

# The development of measuring system for studying the dynamic processes of the main brake components in operation

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**Abstract.** The paper discusses and solves the problems associated with carrying out full-scale tests of the developed accelerometer sensor mounting system in the “lever gear block-wheel” system under operating conditions, including the main problem of measuring shoe and shoe accelerations, which was the impossibility of installing sensors directly on the shoe or block.

## 1 Introduction

It is one of the main factors of the uneven wearing of rolling stock brake pads that quickly reduces their service life. The possible reasons for the occurrence of uneven wearing of the brake pads are revealed on the basis of a theoretical analysis of the transient and steady-state dynamic modes of the lever transmission of the brake system of a passenger car.

The reason for the uneven distribution of loads both between the pads of one wheel pair and over the surface of the pads as a result of frictional self-oscillations are the dynamic processes accompanying braking system. In mathematical models, inertial and geometric parameters are specified exactly, and the stiffness parameters were taken in the first approximation due to the complexity of measuring these parameters in motion and under load. Besides, the stiffness parameters in conjunction with the geometric and inertial parameters determine the frequency range of dynamic processes occurring in the brake system. Since the stiffness characteristics of the wheel-block contact and the joints in the hinges are generally nonlinear, it is advisable to experimentally determine the frequency range of dynamic processes, which will indirectly indicate the accuracy of setting these parameters in mathematical models and the correctness of the models' structure. As a result, the task of experimental research is to determine the frequency range and analyze the spectrum of dynamic processes occurring in the braking gear during braking [1-12].

## 2 Research object

One of the objectives of the study is to establish the factors affecting the uneven wear of the brake pads. One of the reasons for uneven wear can be frictional self-oscillations in the

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"link block - wheel" system. The nature of these vibrations as excitation conditions, frequency and intensity depends on the amount of uneven wearing which has already presented as well as on the movement of the surface wheel is relative to the pad surface.

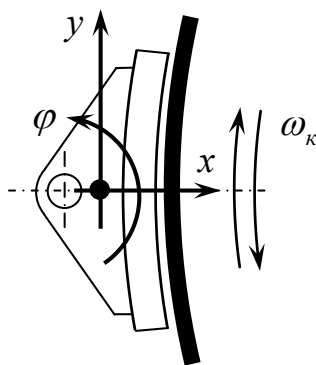
Therefore, the second task of experimental research is to establish the fact of the frictional self-oscillations' development during braking as well as to determine the excitation conditions and parameters of these self-oscillations. The solution to the second problem is assumed both for a block with even wearing and for a block with an already existing uneven wearing. This approach will confirm or refute the hypothesis about the further progression of uneven wearing in the event of its initial initiation.

The study of the frictional interaction of surfaces is advisable at the testing facility. To eliminate errors introduced by the application of similarity criteria, it is desirable to have a testing facility in full size. The creation of such a testing facility requires huge expenditures of funds, time and high energy consumption during its operation.

At the same time, the tests exclude from consideration many factors presenting in real conditions. These factors, even if they are random, they can have a significant impact on processes that are no longer stationary in nature. These processes include the process of simultaneous interaction of the wheel with both the rail and the block due to the fundamental difference in the nature of such interaction.

It was decided to carry out full-scale tests in real conditions using one of the cars in service.

The study of the dynamic processes is supposed to be carried out by the method of measuring the accelerations ( $\ddot{x}, \ddot{y}, \ddot{\varphi}$ ) of the brake block holder system in the longitudinal vertical plane that is in the plane of the wheel rotation Fig. 1.



**Fig. 1.** The directions of the investigated accelerations.

### 3 Equipment, apparatus and research methods

The full-scale tests under operating conditions dictate stringent requirements for experimental equipment and apparatus.

