CONTROL OF VEHICLE'S DYNAMIC IMPACT ON A TRACK

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ABSTRACT

Risks of natural and man-made nature force specialists to continuously monitor the state of rails and roadbed, road operating conditions. In this case, the security is dependent on ways and means of technical control of existing loads and physical influences. The authors propose an experimental method for estimating dynamic impact of a vehicle on a track, based on the spectral analysis of responses of structural elements of a track on a shock pulse. The method used involves a monitoring tracking of the movement of trains using digital measurement systems – vibration sensors converting mechanical vibration, which have an impact on them, into an electrical signal.

ENGLISH SUMMARY

Background. *The state of a track influences continuity and traffic safety, as well as the effective use of technical means of railways. Under conditions of constant exposure to natural and man-made factors a track takes big loads from passing trains. In this case, all its elements in terms of reliability, durability and stability must ensure safe and smooth movement of a train. The nature of impact on a track is determined by influence of various factors, including the level of vibrations arising from the movement of trains. The reasons for their occurrence are:*

– Moving load (quasi-static excitation) that is deflection of a track and support system, moving with the movement of a train.

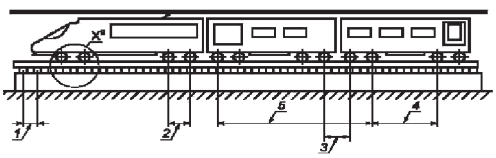
If we fix a point on the track, then variable loads, acting in it, will cause the appearance of bending waves in the rails and in the surrounding soil. The mechanism of this excitation is not yet known in detail (including the effect of boundary conditions, nonuniformity of a track and the soil on wave transmission). When a high-speed train moves along the track laid on soft soil, then its velocity can exceed the speed of a surface (Rayleigh) wave transmission in the soil. This creates a high level of vibration just as the flight of supersonic aircraft is accompanied by sonic boom. To solve the problem, rail ballast is set on compacted soil or concrete slabs with pile foundation, which reaches the denser layers of soil. If a track is laid in the tunnel, its lining and inverted arc provide a rigid foundation, which reduces vibration transmitting in the surrounding soil.

– Irregularities of wheel and rail threads.

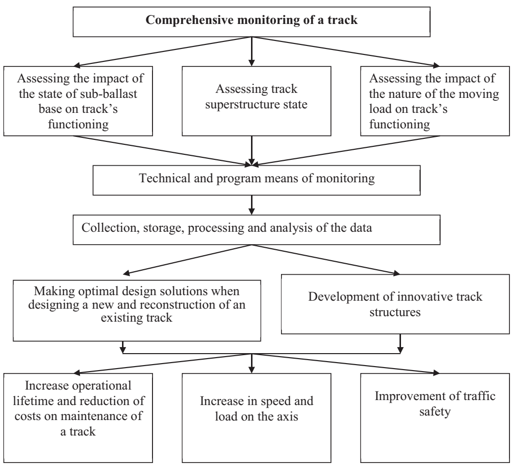
Random irregularities in the contact zone of a rail with a wheel cause excitation of the entire system of «rolling stock – track». They appear primarily in the manufacturing process, thus setting up the requirement that the state of a track and wheels should be subject to control. However, it cannot prevent from occurrence of irregularities in operation.

– Parametric excitation.

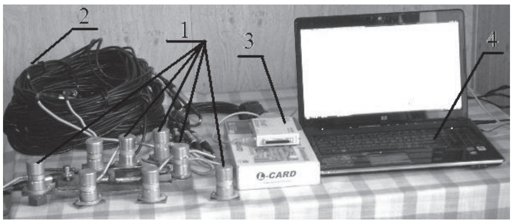
When a rail support has a discrete structure –



