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Mechatronic controller of brake pipe pressure

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In this article mechatronic controller of brake pipe pressure was presented being the result of research and development work carried out at the Center of Rail Vehicles in Poznań. This function is performed by the module using binary voltage signals. Its structural structure and functionality are described and the results of empirical research are presented. The analysis of the research results indicates that the developed module can be used in the control systems of the railway air brake.

1. Introduction

The basic brake of rail vehicles is a railway air brake, which controls the braking process by changing the pressure in the brake pipe. The device used for this is the driver's brake valve. This valve is responsible for both preparing the braking system for operation and controlling it during operation.

Center of Rail Vehicles in Poznań conducts research and development work on pneumotronic devices and systems used in railway air brake control systems. This paper presents the mechatronic controller of brake pipe pressure developed in the Center of Rail Vehicles.

2. Review of the literature

The operation of the driver's brake valve was described in 2012, e.g. by Piechowiak [9]. The author presented its construction and indicated two types of driver's brake valves: analog and impulse. In the case of the first of them, the change of pressure in the brake pipe is conditioned by the appropriate deflection of the adjuster (manipulator). The impulse driver's brake valve, on the other hand, controls the pressure in the brake pipe based on the electrical impulses sent. The method of controlling the braking process of rail vehicles was also described by Perpinya in 2012 [8]. The author presented a simplified diagram of the brake of a combined train consisting of, among others, the driver's brake valve, air brake and brake cylinders.

In 1947, an article [12] was published describing the driver's valve consisting of five settings (sections) corresponding to various loading states of the vehicle.

Brake pipe pressure control developed by George Westinghouse in 1879 is described, among others, by Hasegawa and Uchid in 1999 [4] and by Grzesikowski in 1995 [3]. The appropriate construction of the Westinghouse's driver's valve made it possible to change the pressure in the brake pipe, and thus start braking or brake releasing. This was done mechanically only. The device performed advanced functions, however, it was characterized by a leak causing a reduction in the braking efficiency of the rail vehicle and automatic braking caused by a pressure drop in the brake pipe.

In 1987 r. Becker-Lindhorst et al. [1] patented the design of the driver's brake valve for the pneumatic brake of rail vehicles. The electro-pneumatic pressure control system in the brake pipe was described by Kaluba in 2007 [6]. Pressure shaping in the brake pipe in this control system is carried out by a pneumatic staging unit. This unit is based on the nominal value of pressure from the pressure indicator (control chamber) and elements of the driver's valve controlled by

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electro-pneumatic valves installed on the pneumatic board. This unit is shown in Fig. 1.

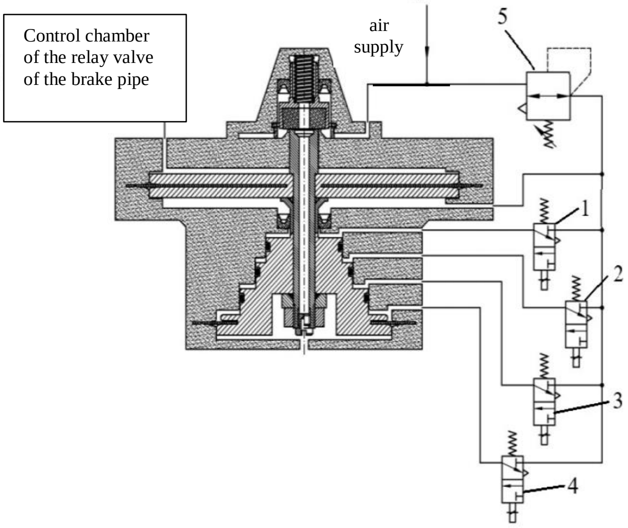

Fig. 1. Electro-pneumatic brake pipe pressure control system: 1, 2, 3, 4 – electro-pneumatic valves, 5 – reducing valve [6]

Upon initiation of any stage of service braking, the electro-pneumatic valves are energized in the appropriate combination. The pressure from the reducing valve decreases the pressure in the control chamber at the rate required by the UIC from the nominal value to the value appropriate for the initiated degree of braking. The microprocessor pressure control system in the brake pipe was described by Kaluba and Maluśkiewicz in 2015 [7]. The system described by the authors allows for software control of the pressure in the brake pipe and its measurement with feedback. In this system, the pressure in the brake pipe is determined by the control system on the basis of an analog signal from a transducer measuring the pressure in the control chamber of the relay valve.

