CHOICE OF PARAMETERS OF ELASTIC ELEMENTS OF «CAR–TRACK» MATHEMATICAL MODEL

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ABSTRACT

The expediency of calculating a spatial multi-mass system for optimizing the dynamic processes of interaction between rolling stock and the track is substantiated. The results of the experimental identification of the static and dynamic parameters of the damping material of elastic elements of a multi-mass system are shown. The influence of geometric dimensions and temperature factors on the elastic-hysteresis properties of damping elements is determined. The energy analysis of the obtained data is carried out. The use of the obtained experimental data as input parameters of the designed damping element of the over-axle box unit of a freight car is proposed.

Keywords: *railway, «car–track» model, multi-mass dynamic system, vibration-loaded state, damping material, rigidity coefficient, damping of forced oscillations, static hysteresis, dynamic hysteresis, temperature influence.*

Background. *With the purpose of increasing axial loads in the 60s of the last century, a large-scale modernization of the track superstructure components began, which included the use of heavy rails – R65, R75, ferro-concrete sleepers instead of wooden ones and an increase in the thickness of the ballast layer. At the same time, some specialists, including G. M. Shakhunyants [1], suggested that it is advisable to increase a diameter of a wheel of a non-self-propelled rolling stock (car) from a nominal diameter of 950 mm to 1050 mm, which will lead to a decrease in frequency of oscillations of wheel sets, bogies and bodies. It should be noted that such a wheel diameter was previously realized in variants of shrouds and cast-iron wheels of freight cars. Thus, the increase in axle loads was obtained through an increase in the mass and rigidity of the elements of track superstructure and rolling stock.*

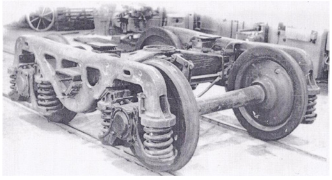
Objective. *The objective of the authors is to consider choice of parameters of elastic elements of «car–track» mathematical model.*

Methods. *The authors use general scientific and engineering methods, comparative analysis, mathematical methods, evaluation approach.*

Results.

1.

It is known that dynamic forces arising from the interaction of a wheel and a rail are an integral part of the dynamic processes of interaction of elements of a multi-mass system (running gears–track). Therefore, changes in the inertial parameters of the rail track facilitated the beginning of work on development of freight car bogies with an over-axle box and two-stage spring suspension (over-axle box and central box) [2]. In this regard, Uralvagonzavod (UVZ) in the 1970s developed and tested about a dozen variants of freight bogies with a two-stage suspension system. One of the options is shown in Pic. 1 [3]. Due to the use of two suspension stages, the mass of unsprung parts significantly decreased, which positively influenced the dynamic qualities of the bogie. Such a scheme is used in a simplified version on the railways in Europe [4]. Similar schemes are used in passenger cars.



Pic. 1. Freight bogie model UVZ-6KM.

The most common variant of such a bogie was the serial bogie model Y-25. The increase in speeds of passenger cars also required a reduction in the weight of unsprung running parts that participated in the oscillations of the «wheel–track» system. In particular, on high-speed trains of Japanese railway lines «Sinkasen» hollow axles and corrugated wheel disks began to be used [5]. One of the variants of the Japanese wheel design is shown in Pic. 2.

The work on creating hollow axes was carried out in the USSR by specialists from UVZ, VNIIZhT, VNITI, VNIIV and others [6, 7].

In the same period, scientific research in the field of transport materials science was aimed at increasing hardness and wear resistance of working surfaces of a wheel and a rail, and new methods for their thermal hardening were proposed. However, the implementation of these ideas did not lead to achievement of a desired result, since application of a classic braking scheme with one-sided pressing on domestic freight cars contributed to a decrease in strength properties of a wheel surface due to high temperatures occurring in the zone of interaction between a wheel and a brake shoe. The temperature below the surface of their contact could reach 600–700˚C [8]. In everyday practices there were «blue wheels», the sign that indicates high temperatures, and there was a need for a comprehensive study of dynamic characteristics of objects of the system.

To study the dynamic characteristics of interaction of a railway vehicle and a rail track, special mathematical models of a multi-mass dynamic system have been developed in MIIT. Some results of such studies on choice of parameters of an over-axle box suspension stage are given in [3]. Simultaneous calculation models were used to study dynamic qualities of a bogie, in which a railway track is represented as a system of rigid supports with finite rigidity. However, in recent years, significant structural and technological changes have occurred in the elements of track superstructure (sleepers, rail fasteners, ballast prism), and there is a need for additional studies on the effect of these design solutions on dynamic properties of bogies, taking into account the climatic effects.

