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MATHEMATICAL MODEL AND STRUCTURE OF THE DEVICE FOR DIAGNOSTICS OF DRUM-BLOCK BRAKE OF THE TRAM

Mathematical model for diagnostics of drum-block brake of the tram is developed. In this model the operation of brake linings and clearances in hinges and levers is expressed by means of time delay between the signal supply on the drive of brake and the start of braking, taking into account the characteristics of this tram system operation; structural diagram of the device intended for realization of mathematical model is suggested.

Key words: *diagnostics, drum-block brake, wear of brake lining.*

Problem set up

The system of tram-car repair by distance run between overhauls, based on mean statistical estimates of technical state of the set of vehicles, that is applied in greater part of tram shops, nowadays does not meet modern requirements, neither regarding the level of trams reliability on routes, nor regarding the level of material expenditures.

Modern tram is the set of mechanical, electromechanical, pneumatic, hydraulic, electronic and other units and systems, which while the operation undergo various physical chemical impacts of different character and level of loads. As a result of units and systems repair , the tram becomes a system, consisting of components having various balance of operating resource. As a result, in conditions of random character of loads on different unit, part of units is replaced ahead of schedule, but other units are replaced while overhaul period due to failures. If it deals with units and systems, which are responsible for braking, in this case, the latter variant is inadmissible.

Reliability and efficiency of braking system of the tram-car directly influences such important indices of quality of passenger transportation as safety, speed, comfort and profitability. Although the ratio of traffic accidents stipulated by the failure of braking system is minor, these failures result in considerable material losses, and sometimes casualties. Besides, the analysis, carried out, shows that some traffic accidents could be avoided due to more efficient operation of braking system (less braking distance).

Analysis of latest research and publications

Research, aimed at the development of devices for diagnostics of functional units and systems of the tram, intended for improvement of their operation and measurement of wear level of the units which determine scheduled preventive maintenance intervals [1, 2, 3, 4, 5]. Thus, we can reduce labour content of maintenance, improve the reliability of tram-car functioning and decrease the level of material expenditures correspondingly. In [6, 7], the structure, principle of operation of tram drum-block brake is considered, mathematical models are constructed, the structures of the devices for brake diagnostics are suggested. But these developments require further improvement, in particular, due to the lack of the possibility to determine the wear rate of brake lining at any moment of functioning and operation clearances of mechanic drive (levers and brake equalizers), of drum-block brake of the tram.

Research problem set-up

The aim of the research is to improve operation reliability functional units of drum-block brake of the tram. To reach this goal we are to construct mathematic and computer models. Structural diagram of diagnostic device, based on these models is to be constructed, which unlike the known diagrams [5], must provide the possibility to determine the wear rate of brake linings and wear level of mechanical drive path, that operates in detrimental conditions, which depend on climatic

conditions.

Basic material of research

In order to avoid emergencies due to noncontrolled motion of the tram-car, the spring having residence factor k (Fig 1), is used in drive of drum-block brake to create braking effort [8]. Hence, output state of the system is the braking state, when the effort from the spring is transmitted to brake linings by means of rod, levers and rollers. To initialize braking system, the solenoid with moving core is built in the drive of drum-block brake, which, moving along the guides, compresses the spring and, correspondingly, initializes the operation of the system. The construction of brake drive, used in tram-cars, and described above provides the stop of the tram-car, if voltage supply from the grid is disconnected. The motion of the tram-car becomes possible if voltage supply is available, and braking process can be described by the system of equations (1), in which the first equation describes the dynamic of rod motion, the second equation describes the static state (braked state), and the third equation shows the reduction of braking force, created by the rod, to the force of drag friction.

