CONTINUOUS MEASUREMENTS OF VERTICAL FORCES OF TRACK AND ROLLING STOCK INTERACTION

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ABSTRACT

The article highlights issues related to developed and implemented techniques of continuous measurements and dynamometering wheel sets, allowing with a sufficiently high degree of accuracy to determine dynamic vertical loads of railway rolling stock on the track (interaction of components of the system «vehicle-track»).

ENGLISH SUMMARY

Background. *Relevance of the study of interaction forces of track and rolling stock is determined by the need to find reserves in the operation of the system «vehicle-track», to increase the strength and reliability of all its units, as well as to adjust standards and methods of assessment of the track's state.*

One approach to this issue (proposed by prof. M. F. Verigo and developed by A. K. Shafranovsky [1]) is based on the fact that the magnitude of forces acting between wheel and rail can be seen in deformations of some parts of spokes or disks of train wheels.

Analysis of the effectiveness of this method has revealed a number of significant drawbacks, main among them are the following: errors caused by the simultaneous action of lateral (horizontal) forces on the wheel; errors due to change of the eccentricity of wheel contact with the rail; significant remoteness of placements of resistive strain gages from the point of wheel contact with a rail that affects the measurement accuracy of vertical interaction forces at high speeds.

Objective. *The objective of the author is to present a technique of continuous measurements and to determine dynamic vertical loads of railway rolling stock on the track. The aim of the initial reserach was to develop a technique and create measurement instruments for its implementation that enable not only to get information about vertical interaction forces acting within almost unlimited in length track section, but also to improve greatly the accuracy of measurement.*

Methods. *The author uses analysis, comparative method, engineering, statistics instruments, and method of continuous measurements.*

Results. *The feature of proposed method is that in order to proceed with continuous recording of vertical forces between wheel and rail force, measuring sensor is installed (pressed) into the hole, bored in the wheel rim. This sensor detects forces in a zone, located close to the wheel-rail contact area. This placement allows the recording system to significantly reduce estimation errors of lateral forces acting on the wheel and changes in the eccentricity of an area of wheel contact with the rail, which is inevitable when rolling. Also, the location of the sensor near the wheel thread allows to expand the frequency range of the recorded loads, that allows to measure projectile forces of wheel with rail arising during rolling through short irregularities and joints of the rails, forces in a flat wheel, and the like.*

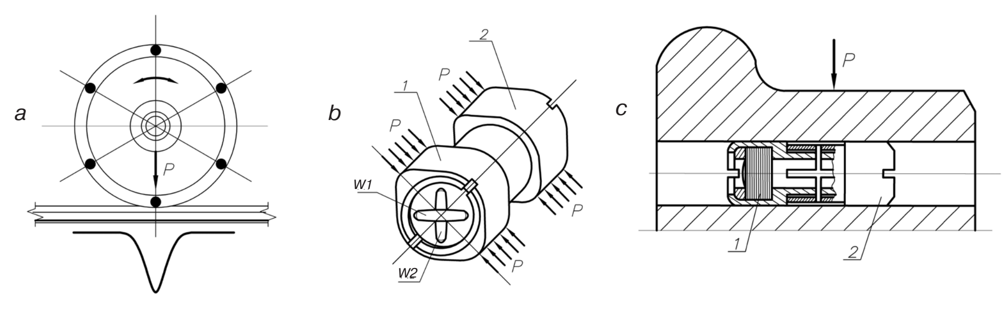
The number of force measuring sensors in the wheel determines the nature of the registration of acting forces. The adopted angular spacing between sensors, equal to 60 with the diameter of the railway wheel of 950 mm, provides information about the magnitude of interaction forces through 1/6 turn of the wheel, i. e. almost continuous picture of forces along the entire section of the track. When on one bogie two (dynamometric) wheel sets are installed, information about vertical forces can be obtained with a smaller interval on both lines of the rails.

Force sensors with magnetoelastic transducer (magnetoelastic sensors) are used as force measuring devices in a dynamometric wheel and they are characterized by high sensitivity, stability, simplicity of design, strength and stiffness of the elastic element. The principle of operation of these transducers is based on the physical phenomena associated with the change of magnetic properties of ferromagnetic material under the mechanical load applied to it [2].