Currently, the subject of considerations of scientists dealing with braking systems of rail vehicles are the brakes of high-speed trains and systems for predictive detection of their failures. This is evidenced by numerous scientific articles. One of them is the article Jin et al. [5] published in 2020. The authors presented a discrete model of emergency braking of a high-speed train, which enables the observation of time-varying parameters, such as the coefficient of friction of a friction pair. The results of the research confirmed the effectiveness of the model developed by the authors.

In 2021, Zhao et al. [14] conducted an analysis of the braking efficiency of a high-speed train operated in a complex braking environment (e.g. low temperatures). The authors presented the developed discrete model, which reflects the pneumatic brake of a high-speed train and its control system. The article presents the results of numerical research carried out in Simulink software.

In 2019, Fang et al. published an article [2] in which they presented a fault diagnosis model using the phased features and multi-layer perceptron (MLP) for brake system of high-speed trains. The article presents the stand for testing the developed method in order to verify its effectiveness and the results of these tests.

In 2021, Xu et al. [13] described three unsupervised causality-based feature extraction methods that can be used in fault detection diagnosis systems of high-speed trains braking systems. The article also presents experimental results of research on the effectiveness of these methods, which show the advantage of these methods over classical techniques based on correlations between variables.

In 2021, Sang et al. [10] published an article in which they proposed a new method for detecting pressure changes in brake cylinders. The authors noticed that the braking efficiency of high-speed trains depends primarily on the accuracy of pressures in the cylinders, the variability of which cannot be tested using traditional methods that only detect changes with a large amplitude. The effectiveness of the proposed method was confirmed by the authors through experimental research.

In 2022, Zuo et al. [15] presented an intermittent braking strategy of high-speed trains. The purpose of developing this strategy was to improve the thermal-mechanical performance of friction pair. The authors presented the results of numerical tests comparing the characteristics of the friction pair during continuous and intermittent braking.

In 2022, Sheng and Ji [11] proposed a new method for detecting faults in the pneumatic braking system of high-speed trains. This method, called the exter-variable variance method, was verified by the authors in simulation studies, which confirmed its effectiveness.

Despite the increase in service speed and the development of high-speed trains, the combined air brake is still their basic safety brake.

3. Mechatronic controller of brake pipe pressure

In the era of progressive electronization, the Center of Rail Vehicles in Poznań conducted research and development work, as a result of which a mechatronic controller of brake pipe pressure of rail vehicles was developed.

3.1. Structural structure and operation of the module

This module consists of pneumatic, electropneumatic and electric devices, which in a distributed structure have been built into a pneumatic board type

200ZH 92-1 (Fig. 2) developed by Center of Rail Vehicles.