The strategy for development of rail transport until 2030 envisages an increase in axle loads to 27–30 ton-force, an increase in speed of movement, a reduction of the impact of interaction in the «wheel–rail» system, and a reduction of a lightweight of a container car by 25 percent. Since the sections and directions of railways included in the prospective range for trains of increased weight and length are envisaged in different climatic zones of the Russian Federation (North-West, South, East, Trans-Siberian), research should be carried out taking into account the climatic characteristics of different regions of operation.

2.

The railway track and carriages moving along it are a complex thermodynamic system with many degrees of freedom, linear (elastic) and nonlinear (visco-plastic) connections. In a general case, a design scheme of their interaction can be represented in the form of a system of rigid bodies elastically coupled to one another, performing forced oscillations under the influence of a disturbing dynamic load. Elastic characteristics are built by calculation or experimentally. The stiffness of viscoelastic coupling is assumed to be tangential or secant to a loading branch of a shock absorber compression diagram. In this case, a rigidity coefficient, which is a ratio of static rigidity to dynamic for different temperature effects, is assumed as an index of elastic and viscoelastic bonds.

In connection with the above circumstances, scientific research should be focused on the study of existing designs and on development of additional structures of shock-absorbing elements in the common «wheel–rail» system, selection of a damping material capable of absorbing vibrations over a wide range of ambient temperatures, both in static and dynamic modes [9]. The appearance of new materials in the system of dampling of the elements of track superstructure, in fact, opens the possibility for the use of analogs in the systems of over-axle box stage of suspension of freight cars. According to the authors, it is expedient to develop and study a version of a generalized wheel-track model according to the scheme shown in Pic. 3.

It is known that a measure of plasticity of an elastic material is a value of the coefficient of mechanical losses, determined from a compression diagram of a sample. The larger is the area of the hysteresis loop, the more energy is dissipated, spent on heating and activation of chemical processes, and hence on damping of forced oscillations. It is advisable to evaluate both static and dynamic hysteresis under various temperature influences.

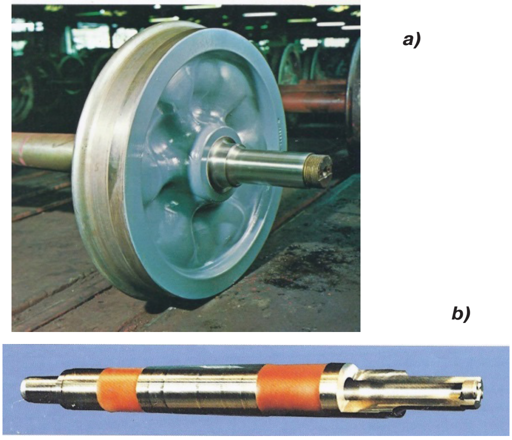
The goal for us was to study the change in elastic-hysteresis properties of TPK-5 polymer composition depending on thickness of a sample and a test temperature. The comparison was made according to the following indicators:

– Static rigidity for compression in the range of loads from 20 to 90 kN.

– Dynamic rigidity, determined at an amplitude of loads of 20–90 kN and a frequency of 10 ± 1 Hz.

– Rigidity coefficient, defined as a ratio of dynamic rigidity at an amplitude of loads of 20–90 kN and a frequency of 10 ± 1 Hz to static.

The results of experimental studies showed that static rigidity of samples with a thickness of 14,5 mm at a temperature of 23 ± 2°C was 78 kN/mm, and of a



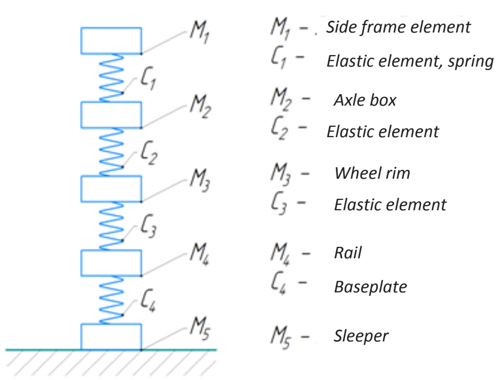
Pic. 2. Variants of reducing the weight of unsprung running parts. a) Corrugated wheel, b) Hollow axis of a wheel set.

thickness of 10 mm was of 123 kN/mm (Pic. 4), which is ≈ 1,5 times (by ≈ 50 %) greater than static rigidity of samples with a thickness of 14,5 mm. Consequently, static rigidity with decreasing thickness of a shock absorber decreases in proportion to its thickness under other equal test conditions.