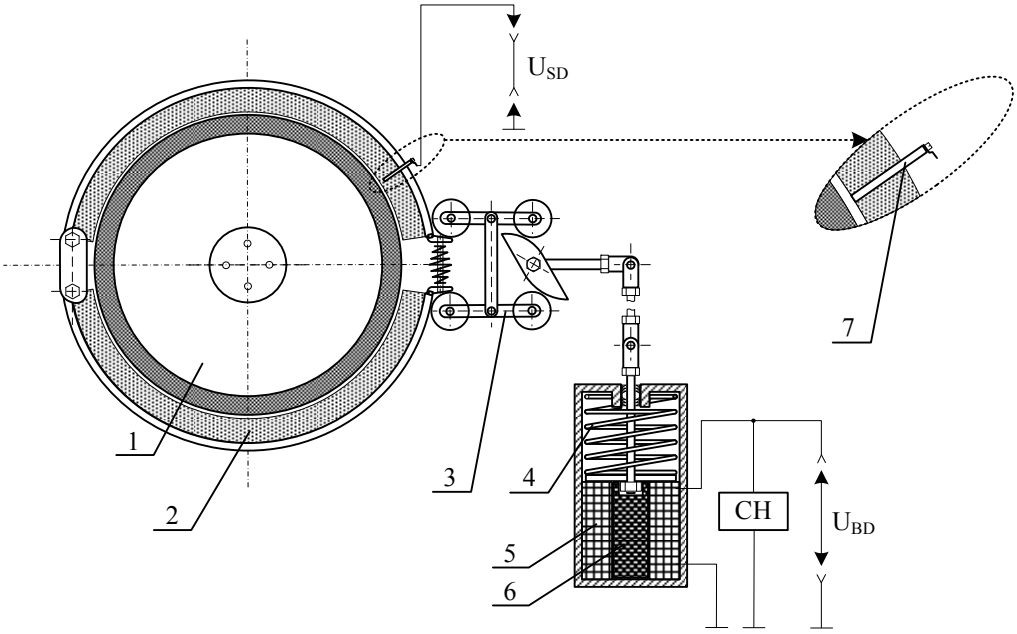

Fig. 1. Construction of drum-block brake of electric-driven tram-car: 1 – brake drum, 2 – brake lining, 3 – mechanism of brake drive, 4 – brake spring, 5 – coil of brake solenoid, 6 – drive of solenoid core, 7 – rod, made of light-weight alloy (diameter 3-6 mm)

$$\begin{cases} \vec{F}_{se} + \vec{F}_{ff} = \vec{F}_{pr}; \\ \vec{F}_{se} + \vec{F}_{b} = 0; \\ \vec{F}_{bf} = \vec{F}_{b} \cdot \vec{S}, \end{cases} \quad (1)$$

where $\vec{F}_{se}$ – is vector of force of spring elasticity, $\vec{F}_{ff}$ – vector of friction force, than characterizes the losses of the effort, $\vec{F}_{r}$ – is vector of resultant force, $\vec{F}_{b}$ – is vector of braking force, created by the rod, $\vec{F}_{bf}$ – is vector of frictional force of braking, $\vec{S}$ – is vector of braking force reduction factor to frictional force of braking.

The system (1), taking into account certain conditions and neglecting friction forces losses, can be rewritten in the form of the following system of equations:

$$\begin{cases} k \cdot x = m \cdot a; \\ k \cdot x = F_b; \\ F_{bf} = F_b \cdot S; \\ m = m_{rb} + m_{bdr}, \end{cases} \quad (2)$$

where x – is elongation of braking spring, m_{rb} – is braking rod mass m_{bd} is reduced mass of braking drives, m –is the sum of braking rod mass and reduced mass of braking drives, a – is acceleration of braking rod.

$$\begin{cases} F_{bf} = k \cdot x \cdot S; \\ -\frac{m}{k} \cdot \frac{d^2x}{d^2t} + x = 0; \\ x_0 = x_{com}; \\ x_1 = x_{nc} + x_m + x_{lw}, \end{cases} \quad (3)$$

where x_0 – is initial coordinate of the rod at t_0, x_{com} – is linear compression of the spring in operation state, t_1 – is time, equivalent to braking delay, x_1 – is final coordinate of the rod (braked state), x_{nc} – is the value of normal clearance between brake linings and the drum, x_m is value of clearance (wear) in levers, hinges, couplings, x_{lw} – is the value of brake lining wear.

For investigation of mathematical model for diagnostics of drum-block brake we have chosen object-oriented package of applied programs Matlab with its graphic tool for visualization Simulink. Computer-based model, presented in Fig 2 is developed in the given environment. By means of Gain-Gain 2, Integrator-Integrator5 units differential equation of equations system (3) was realized. Units Gain-Gain 2 set the coefficient near highest derivative of differential equation of the system (3) $\frac{m}{k} = 0{,}328$. Initial conditions of Integrator-Integrator5 units are – $x'(0) = 0$ (speed at start moment equals zero), $x(0) = 0{,}08$ m (the level, to which the spring is compressed in operational state). For verification of computer model operation, let us consider the cases, when time of operation delay is t1=0,4 sec; t1=0,42 sec; t1=0,45 sec. Fig 3 shows the graph of spring elongation, that characterizes the total interval, caused by operation of hinges, levers, brake equalizers and brake linings of drum-block brake in certain cases.

The device for implementation of the above-mentioned mathematical model can be manufactured using standard elements of industrial fabrication. The structure of the device, intended for diagnostics of drum-block brake of the tram-car is shown in Fig 4, where 1 – sensor of brake linings pressing, 2 – sensor of brake drive voltage, 3, 4 – the first and second threshold elements, 5 – pulse generator, 6, 7 – the first and the second OR-NOR elements, 8 – I element, 9, 10 – the first and the second univibrators, 11 – pulses counter, 12 - register, 13 – functional converter, 14 – decoder , 15 – digital indicator.