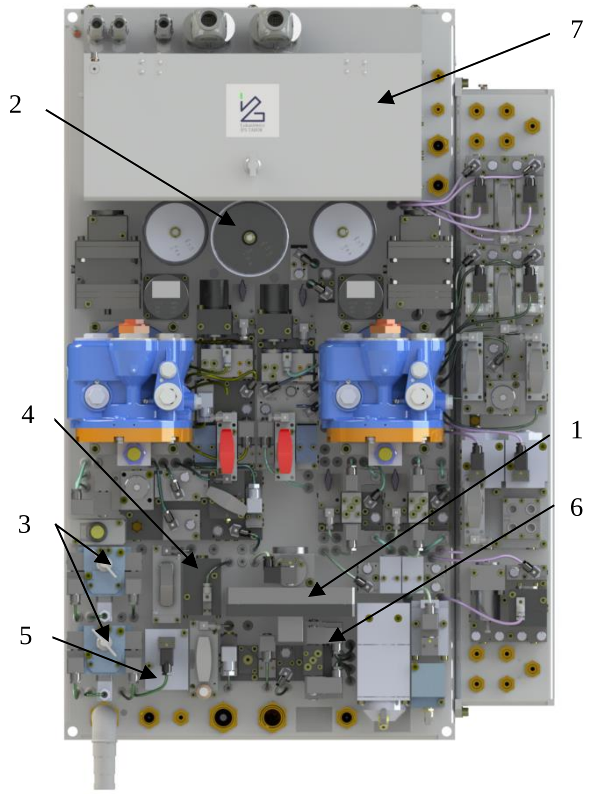

Fig. 2. Type 200ZH 92-1 pneumatic board with integrated brake pipe pressure control module

The operation of all valves and servo valves of the electropneumatic brake control system is supervised by a 32-bit microprocessor controller built into the electrical system (7) of this pneumatic board. This system is controlled by means of binary voltage signals sent from the active driver's station. Thanks to these signals, the microprocessor regulator maintains the appropriate pressure in the control chamber (2) of the relay valve (1) by means of electropneumatic valves installed on the valve manifolds (6) responsible for increasing and decreasing the pressure in the brake pipe. In addition, this regulator includes a transducer used to measure the pressure in the control chamber (2). The pressure-controlled relay valve by means of a regulator maintains the pressure value in the brake pipe appropriate for the required function of the brake. The rapid pressure drop in the brake pipe causing emergency braking is provided by the emergency braking valves (3). The flow restrictor (4) allows the filling capacity of the brake pipe to be limited to the level required in the brake ready state, and the servo valve (5) allows the system to be isolated from the brake pipe.

The system designed in this way was subjected to tests, the results of which are described below.

4. Research methods

The research method used are experimental tests of the prototype of the developed pressure control module in the brake pipe. The following functionalities of the module were tested: service braking, emergency braking, high pressure release, pressure equalization, sensitivity/insensitivity. During the tests, pressure changes in the brake pipe generated by the developed control module were recorded.

The purpose of the tests is to diagnose whether the control system meets the requirements set out in the UIC 541-03 code sheets. The tightness of the system and each function and its parameters required in the UIC card are checked (meeting these requirements ensures that the designed control system is safe and reliable).

4.1. Research stand

The tests were carried out on the stand, the visualization of which is shown in Fig. 3.

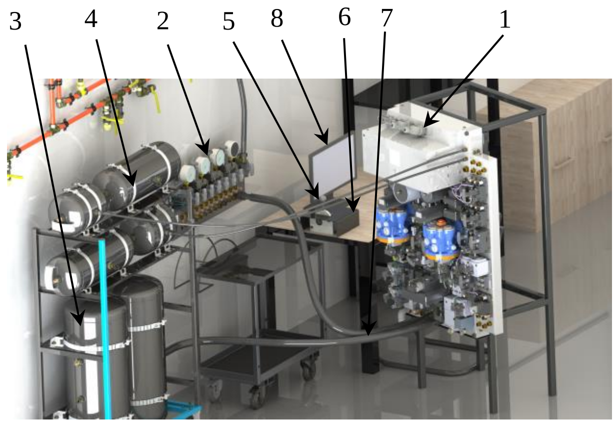

Fig. 3. Test stand of the pressure control system in the brake pipe

The designed stand includes:

- the tested pressure control module in the brake pipe integrated in the pneumatic board (1),
- control and measurement module with manometers (2),
- pressure tanks representing the capacity of the brake pipe (3) and brake cylinders (4),
- railway air brake manipulator (5),
- a system simulating the brake setting ("passenger" and "freight") (6),
- pneumatic hoses (7),
- computer with software (8).