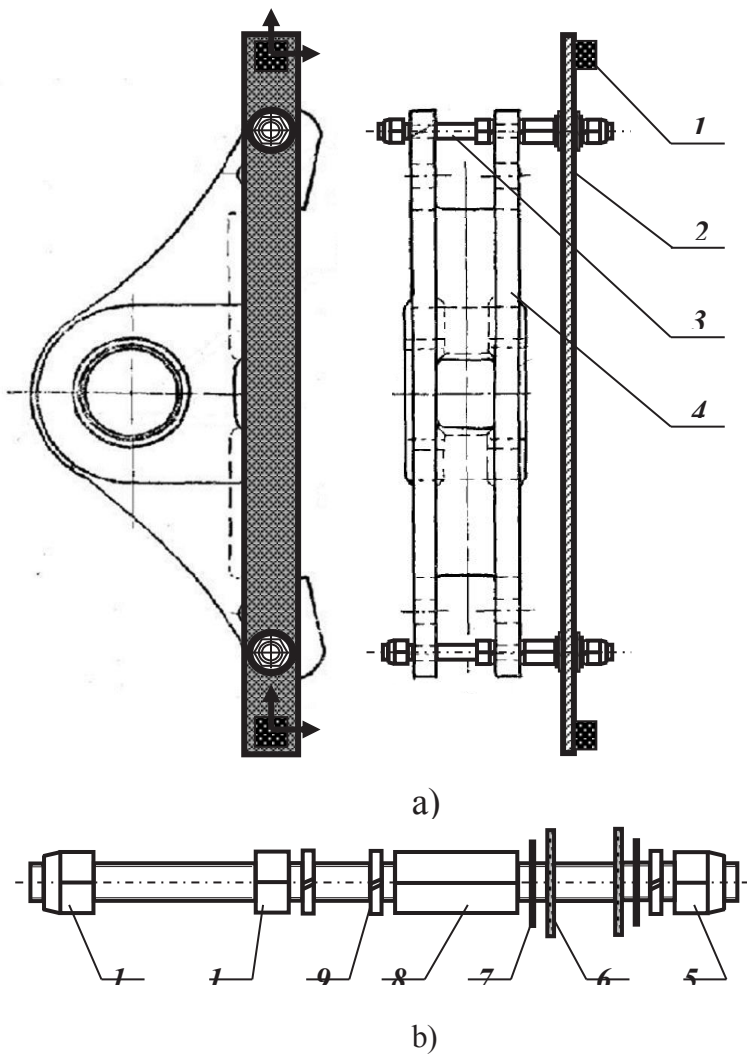
First of all, it is ensuring traffic safety.

For this purpose, a system for fastening accelerometer sensors has been developed which does not require any changes in the design of the drag shoe and the block holder with additional drilling, cuts, bends, welding and others.

The main problem of measuring drag shoe and drag shoe accelerations is the impossibility of installing sensors directly on the drag shoe or hob since during braking process these parts heat up to a temperature of 200-400 ° C or more, and the operating temperature range of the sensors is 0-70 ° C. In this regard, it was decided to thermally

insulate the sensors 1 by installing them on a fiberglass beam 2, fixed by means of the bolt pins 3 on the drag shoe 4 Fig. 2.

The bolt pins 3 are installed in the holes intended for the keeper pins to prevent the block pin from falling out. As a result, at the time of testing, the role of the fixing upper keeper pin is played by a bolt pin.



**Fig. 2.** Installation of sensors: a - on the drag shoe body; b - bolt pin with fastening details.

The bolt pin is rigidly attached to the drag shoe with a nut 10 and a nut-sleeve 8 with the installation of the check plate 9 to protect it from self-loosening. The beam is attached to the bolt pin using metal plate 7, rubber plate 6 and a self-locking nut 5 and also with the installation of a check plate. The opposite end as it is shown to the left in Figure 2 fits freely into the hole in the drag shoe. With a small gap sized 5-7 mm from the drag shoe body, a self-locking safety nut 11 is screwed onto the opposite end of the bolt pin.

Nuts 5 and 11 have rolled polyvinyl stops. Outside on both sides of nuts 5 and 11, there are left 3-4 threads. This thread reserve is provided to prevent the nuts from loosening, the

beam with sensors falling onto the rails and the bolt pins falling out of the drag shoe in case of loosening and loosening nuts 8 and 10.

The rubber plates 6 are installed to reduce the influence of high-frequency components of the vibrations arising in the space formed by the drag shoe, bolt pins and beam as well as to compensate for the thermal deformation of the drag shoe.

The installation of both sensors on a common beam and on individual attachment points is dictated by the desire to ensure maximum rigidity of the sensors` connection to the shoe and to transfer the motion characteristic of the drag shoe to the beam.

The information received from the sensors must be recorded and saved for further processing.

Traditionally, for these purposes, various matching devices are used to transmit and write information to a laptop. But in this case, it is necessary to additionally re-equip the car as laying cables from sensors, connecting to the car's energy sources, and it is very important to have the mandatory constant presence of the operator.

You can also use the means of existing laboratory cars, which will entail additional costs and, in conditions of regular passenger traffic, may not be feasible for organizational reasons.

The creation of energy-saving small-sized equipment with a built-in as rechargeable or replaceable the power source, capable of recording signals and recording the received information on a removable medium, makes it possible to eliminate the listed problems.

For testing, the equipment was manufactured with the following characteristics:

- 1. The number of registration and recording channels – 4;
- 2. The quantization frequency of the recorded signal is 2000Hz;
- 3. The volume of a removable memory block - 2 GB (MicroSD);
- 4. Power supply voltage - 3V;
- 5. Consumption current which is no more than 50 mA;
- 6. Dimensions of the housing of the electronic unit - 115x65x30 mm.

