cracking, as mentioned above. This implementation will improve the operation of the hydraulic vibration damper and ensure the safety of the rolling stock.

Table 2. Magnet Specifications

Characteristics	
Height, mm	10
Diameter, mm	20
Adhesion, kg	11
Magnetization	Axial
Maximum temperature, °C	80
Degaussing period, years	1% in 10
Country of origin	China
Weight, g	23,5

Table 3. Determination of the Annual Fund of Modernization Costs

Types of work	ChS 5 digit, RUB	Time, min	Price, RUB	Quantity, pcs.	Total RUB
Drilling Deepening	109	15	27.25	536	14606
Magnet Installation	109	10	11	536	5896
Total					20502
Including surcharges					38954
Social contributions: 30.4%					11842
Total					50796

Consequently, the one-time costs of the labor supply fund amount to 50,796 rubles. To date, according to statistics, the company rejects 536 hydraulic vibration dampers out of 1500 units. We propose to reduce the number of repairs by 2 times after modernization.

Table 4. Annual Repair and Maintenance of Hydraulic Vibration Dampers

Hydraulic dampers	Quantity, pcs	Cost price, RUB	Costs, RUB
Acquisition	1500	12720	19080000
Maintenance of hydraulic dampers	1500	5088	7632000
Repair	536	7890	4230000
Total			30942000

References

1. B.V. Bykov, V.E. Pigarev, Technology of wagon repair (Moscow, Zheldorizdat Publ., 2001)
2. V.P. Egorov, Structure and operation of passenger wagons (for conductors) (Moscow, UMK MPS Rossii Publ., 1999)
3. V.V. Lukin, P.S. Anisimov, Yu.P. Fedoseev, Wagons. General course (Moscow, Route Publ., 2004)
4. V.V. Lukin, L.A. Shadur, V.I. Khoturanov, A.A. Khokhlov, Designing and calculation of wagons (Moscow, UMK MPS Rossii Publ., 2000)
5. A.S. Pantyukhin, Handbook of Wagon Inspector (Moscow, Zheldorizdat Publ., 2008)

6. R.P. Strekalina, Economics and organization of wagon economy (Moscow, Route Publ., 2005)
7. P.A. Ustich, I.I. Haba, V.A. Ivashov, Wagon economy (Moscow, Route Publ., 2003)
8. I.I. Chelnokov, Hydraulic Dampers of Passenger Wagon Oscillations (Moscow, Transport Publ., 1975)