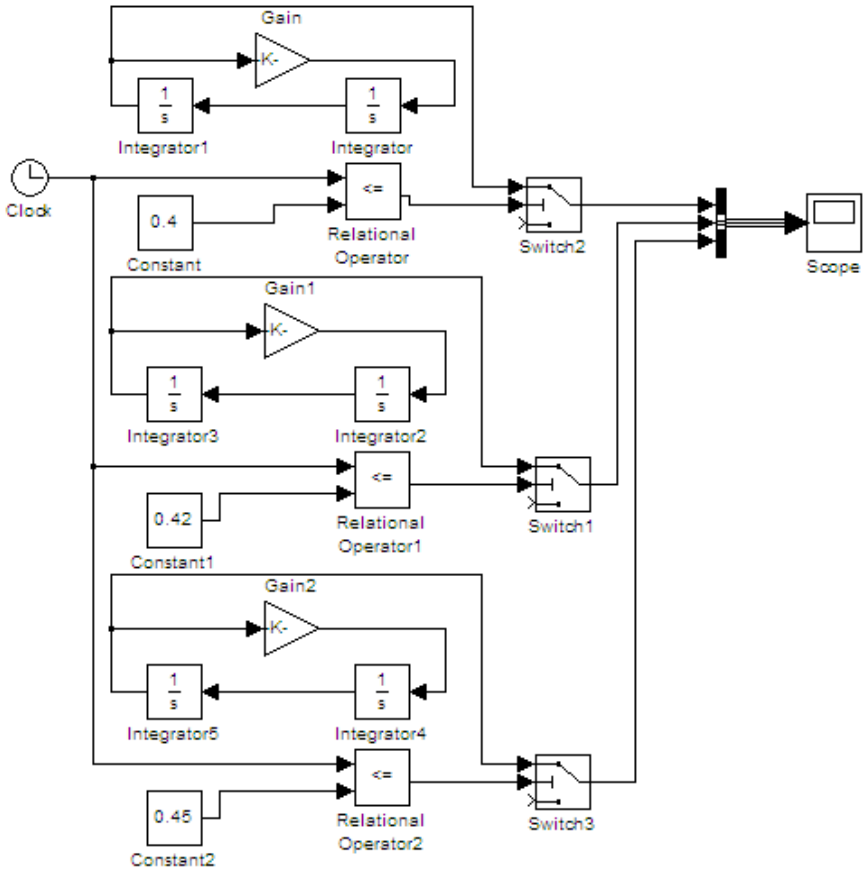

Fig. 2. Computer model, intended for diagnostics of dram-block brake

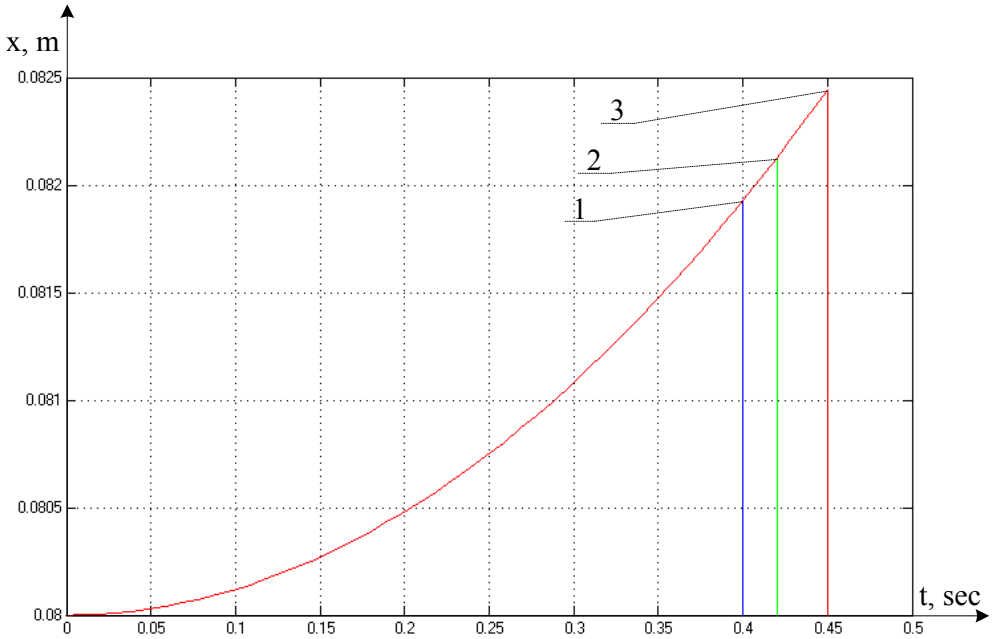

Fig. 3. Graph of brake spring drive elongation while operation: 1) t_1=0,4sec, 2) t_1=0,42sec, 3) t_1=0,45sec

Pressing sensor is fabricated in the form of light-weight alloy rod, inserted into brake lining on the same level with its brake surface; brake delay is the delay of brake linings pressing to brake drum caused by normal distance between brake linings and brake drum, the distance obtained as a

result of brake linings wear and wear in hinges of mechanical path of brake mechanism. The number of indicator segments is not less than four.