5. Results

5.1. Tightness test

The results of the conducted research are presented below.

During this test, the tightness of the tested system is checked by observing the difference between the initial pressure of the system and its pressure after 10 minutes. Figure 4 shows that the pressure drop is less than 10 kPa/10 minutes, which means that the system is tight.

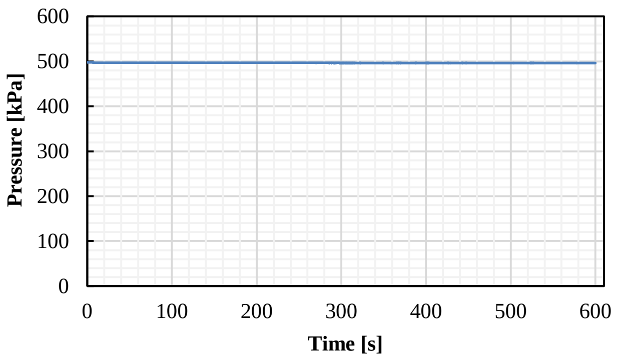

Fig. 4. Variation of pressure in the brake pipe as a function of time during the brake pipe leak test

5.2. Full service brake

Starting the full service braking process should cause the pressure in the brake pipe to drop by 160–180 kPa relative to the initial pressure within 6–9 seconds. The result of this test is shown in Fig. 5. It can be seen that after 8.1 seconds from the start of the pressure drop, the assumed pressure value was reached.

On this basis, it was found that the full service braking function is implemented correctly.

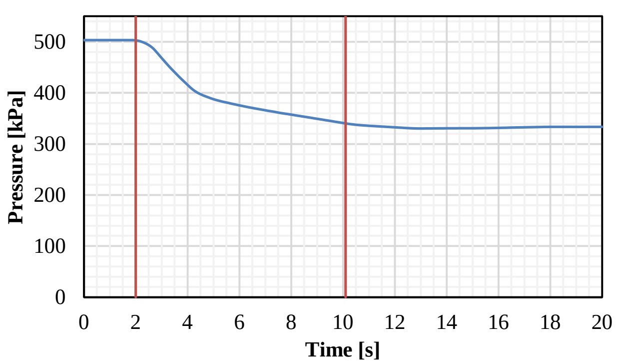

Fig. 5. Change of pressure in the brake pipe as a function of time during full service braking

5.3 Gradual braking and releasing

Figure 6 shows that the tested module allows to initiate 8 stages of braking and releasing the brake of the railway air brake. The presented course shows that starting the 1st stage of braking causes a pressure drop in the required range of 30–60 kPa, and after full service braking the pressure in the brake pipe is in the range of 160–180 kPa below the nominal pressure. Moreover, after reaching the last degree of brake release, the pressure in the brake pipe is 505±5 kPa.

Based on this, it was found that the gradual braking and releasing function is working properly.

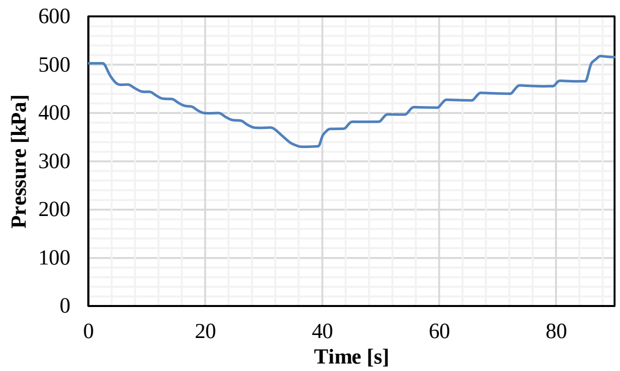

Fig. 6. Change of pressure in the brake pipe as a function of time during gradual braking and releasing

5.4 Emergency braking

Emergency braking, which generates the maximum braking force, can be initiated in this control system as a result of the activation of several possible options:

- at the command of the driver,
- when commanded by the SHP (automatic braking of the train) system and the dead man's switch,
- at the command of the radio stop system,
- interruption of the continuity of the brake pipe,
- at the command of the ETCS.