With the specified sampling rate and memory capacity, continuous recording can be carried out for 36 hours. If two elements with a voltage of 1.5 V and a capacity of 1000 mA/h are used as power sources, then the continuous operation of the equipment is ensured for 20 hours.

The autonomous electronic equipment has another important advantage such as high noise immunity, since there is no galvanic connection with various on-board power supplies and electric power conversion of the car.

Two-axis accelerometers ADXL311 manufactured by Analog Devices [13] are used as sensors. The parameters of the sensors are shown in Table 1.

**Table 1.** The sensor parameters.

| Model   | Operatin<br>g range g | Responsi<br>vity,<br>mV / g | A type<br>output<br>signal | Line<br>freque<br>ncies,<br>kHz | Voltage<br>power<br>supply,<br>V | Managed<br>current,<br>mA | Operating<br>temperatu<br>re<br>range, °C |
|---------|-----------------------|-----------------------------|----------------------------|---------------------------------|----------------------------------|---------------------------|-------------------------------------------|
| ADXL311 | ±2                    | 174±15%                     | analogue                   | 6                               | 2.4...5.25                       | 0.4                       | 0...+70                                   |

The advantages of the ADXL311 sensors include:

- a low current consumption;
- the small dimensions as it is packed in 5x5x2mm 8-pin sealed LCC body;
- the ability to independently measure accelerations in two mutually perpendicular directions with one sensor.

The disadvantages include a small lower limit of operating temperatures, which limits testing in the cold season.

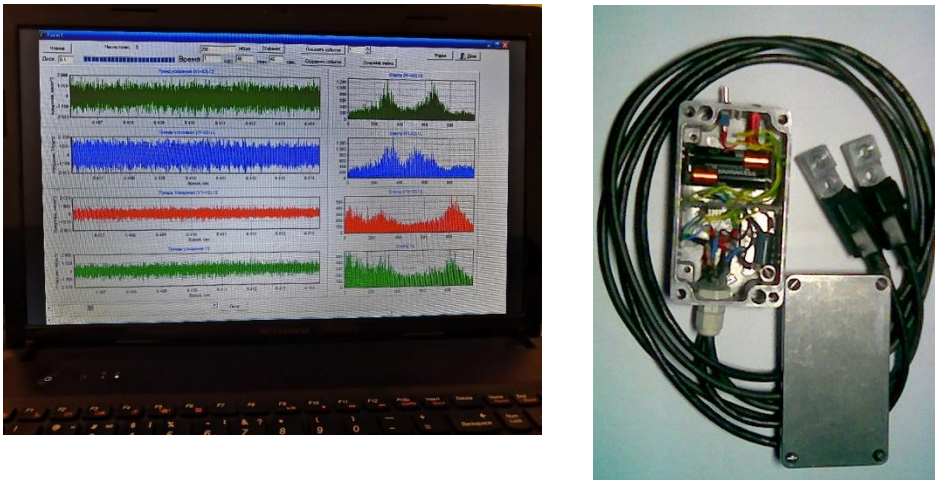
Trial tests of the ADXL311 sensors on a vibration testing facility showed that their operating range has a margin of amplitude up to 3g, however, at the amplitudes above 2.5g in the high frequency region it is more than 900 Hz, slight nonlinear distortions appear, which should not have a significant effect on the qualitative side of the processes under study.

The selected sampling frequency of the signal 2000 Hz allows one to study dynamic processes in the frequency range 0–1000 Hz [14].

As a result, the experimental measuring complex consists of two vibration sensors and an electronic unit. Each sensor is connected to the unit with a 1.5 m shielded multicore cable Fig. 3. The connection is single part.

Each sensor with additional electronic "strapping" elements is rigidly fixed on a duralumin bracket with holes for its attachment to the object; their vibrations are to be measured if it is to beam 2. The compact small-sized electronic unit can be fixed on the trolley frame in an easily accessible place by means of temporary mounting such as adhesive tape and others. There is a toggle switch for on / off and two control light indicators on its body:

- the green light means "unit is on, recording is in progress";
- if the red indicator flashes when the green is on, it means "the unit is on, no recording is in progress, the memory is full".



**Fig. 3.** The interface of the data processing program and the appearance of the electronic unit with sensors.

With such simple use, the tests can be carried out automatically without operator. It is enough to turn on the unit before the trip, and turn it off after the trip. After the trip, it is important to dismantle the unit, remove the cover and replace the flash memory card and batteries, after that to reinstall the unit on the cart frame for a new trip.