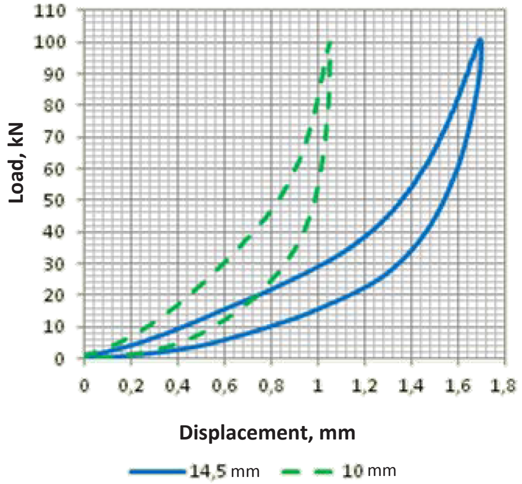
Dynamic rigidity of samples 14,5 mm thick at a loading frequency of 10 ± 1 Hz and test temperatures of 23±2°C, -40_{-2}°C, 50±2°C was 136, 304 and 133 kN/mm, and rigidity coefficient at the same temperatures was 1,74; 3,91; 1,71 respectively. A slight difference in indices of dynamic rigidity of samples at temperatures of 23±2°C and 50±2°C (within the allowed error of the experiment) indicates stability of physical properties of a polymer composition at elevated temperatures.

However, at a temperature of –40°C, the value of dynamic rigidity of samples with a thickness of 14,5 mm increases by 3,91 (Pic. 5) in comparison with the static one, and by 2,23 times in comparison with dynamic rigidity determined at a temperature of 23±2°C (Pic. 6).

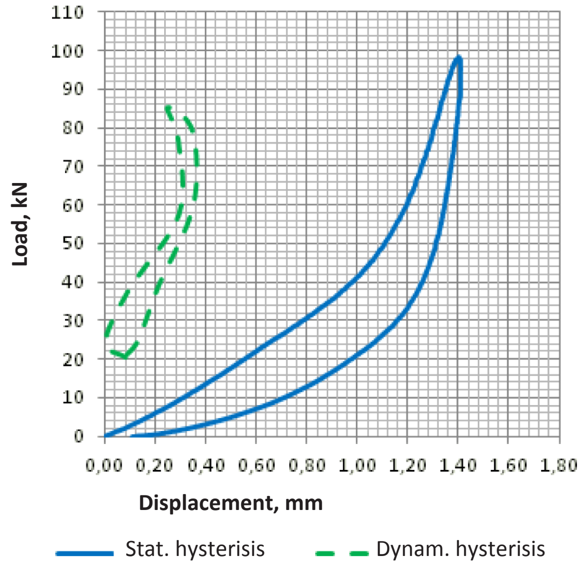
Dynamic rigidity of samples of reduced thickness (10 mm) at a loading frequency of 10 ± 1 Hz and test temperatures of 23 ± 2°C, -40_{-2}°C was 240 and 358 kN/mm, and rigidity coefficient at the same temperatures was 1,96 and 2,96. Consequently, dynamic rigidity of samples 10 mm thick at a temperature



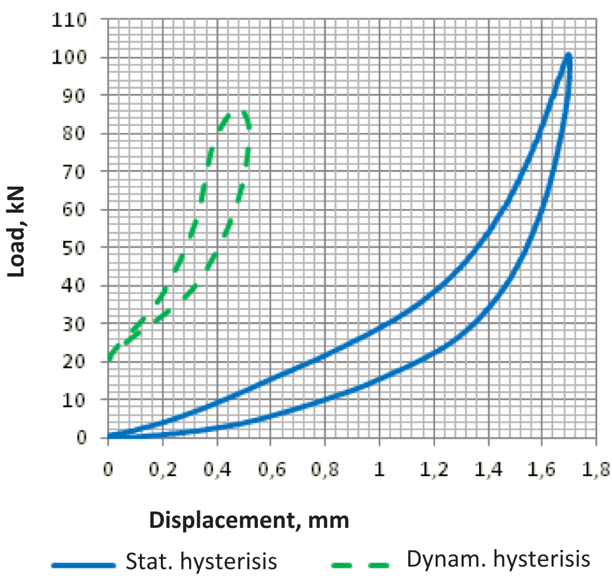
Pic. 3. Generalized model of interaction of running parts with track superstructure.



Pic. 4. Static hysteresis of samples from TPK-5 polymer composition 10 mm and 14,5 mm thick.



Pic. 5. Static and dynamic hysteresis of samples with a thickness of 14,5 mm at -40°C.



Pic. 6. Static and dynamic hysteresis of samples with a thickness of 14,5 mm at +23°C.

of –40$_{-2}$°C increased by 2,96 times in comparison with the static one and by 1,49 times – in comparison with the dynamic one at a temperature of 23±2°C.