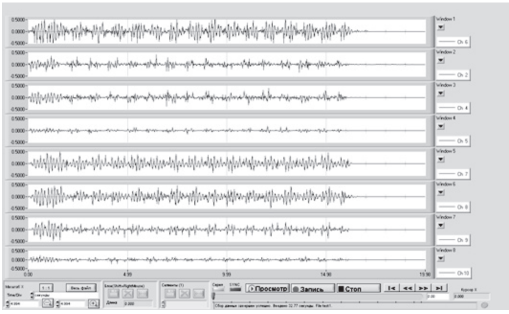
Pic. 1. Characteristic parameters of the vibration source: 1 – distance between support elements of a track; 2 – distance between wheel pairs of a bogie; 3 – distance between adjacent bogies of nearby cars; 4 – distance between bogies of one car; 5 – distance between cars.



Pic. 2. Block diagram of comprehensive monitoring of a track.



Pic. 3 General view of a mobile vibration measurement complex: 1 – vibration sensors; 2 – connection cable; 3 – multi-channel ADC; 4 – a portable computer.



Pic. 4. General view of the interface of the program «LGraph2», used to collect and store the data.

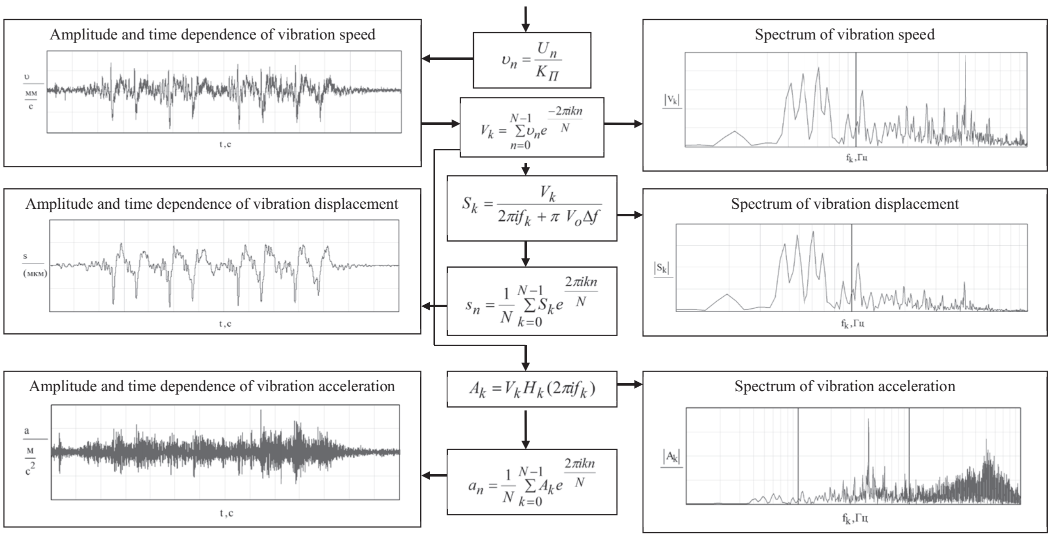
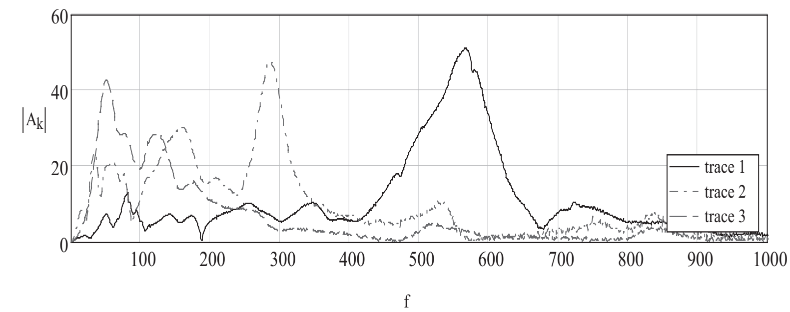
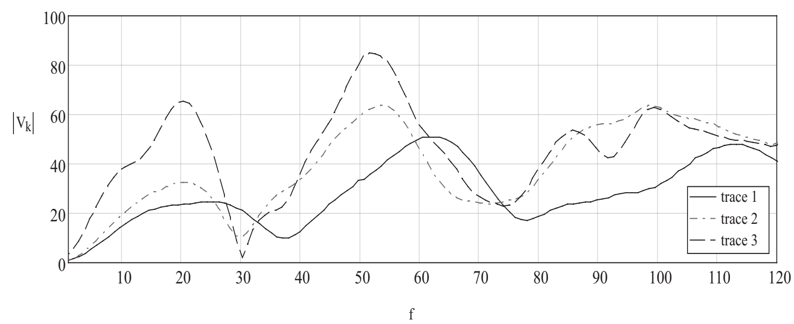