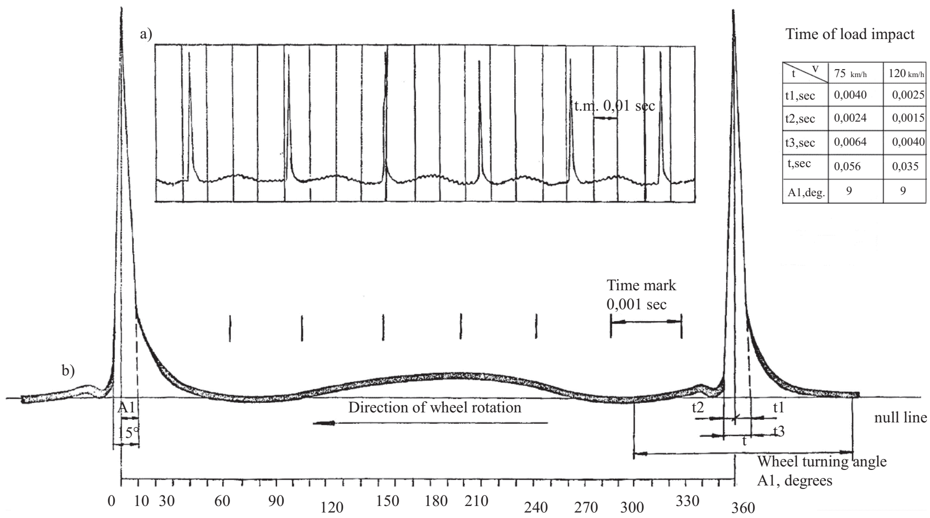
In the developed magnetoelastic force measuring sensor magnetoelastic transducer of transformer type is used. In these transducers supply circuits (primary winding) and chains with measurement devices (secondary winding) are separated, their contact with each other is provided solely by magnetic coupling. This magnetic coupling results in probability of emergence of high rates of transformation in between primary and seocndary windings, followed by high voltage output signal.

General view of the magnetoelastic force measuring sensor and its location in the wheel rim are shown in Pic. 1.

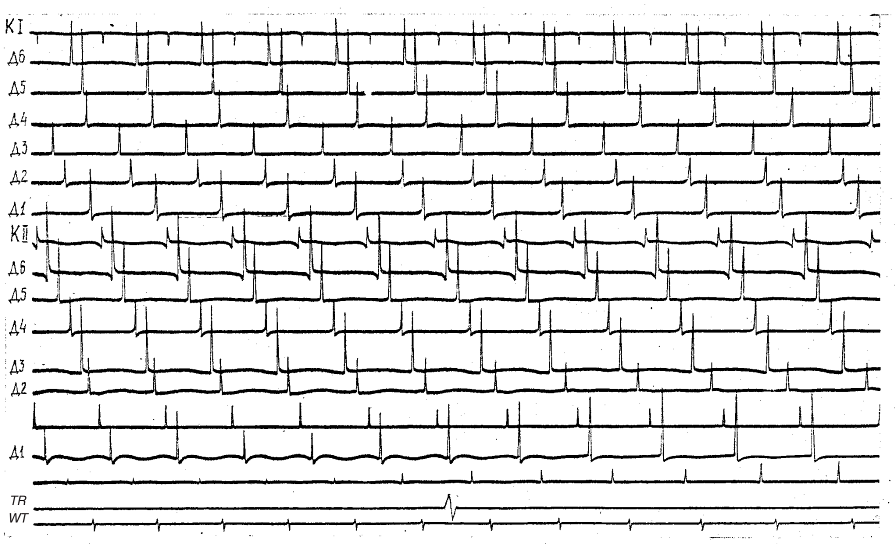
Prepared and calibrated on a special stand, force measuring sensors are pressed into the wheel rim in



Pic. 1. Dynamometric wheel set:
a – functional layout; b – magnetoelastic force measuring sensor; c – location of the sensor in the wheel rim; 1, 2 – elastic sensor elements; W1, W2 – windings of the transducer.



Pic. 2. The output signal of the force measuring sensor with continuous rotation of the wheel: a – fragment of the waveform record; b – expanded form of the output signal.



Pic. 3. Fragment of the recording of interaction forces at υ = 80 km / h: KI, KII – dynamometric wheels of a wheel set; D1...D6 – force measuring sensors; TR – reference of the track; WT – mark of the turn of the wheel.