After initiating emergency braking by any of the above options, it causes a pressure drop in the brake pipe at a rate faster than 180 kPa/3 seconds, as shown in Fig. 7, where such a drop occurs in a shorter time.

Based on this, the emergency braking function was found to be working properly.

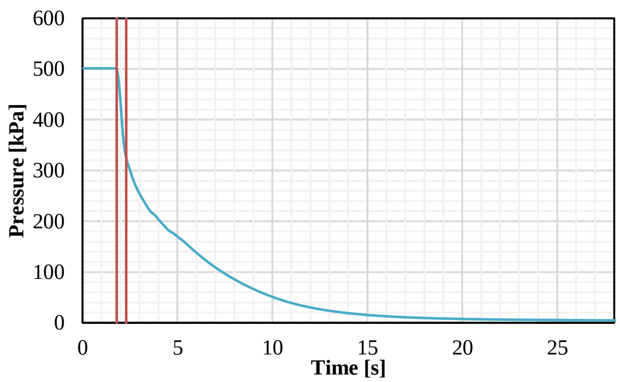

Fig. 7. Change of pressure in the brake pipe as a function of time during emergency braking

5.5. Pressure course in individual brake settings – "passenger" and "freight"

During this test, the time of emptying and filling the brake cylinders was checked. This control system allows you to select two settings: "Passenger" and "Freight". These times vary depending on the current brake setting and should be within the ranges presented in Table 1, and the courses of these pressures are presented in Fig. 8 and 9.

Table 1. Required times for filling and emptying the brake cylinders out of the compressed air

Brake setting	Course	Required times [s]
„Passenger"	Filling	3–5
	Emptying	15–20
„Freight"	Filling	18–30
	Emptying	45–60

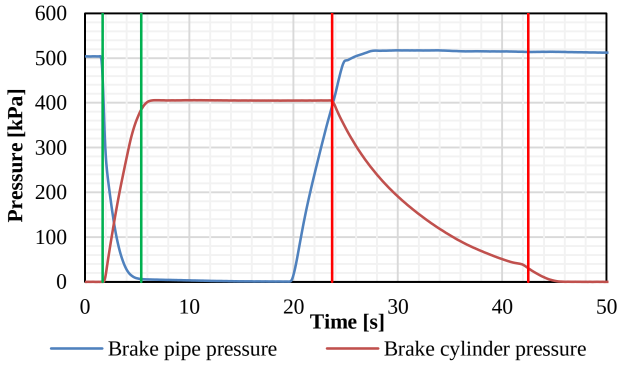

Fig. 8. Changing the pressure in the brake pipe as a function of time in the "Passenger" setting

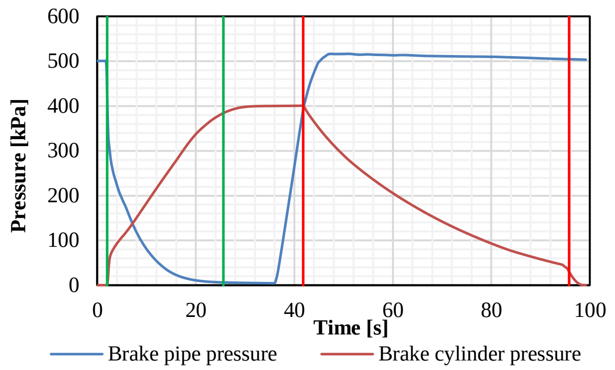

Fig. 9. Change of pressure in the brake pipe as a function of time in the "Freight" setting

Based on the above figures, it was found that the function of filling and emptying the cylinders out of compressed air for individual settings works properly.