Fig. 5 Block diagram of a program for processing and visualization of track monitoring data.



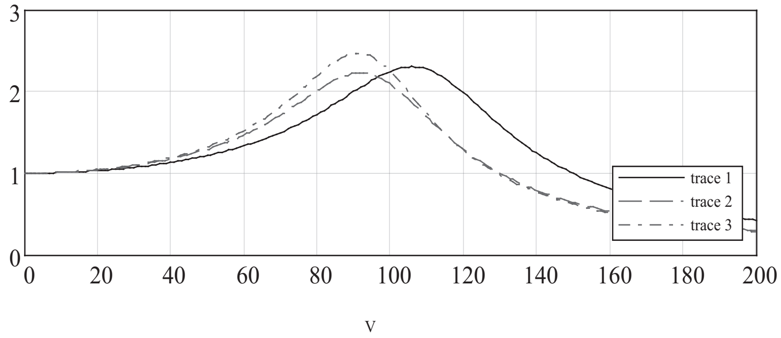
Pic. 6 Graphs of spectral density of vibration acceleration of free oscillations of the middle of a concrete sleeper: trace 1 – at a good contact of a sleeper with gravel base; trace 2 – at a poor contact of a sleeper with gravel base; trace 3 – in the absence of contact of a sleeper with gravel base.



Pic. 7. Graphs of spectral density of vibration spped of free oscillations for different designs of the track superstructure: trace 1 – fastening of FOSSLOH type; trace 2 – fastening of KZF-07 type; trace 3 – fastening of ZHBR-65SHD type.

sleepers, elastic supports on top of concrete foundation (as opposed to rails sunk in concrete), then a wheel rolling on a rail «feels» the change in support stiffness. Variable elastic force creates vibrations of wheel and rail at a frequency that depends on the speed of the train and the spatial discreteness of support. Other discreteness (and the corresponding excitation frequency) is characterized by the distances between the axes of wheel pair and bogies. If the excited frequencies coincide with own frequencies of a track, vibrations of the track and surrounding soil can be significant. Frequency exposure f_v, Hz, corresponding to n-th characteristic distance l_v, m (see Pic. 1) is determined through train speed V, m / s according to the formula:

$$f_v = \frac{V}{l_v}.$$



Pic. 8 The dependence of dynamics coefficient from speed of the rolling stock for the different designs of track superstructure: trace 1 – fastening of FOSSLOH type; trace 2 – fastening of KZF-07 type; trace 3 – fastening of ZHBR-65SHD type.

– <u>Defects of wheels (rails).</u>

In addition to the irregularities on wheel and rails threads, we can observe more gross defects arising during the operation of vehicles and a track. The most serious defects are associated with the presence of slides on wheels and wavy wear on the rail thread. Furthermore, wheels are characterized by out-of-roundness, disbalance and radius. Over time, defects accumulate, especially if there is no timely and proper technical maintenance of a track.

– <u>Solution of uniformity of rail threads</u> (on turnouts, joints of rails, etc.), causing the appearance of bumps. If the length of jointed or welded rails is equal to the distance between bogies of cars, vibration may increase substantially.

– <u>Suspension of the rolling stock</u>.

– <u>Random or periodic changes in the hardness of the rail thread</u>, resulting from defects in manufacturing or (more likely) the result of the aging of the track.