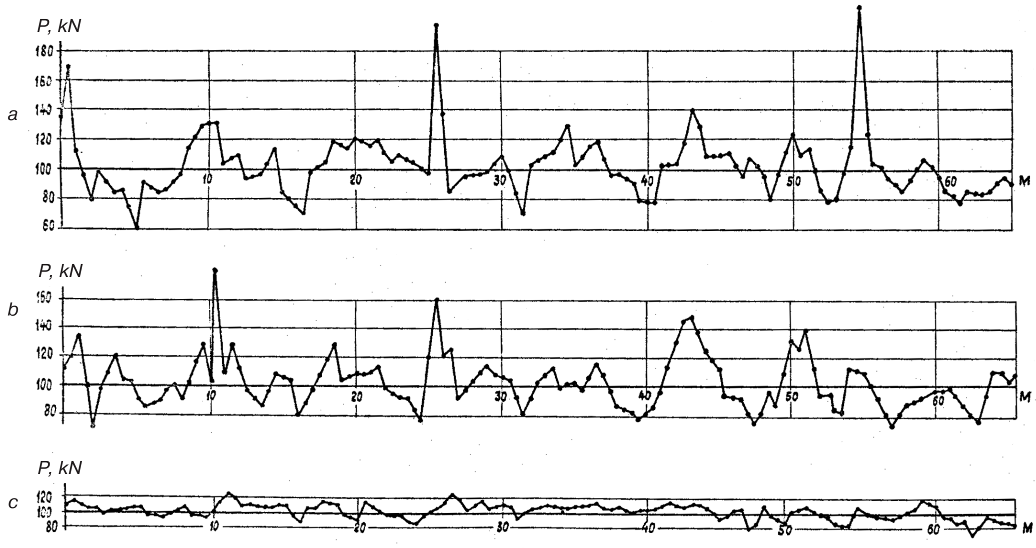
specially prepared holes. The longitudinal axis of the hole is performed with a gradient of 1:20, slope is equal to the not worn wheel thread.

Before pressing, rim in the area of the hole is heated to a temperature of 200–220 °C. Then, the sensor is inserted into the hole. Experiment has shown that after cooling the sensor is pressed with the force of 10–15 kN, which greatly improves its work and improves the linearity of its characteristics.

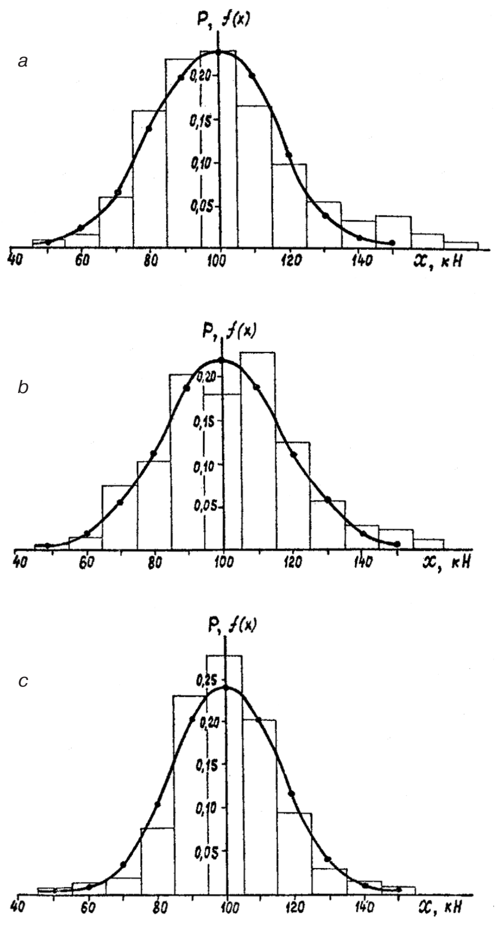
Key control characteristics of magnetoelastic transducers are recorded on the stand in the laboratory. According to them optimal parameters of the sensors in the dynamometric wheel are chosen, which provide the best linearity, maximum sensitivity and stability over time.

Static characteristics of a dynamometric wheel set are: dependence of the output signal of the magnetoelastic force measuring sensor on the load applied to the wheel; error introduced in the measurement result of vertical load by the effect of lateral (horizontal) forces; influence on the result of recorded (during the rotation of the wheel) changes in the eccentricity of vertical force application to the wheel thread.

Output characteristic of magnetoelastic sensor when different vertical load P is applied to the wheel is determined by graduation on the stand of force measuring sensors pressed in the wheel by slow loading of dynamometric wheel sets with vertical forces. The wheel set is installed so that the vertical axis of the sensor passes through the center of the ellipse of the contact area of wheel and rail. The value of vertical load applied to a wheel is controlled by a high-precision strain gauge load cell. As shown by the results of calibration, sensors have a linear output characteristic within the operating range of the measured loads. Elastic hysteresis is not observed.



Pic. 4. Changes of forces along the length of the track section without irregularities at: a – speed of 80 km / h; b – 40 km / h; c – 3 km / h (measurement points are connected conventionally).