5.6. High pressure release

High pressure release in the designed system is as follows:

– after emergency braking or full service braking, the pressure in the brake pipe increases to 480 kPa in no more than 3 seconds at the high pressure release command,
– reaching a pressure in the brake pipe greater than 700 kPa,
– quick pressure reduction to 540±10 kPa and its stabilization for 30–60 seconds,
– pressure equalization consisting in its slow decrease (15 kPa/60–75 seconds, i.e. below the sensitivity limit of distributor valves) to the nominal pressure. The rate of pressure drop is measured from reaching 530 kPa to 510 kPa, which should be 60–120 seconds.

Such configuration of the pressure in the brake pipe is conducive to even and full release of the brakes of all wagons of a long train. Figure 10 shows the course described above.

Based on this, the emergency braking function was found to be working properly.

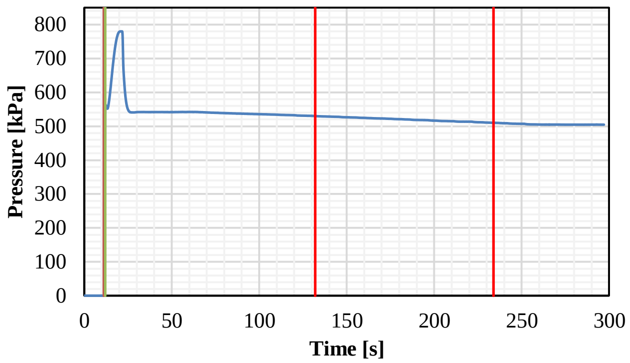

Fig. 10. Change of pressure in the brake pipe as a function of time during high pressure release

5.7. Brake sensitivity

During this test, a pressure drop in the brake pipe was simulated at a rate of 60 kPa/6 seconds, which resulted in braking (rise of the pressure of the brake cylinders) within 1.2 seconds of the start of the pressure drop.

Based on this, the brake sensitivity function was found to be working properly.

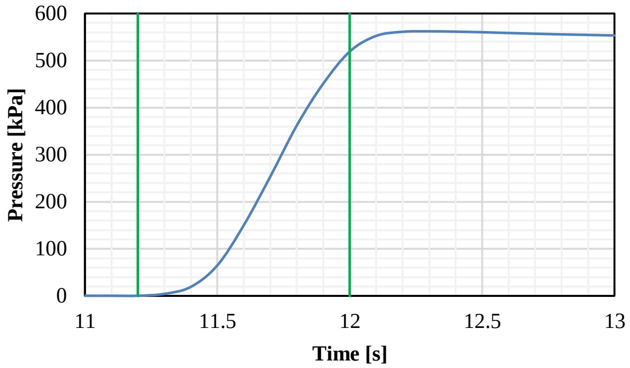

Fig. 11. Change of pressure in the brake pipe as a function of time during brake sensitivity test

5.8. Brake insensitivity

During this test, a pressure drop in the brake pipe was simulated at a rate of 30 kPa/30 seconds. Such a pressure drop may be caused by leaks in the vehicle's pneumatic system or specially applied during the pressure equalization function and should not cause braking, as shown in Fig. 12.

Based on this, the brake insensitivity function was found to be working properly.