– <u>Loads in the across-track direction</u>, in particular when rolling stock moves along the curved track section of small radius, or passes turnouts.

– <u>Changes in the mode of movement</u>. Acceleration or deceleration of the rolling stock is accompanied by the emergence of variable forces and, accordingly, the oscillations.

– <u>External factors</u>. For example, the temperature and humidity of the rail head influence its wear, and consequently, vibration emerging as a result of it.

Vibration level due to the reasons listed above, depends on the input impedance (resistance of the medium, promoted for mechanical vibrations transmission) of the rail head and the wheel rim in the area of their contact. The input impedance of the rail head is determined by the design of track superstructure, its foundation, as well as characteristics of the adjacent soil.

The output impedance of the wheel essentially depends on the unsprung mass of a train. However, for a rigid suspension (for example, due to the design features of the damper and its behavior at high frequencies) the total mass of a train together with the load is of great importance.

Considering the above, improvement of security of railway operation becomes a task in which innovative methods of diagnosis and monitoring, special engineering solutions to assess the effects of vibrations during the motion of the train on the current state of the elements of the track step forward. Necessity and urgency of implementing innovative systems and diagnostic and monitoring programs are reflected in the railway track development programs of the Russian Federation and the Republic of Kazakhstan.

Objective. *The objective of the authors is to investigate dynamic impact of a train on a track and to propose a method of comprehensive track monitoring.*

Methods. *The authors use mathematical method, analysis and description.*

Results. *Based on the study of dynamic processes at strategic sites [1–5], including key points in track superstructure, a comprehensive monitoring of their state is offered (see. Pic. 2).*

Monitoring is carried out using mobile vibration measurement complex. It consists of vibration sensors MV-25D-V, which convert mechanical vibrations into an electric signal. Converting an analog signal to a digital form is performed in the electronic unit of analog-to-digital converter (ADC). Collection of digital data from the ADC and the overall management of measurements are realized by special software for the PC.

General view of a mobile vibration measurement complex is shown in Pic. 3. All measuring tools included in it are certified and calibrated.

The main advantages of a mobile vibration measurement complex include:

– Modular packaging approach with account of universal power supply;

– The use of vibration sensors with high sensitivity in a wide range of frequencies and amplitudes of the exposures;

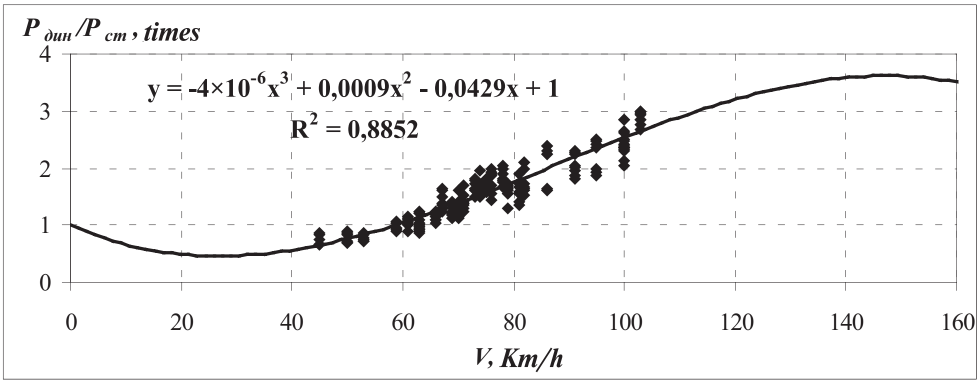
– The use of a multi-channel ADC, which enables the transfer of digital data with high accuracy to the parallel port of a PC;

– Reception of data in a digital format with the opportunity of program processing of the information received, its storage and systematization in order to identify the correlation dependencies;

– High reliability and performance in a wide range of climatic conditions;

– Small dimensions of all components.