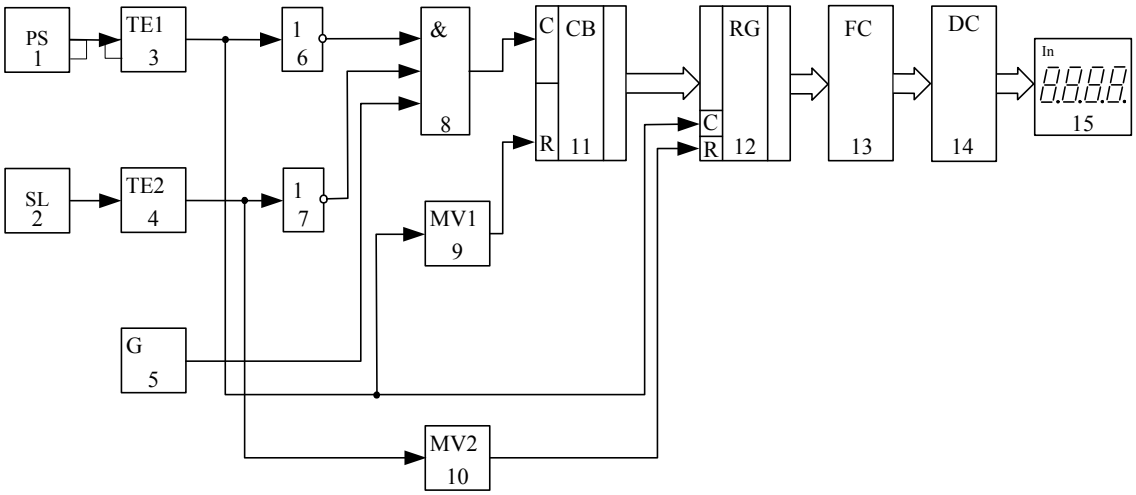

Fig. 4. Structure of the device for diagnosis of drum-block brake the tram-car

The suggested device operates in the following manner. When voltage is supplied pulse generator 5 starts generating pulses with rather small period, that will mainly characterize the error of device operation.

While braking of tram-car the voltage is disconnected from the brake drive, controlled by voltage sensor of brake drive 2 , the signal disappears at its input, as a result at the output of OR-NOR 6 element the signal of logic one appears. Since there is certain time interval between the appearance of braking signal and pressing of brake linings, that characterizes numerical delay of braking, then at the output of brake linings pressing sensor 2 the signal will not appear, hence the signal of logic one is available at the output of OR-NOR element 6. As a result pulses form the generator 5 pass across the logic element AND at incremental input of counter 11, that starts counting them.

While pressing brake lining against braking drum at the output of brake lining pressing sensor the signal appears, that enters the input of threshold element. From the output of threshold element 3 the signal of logic one enters the input of recording permission register 12, input OR-NOR and input of univibrator 9, form the output of which in a certain period of time delay the signal enters the input of counter reset. At the output of OR-NOR element 6,the signal of logic zero appears, as a result the pulses from generator 5 stop entering the incremental input of the counter. The signal that characterizes numerical delay of braking, passes from the output digital bus of the counter11 to input digital bus of the register 12, where it is stored. From output digital bus of the register, the signal passes to input digital bus of functional converter 13, where, according to initial conditions, differential equations system 3 is solved, the information, regarding the parameter of clearance, brake linings wear, brake path passes from output of digital bus to input digital bus of the decoder 14, signal from output digital bus, received for display on digital indicator, passes to the input of digital indicator 15, where numerical delay of braking is indicated.

At the start of tram-car motion brake drive voltage is applied on brake drive, that initiates drum-block brake, as a result, at the output of voltage sensor the signal appears, that passé to the input of threshold element, the signal of logic one from the output of threshold element passé to the input OR-NOR element 7 and to the input of univibrator 2, from the output of univibrator the signal with time delay arrives at the input of register 12 reset and resets it. While the next braking the operation of the scheme is repeated.

Conclusions

1. Mathematical and computer model for diagnostics of drum-block brake of the tram-car is developed; the given model unlike the existing ones enables to determine the value of brake linings wear and clearances in mechanical levers and hinges, obtained in the process of system operation.

2. Structural diagram of the device for diagnostics of drum-block brake of the tram-car realizing the developed mathematical model is suggested.

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