The research technique involves recording and subsequent reading of the saved information. In this case, it is supposed to carry out several trips with a block that has even wearing, and with a block that already has obvious, but within acceptable limits, uneven wearing. In each trip, a change in the direction of the car wheel rotation is assumed, since it is assumed that the car movement is changed as "forward" and "backward".

Reading from a flash card and processing of the received data is carried out on a computer under stationary conditions. For this, a specialized program was written in the Delphi system.

The main window of the program Fig. 4 contains time charts:

- the horizontal acceleration of the gravity center of the brake block holder system  $\ddot{x}_o$  determined by the expression

$$\ddot{x}_o = \frac{\ddot{x}_1 + \ddot{x}_2}{2}; \quad (1)$$

- an angular acceleration of the brake block holder system  $\ddot{\varphi}_o$  determined from the expression

$$\ddot{\varphi}_o = \frac{\ddot{x}_2 - \ddot{x}_1}{L}, \quad (2)$$

where  $L$  is the distance between the horizontal axes of the sensors ( $L = 0,45\text{M}$ );

- the vertical acceleration of the gravity center of the brake block holder system  $\ddot{y}_o$  determined with the ratio  $\ddot{y}_1 \cong \ddot{y}_2$  as the average of these values

$$\ddot{y}_o = \frac{\ddot{y}_1 + \ddot{y}_2}{2}. \quad (3)$$

Each window contains  $16384 = 2^{14}$  time interval points. With a sampling time of  $1/2000$  s, this corresponds to a time interval of 8.192 s.

The fourth window for control contains the acceleration time interval  $\ddot{y}_2$ .

To the right of the time charts are the windows with the spectra of the corresponding accelerations, calculated by the FFT method for the selected time interval. The frequency range of the spectra is 0–1000 Hz.

During the recording process, the time is counted continuously. The process recording time in seconds is indicated on the horizontal axes of the time charts. In addition, the time corresponding to the beginning of the selected interval is shown in the upper part of the window in the format as hour, min, sec.

The selection of the interval to be viewed is carried out discretely using scrollers 1 and 2 Fig. 4. One interval of the upper (2) scroller is 8.192 sec. One interval of the lower (1) scroller is equal to 64 interval of the upper scroller. This ratio was selected for reasons of convenience in working with the program and using the peculiarities of the processes under research.

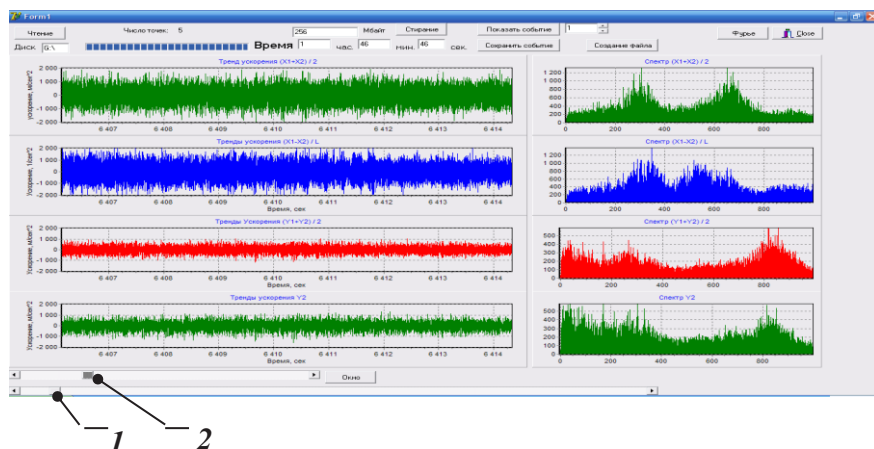


Fig. 4. The main window of the data processing program.

Each chart provides the ability to change the scale along each of the axes as well as to shift the image in any direction. The autoscale on the axis is applied by default on spectrum Y.

In addition, the program provides for saving the time interval of the selected interval in text format for transferring them to other software for data processing.

As a result, the experimental research technique is reduced to recording accelerations and visual analysis of the time signal and its frequency spectrum. If it is necessary, a more detailed processing of the obtained data is possible using specialized programs.



**Fig. 5.** The Installation of measuring equipment on the car.

## 4 Conclusion

The developed system for mounting accelerometer sensors which does not require any changes in the brake block holder design, has shown good results in field tests.

The main problem of measuring the accelerations of the brake block holder was solved, which consisted in the impossibility of installing the sensors directly on the drag shoe or hob, by installing them on a fiberglass beam that is fixed with the bolt pins on the drag shoe.

The design of the energy-saving small-sized equipment with a built-in the rechargeable or replaceable power source which is capable of recording signals and recording the received information on a removable medium, made it possible to eliminate many problems such as the car re-equipment and the use of an expensive laboratory car.

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