Processing of signals, recorded by vibration sensors, is performed with help of special software, including software package «LGraph2». Using those tools, it becomes possible to configure the recording and visualization of signals in real-time (Pic. 4). Functionally «LGraph2» is a digital oscilloscope. At a later stage, measurement results are stored on the hard drive in the format «txt». During conversion of the primary data into the text format, one witnesses



Pic. 9. Correlation dependence of ratio of dynamic force on the rail base to the static strength on the speed of the electric locomotive VL-80

the dependence of the electric voltage values, generated by the sensor, on time. To determine the transformation coefficients vibration sensors are calibrated beforehand.

For the purpose of evaluation of the results of the monitoring application package for processing and visualization of data on platform «Mathcad» has been developed. Block diagram of the program is shown in Pic. 5.

A monitoring support of trains for the studied design of the track is carried out for 6–15 days (depending on the workload of the section under consideration) and includes:

– Recording of dynamic processes in the elements of railway track at moving load of different character;

– Determination of the contact conditions between elements of the track superstructure (rail – rail fastening, rail fastening – sleeper, sleeper – ballast prism) with vibro-acoustic method (see Pic. 6);

– Determination of own (resonance) frequencies and damping properties of various trackforms (see Pic. 7).

– Forecasting of rolling stock speeds, at which resonance phenomena will occur (see Pic. 8);

– Determination of the impact of a vehicle on a track (see Pic. 9).

Conclusion. *Comprehensive monitoring of a track will enable to carry out an objective assessment of the impact of design features of track elements (different types of rail fastenings, different size of ballast) on the level of vibrations arising from the movement of the train, and make optimal decisions by designing a new and reconstruction of an existing track.*

Regular monitoring helps to improve the safety of a track, increasing its operating life and reduce costs of maintenance. Even in the presence of natural and man-made factors in the operating area of the railway, risks from the expected effects reduce considerably.

Keywords: *railway, traffic safety, rails, roadbed, vehicle, impact on a track, risk factors, assessment, monitoring, vibration sensors.*

REFERENCES

1. Kvashnin, M. Ya., Kvashnin, N. M. Investigation of flexural vibrations of elastic plates to optimize methods of vibro-acoustic control [*Issledovanie izgibnyh kolebanij uprugih plastin s cel'ju optimizacii metodov vibroakusticheskogo kontrolja*]. *Vestnik KazATK,* 2009, No.3, Vol.58, pp. 152–160.

2. Makhmetova, N, M., Kvashnin, M. Ya., Akhanov, A.R., Kvashnin, N. M. Practical application of vibro-acoustic method for nondestructive testing of layered constructions [*Prakticheskij opyt primenenija vibroakusticheskogo metoda pri nerazrushajushhem kontrole sloistyh stroitel'nyh konstrukcij*]. *Materials of III International scientific and practical conference «Actual problems of mechanics and machine engineering»*. Almaty, 2009, Vol. III, pp. 182–185.

3. Kvashnin, M. Ya., Ibragimov, O.A., Kvashnin, N. M. Some results of experimental determination of dynamic characteristics of the permanent way with fastening of «Fossloh» type during «Talgo» train passage. [*Nekotorye rezul'taty jeksperimental'nogo opredelenija dinamicheskih harakteristik verhnego stroenija puti so skrepleniem tipa «Fossloh» pri prohode «Talgo»*]. *Promyshlennyj transport Kazahstana,* 2010, No.3, Vol.27, pp. 84–93.

4. Satov, M.D., Kvashnin, M. Ya., Kvashnin, N. M. Monitoring of a railway track [*Monitoring zheleznodorozhnogo puti*]. *Promyshlennost' Kazahstana,* 2010, Vol.5, pp. 58–60.

5. Kvashnin, M. Ya., Kvashnin, N. M. Method of determining dynamic characteristics of a railway track [*Metodika opredelenija dinamicheskih harakteristik zheleznodorozhnogo puti*]. *Izvestija Transsiba,* 2012, No.2, pp. 136–141.

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