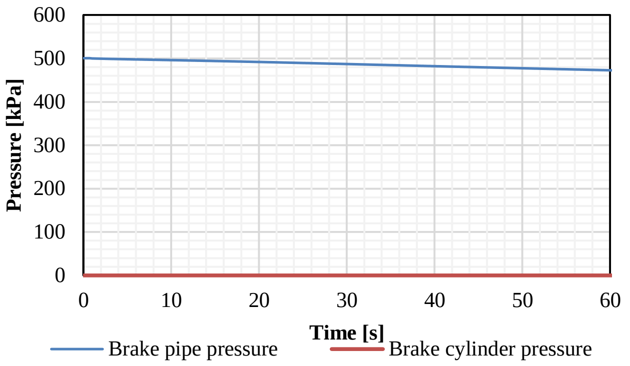

Fig. 12. Change of pressure in the brake pipe as a function of time during brake insensitivity test

6. Summary

As a result of research and development work, a mechatronic module was developed, in which a microprocessor pressure regulator, using binary voltage signals, maintains the appropriate pressure in the control chamber of the relay valve, which is the basic element of this module.

The results of experimental tests of the control module prototype confirmed its correct functionality. The developed module can be used in systems for controlling the railway air brake of rail vehicles.

Nomenclature

ETCS	European Train Control System
SHP	automatic train braking
UIC	International Union of Railways

Bibliography

[1] Becker-Lindhorst K, Breinl W, Kessel G, Driver's brake valve device for air pressure brakes of rail vehicles. EPO 292830A1. European Patent Office. 1987.

[2] Fang C, Zhang X, Cheng Y, Wang S, Zhang L, Yang Y. Fault diagnosis for brake system in high-speed trains using the phased features and multi-layer perceptron. IOP Conf Ser Mater Sci Eng. 2019;470: 012007. https://doi.org/10.1088/1757-899X/470/1/012007

[3] Grzesikowski A. Hamulce kolejowe. Wydawnictwo komunikacyjne. 1995, 115-121.

[4] Hasegawa I, Uchida S. Railway Technology Today 7. Braking systems. Japan Railway & Transport Review. 1999;20:52-59.

[5] Jin Y, Xie G, Chen P, Hei X, Ji W, Zhao J. High-speed train emergency brake modeling and online identification of time-varying parameters. Math Probl Eng. 2020:3872852. https://doi.org/10.1155/2020/3872852

[6] Kaluba M. Microprocessor control system for brake systems for traction units. Rail Vehicles/Pojazdy Szynowe. 2007;4:7-10. https://doi.org/10.53502/RAIL-139834

[7] Kaluba M, Maluśkiewicz M. Brake control systems in modernized traction units. Rail Vehicles/Pojazdy Szynowe. 2015;1:4-13. https://doi.org/10.53502/RAIL-138793

[8] Perpinya X. Reliability and safety in railway. IntechOpen. 2012:432. https://doi.org/10.5772/2660

[9] Piechowiak T. Rail vehicle brakes (in Polish). Poznan Univeristy of Technology Publishing House. Poznan 2012.

[10] Sang J, Guo T, Zhang J, Zhou D, Chen M, Tai X. Incipient fault detection for air brake system of high-speed trains. IEEE T Contr Syst T. 2021;29(5):2026-2037. https://doi.org/10.1109/TCST.2020.3027673

[11] Sheng N, Ji H. Fault detection and classification of the high-speed train air brake system with an exter-variable variance index. 37th Youth Academic Annual Conference of Chinese Association of Automation (YAC). 2022:801-806.

[12] Stewart CD. New Developments in air brakes. Railway Gazette. 1947;87:126-127. https://trid.trb.org/view/6907

[13] Xu Y, Liu J. High-speed train fault detection with unsupervised causality-based feature extraction methods. Adv Eng Inform. 2021;49:101312. https://doi.org/10.1016/j.aei.2021.101312

[14] Zhao W, Ding J, Zhang Q, Liu W. Investigation into the braking performance of high-speed trains in the complex braking environment of the Sichuan-Tibet Railway. P I Mech Eng F-J Rai. 2021;236(7):766-782. https://doi.org/10.1177/095440972110418

[15] Zuo J, Wang X, Zhou S, Yang F. Investigation on the intermittent braking strategy of high-speed train. Numer Heat Tr A-Appl. 2022;82(4):109-123. https://doi.org/10.1080/10407782.2022.2066923