Pic. 5. Histograms and curves of normal distribution of interaction forces on the track section without irregularities: a – at υ = 100 km / h; b – at υ = 80 km / h; c – at υ = 40 km / h.

Effect of the eccentricity of the load application on the output signal of the sensor is found by loading of a dynamometric wheel with vertical forces with different eccentricity. Changing the position of the eccentrically applied force is produced with a slight shift of a rail relative to a theoretical circle of wheel's rolling. The magnitude of the eccentricity is controlled by an impress on a paper, laid between the rail and the wheel.

Effect of the lateral force H on the measurement results of the vertical load is determined by the loading of a wheel set alternately with vertical and lateral forces and the joint action of these forces. Lateral force is applied to the flange of a dynamometric wheel by a special loading device. Developed for these purposes, it allows joint loading of a dynamometric wheel set with lateral and vertical forces.

The results of experimental studies have shown that the error of lateral forces effect on a dynamometric wheel is systematic. However, due to a small influence (from 3,2 to 4,0% in the worst case) this error can be considered as random, bringing it to the arithmetic mean value of the lateral force measured on the test section of the track.

Pic. 2a shows the result of the calibration of the sensor of a dynamometric wheel obtained by slow (quasi-static) rotation. In expanded form the shape of the output signal of the sensor is shown in Pic. 2b.

According to the results of calculation-experimental studies optimal technical characteristics of the measuring system have been determined:

- *The diameter of a dynamometric wheel: 950 mm;*
- *The number of force-measuring sensors in one of the wheels: 6 units;*
- *The limits of the measured force: 0 ... 180 kN;*
- *Recording interval of vertical forces along the track: 0, 5 m;*
- *The frequency of the test process: 0 ... 600 Hz;*
- *Maximum speed: 120 km / h;*
- *Frequency of the magnetizing current of transducers: 15–30 kHz;*
- *Supply voltage of transducers: 24 V;*

– Magnetizing current of one transducer: 250 mA;

– Sensitivity: at least 3,0 kN / mm;

– Allowable ambient temperature: from –20 to +60 °C;

– Method of registration – separately for each sensor;

– The maximum relative error of registration of forces: 4,5%.

Field tests of the measuring system were conducted at the experimental haul. Specially prepared section, 5 km long had a great assessment of the track's state.

Measurements of vertical forces on this section were made with dynamometric wheel sets installed in bogies CNNI-H-Z-O of four-axle freight open car, which is the most abundant type of rolling stock. Experimental loaded car was included in a specially formed test train consisting of two sections of the locomotive TE-3, a passenger research car and a power-plant car.

Vertical forces were measured under six wheels of three dynamometric wheel sets.

To study the effect of uneven wear of the wheels on the magnitude of the interaction forces a dynamometric wheel set of one of the axes had natural wear. Wheel sets of other two axles prior to rolling them under an experimental car underwent turning.

Checking of the measuring system under natural conditions has shown that it is quite reliable. During tests the experimental car ran more than 6000 km, however there were no cases of significant damage of equipment or failures of sensors and current collectors. Dynamometric wheel sets operated satisfactorily at all train speeds.

Pic. 3 shows a fragment of one of the records of forces acting between a dynamometric wheel set and an experimental track section.

The possibility of determining vertical dynamic forces of interaction of a track and rolling was demonstrated for the first time on a broad front (long-haul) of the railway. It was possible during their registration to approach the zone of contact between wheel and rail.

The graph of changes of forces along the length of the track is shown in Pic. 4.

These statistically processed data of vertical interaction forces between wheels of the experimental car and rails of the experimental section are presented in Table 1. As it implies, average values of these forces are close to average axial loads that were obtained by weighing of the experimental car. Increase in the speed of the train, according to preliminary estimates, does not lead to an increase in mean values of forces on a straight track section in the absence of significant irregularities thereon.

Histograms and curves of normal distribution of forces at different speeds of movement of the test train are shown in Pic. 5.

Conclusion. It was established that on irregularities having different numerical score of the track's state, vertical forces acting on the rails, are close in magnitude. The maximum ratios of forces, arising due to the presence of deterministic irregularities (faults of III–IV grades) on the track do not exceed 1,4–1,5.

The highest probable forces caused by unequal elasticity of the track, is 10–23% below the accepted rules of calculating the track for durability.

The experimentally obtained forces of eccentricity of mounting of wheels coincide with balance weight match forces calculated by the rules.

Forces of impact of flat wheels on the track and from the contact of a vehicle with rails in the area of the joints reach values 3–4 times greater than the static load.

Keywords: railway, system «vehicle-track», interaction forces, measurement technique, magnetoelastic sensor, dynamometric wheel.

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