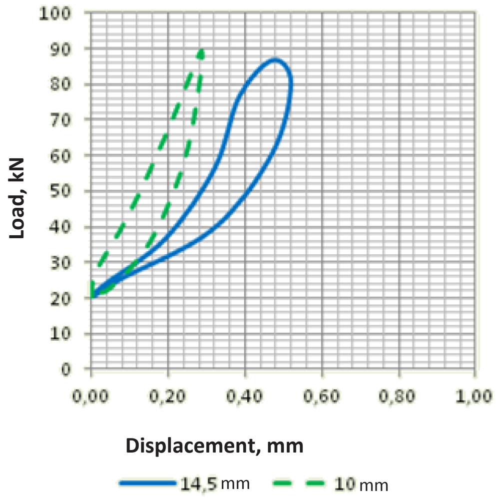
A comparative analysis of dynamic rigidity of samples from a TPK-5 polymer composition with a thickness of 14,5 mm and 10 mm showed that the value of dynamic rigidity decreases with a decrease in thickness at a temperature of 23±2°C by a factor of 1,77 (77 %) (Pic. 7) and at a temperature of –40$_{-2}$°C by 1,18 times (18 %). The decrease in rigidity coefficient for a given material at a temperature of –40$_{-2}$°C is associated with the onset of a transition from a highly elastic state to a glassy state. Therefore, to reduce damping properties at a given temperature, the physical state of the material, rather than geometric characteristics of a shock absorber, turns to be factor of predominant influence.

The fraction of energy dissipation of elastic deformation under dynamic loading of samples 14,5 mm thick compared with static loading was 27,7 %, and of samples 10 mm – 31 %. Consequently, under dynamic loading with a frequency of 10 Hz, damping of vertical oscillations decreases by ≈ 30 % for each thickness of a sample and is a qualitative indicator for this material.

Conclusions. The results of experimental studies of changes in elastic-hysteresis properties of a polymer composition under various operating conditions, as well as a generalized model of interaction of running parts with track superstructure, make it possible to effectively use the obtained data in a refined calculation model describing interaction of a railway track and rolling stock.

The effect of temperature factors on elastic-hysteresis properties of damping materials is highlighted.

The obtained experimental characteristics should be put into the mathematical model as input parameters of a designed damping element of an over-axle box unit to reduce vibration effects in a wide range of ambient temperatures.



Pic. 7. Dynamic hysteresis in tests for dynamic rigidity at +23°C of spacers with a thickness of 14,5 mm and 10 mm.

REFERENCES

1. Shakhunyants, G. M. Railway track [*Zheleznodorozhniy put'*]. Moscow, Transport publ., 1969, 536 p.

2. Shadur, L. A. Development of national car fleet [*Razvitie otechesvennogo vagonnogo parka*]. Moscow, Transport publ., 1988, 279 p.

3. Khusidov, V. D., Evstafiev, B. S., Dvukhglavov, V. A., Sergeev, K. A., Filippov, V. N. Research on dynamic properties of cars with different suspension schemes [*Issledovanie dinamicheskih kachestv vagonov s razlichnymi shemami podveshivaniya*]. *Issues of improving heavy cars: Proceedings of MIIT*. Iss. 399. Moscow, 1972, pp. 42–51.

4. McClanachan, M., Handoko, Y., Dhanasekar, M., Skerman, D., Davey, J. Modelling Freight Wagon Dynamics. *Vehicle System Dynamics,* Supplement 41, 2004, pp. 438–447.

5. Okagata, Y. Design Technologies for Railway Wheels and Future Prospects. Nippon Steel & Sumitomo Metal Technical Report, No. 105, 2013, pp. 26–33.

6. Frenkel, V. Ya., Novikov, V. V. Hollow axes of railway cars [*Polye osi zheleznodorozhnyh vagonov*]. *Transportnoe mashinostroenie*, 1966, Iss. 11, p. 55.

7. Shkolnik, L. M., Martynov, N. I., Novikov, V. V. [*et al*]. Long-term operational tests of wheel sets with hollow axes [*Dlitel'nye ekspluatatsionnye ispytaniya kolesnyh par s polymi osyami*]. *Vestnik VNIIZhT*, 1980, Iss. 4, pp. 36–41.

8. Inozemtsev, V. G. Thermal calculations in design and operation of brakes [*Teplovye raschety pri proektirovanii i ekspluatatsii tormozov*]. Moscow, Transport publ., 1966, 261 p.

9. Kurzina, A. M., Aksenov, Yu. N., Kurzina, E. G., Semak, A. V., Bogachev, A. Yu. Effect of the test temperature and damping layer thickness on static and dynamic rigidity parameters of shock absorbers from a polymer composition [*Vliyanie temperatury ispytaniya i tolshchiny dempfiruyushchego sloya na pokazateli staticheskoi i dinamicheskoi zhestkosti amortizatorov iz polimernoi kompozitsii*]. *In: Deformation and destruction of materials and nanomaterials: Proceedings of 7th International Conference Moscow, November 7–10, 2017.* Moscow, IMET RAS publ., 2017, 951 p. ●

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