THE TE33A SERIES DIESEL LOCOMOTIVE BRAKE EQUIPMENT TESTS

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Resume

The purpose of the article was to present the results of braking equipment testing and determination of the adequacy of compressed air production of the braking system when the train is loaded. Experimental tests of the braking system of TE33A diesel locomotive in a goods train are performed. According to the initial data the main parameters of the braking system in the empty and loaded train were evaluated. As a result of tests, and according to the calculated data, the dependences of the volume of the main reservoirs, and the dependences of the required compressor capacity, on the number of axles have been obtained. It has been established that the braking system operation in release modes for a 400-axle train corresponds to the operating conditions and the main requirements of the normative documents.

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1 Introduction

According to the Rules for the technical operation of railways of the Republic of Kazakhstan [1], one of the main duties of railway transport workers is to meet the needs for the transportation of passengers and goods with unconditional provision of traffic safety and safety of transported goods. To fulfill this requirement, one needs not only powerful locomotives, but the advanced braking systems of the rolling stock, as well.

The rolling stock brakes should have good controllability and operate reliably in different operating conditions. The braking systems must ensure smooth braking, and the slowing force of each unit of the rolling stock must be proportional to its mass.

With pneumatic braking of trains, problems arise related to the non-timeliness of switching the braking devices of the rolling stock from the release mode to the braking mode, due to the delay of this process on cars remote from the locomotive [2].

The braking equipment of the rolling stock operates under conditions of complex processes occurring in the moving train (dry friction of the brake pads of the friction shoe brake with the conversion of mechanical energy into thermal, gas-dynamic processes in the brake line during the charging, braking, when releasing the brakes; rolling of the brake wheel on the rails under conditions of use of the wheel-rail coupling forces; interaction of rolling stock with each other with the occurrence of significant longitudinal forces in conditions of unsteady braking force, etc.). The combination of high reliability, brake safety with good controllability will increase passenger train speeds to 200-250 km/h in the near future, and freight trains to 140-160 km/h with an axial load of 18-20 tons (high-speed shuttle trains for container cargo transportation), and increase the weight of freight trains to 10-12 thousand tons, to increase transportation productivity. To successfully solve these problems, it is necessary to fully expand and strengthen the creative cooperation of engineering and technical workers of the brakes of construction plants, linear enterprises of the carriage industry, as well as researchers related to calculation and design of the braking equipment, in particular the pneumatic and mechanical parts of the rolling stock brakes. It is also necessary to comprehensively and critically study the modern experience of railways of foreign countries to enable and expediently use it on the railways of Kazakhstan, considering the modern conditions of their operation [3-4].

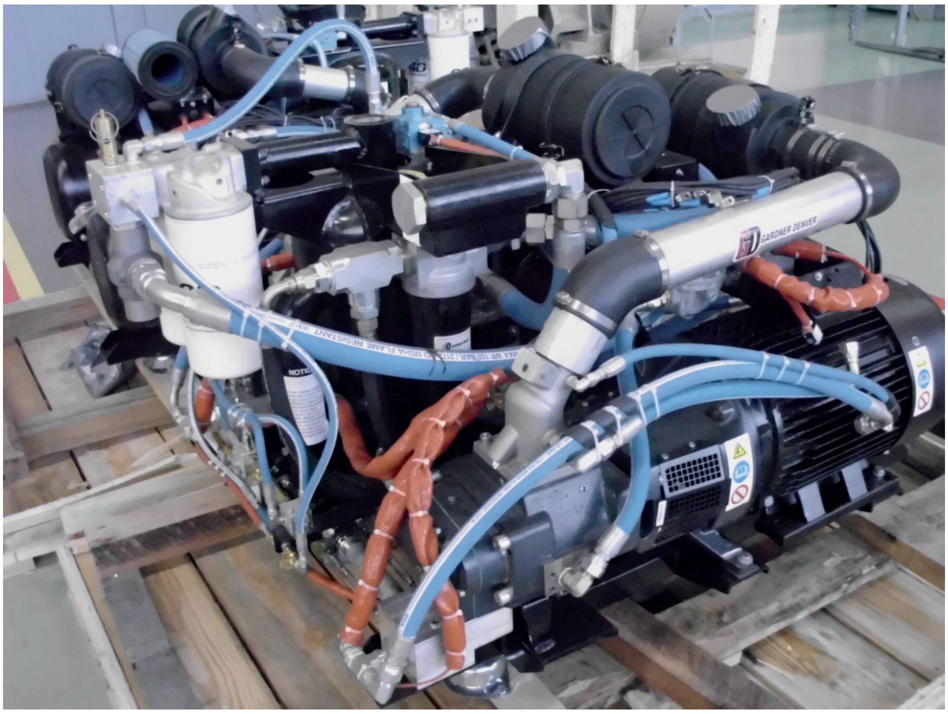

Figure 1 *General view of the Gardner Denver air compressor*

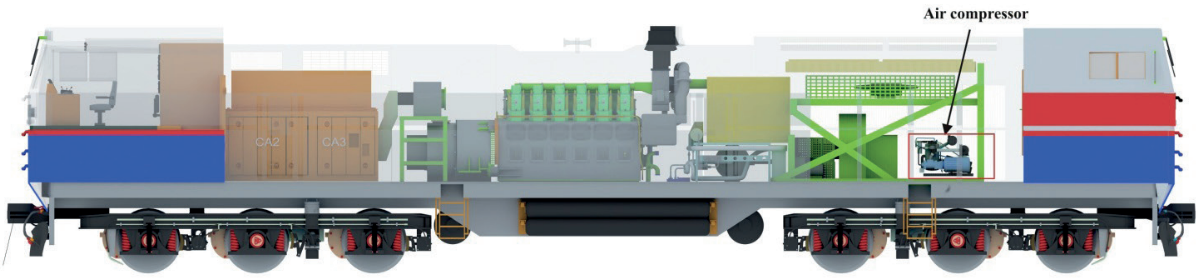

Figure 2 *Location of the air compressors on the locomotive*

2 Main components of diesel locomotive brake system TE33A

The main component for compressed air compression in the compressed air system is a twin-screw compressor manufactured by Gardner Denver (Figure 1). Each compressor head has one AC motor to drive the screw rotor. For each locomotive 2 such units are installed. The location of the air compressors on the locomotive is shown in Figure 2.

Figure 3 shows a schematic diagram of the location of the main elements of the TE33A diesel locomotive braking system. To cool the air, compressed air coolers are used, which are activated after the compressed air temperature reaches 115 °C. One of the coolers is located on the compressor frame, the second in the refrigeration chamber. Cooling is due to convection, or due to the combined influence of convection and the operation of the fan of the diesel cooling system. After the compressor, the compressed air enters the first main tank, where the air is cooled by the moisture condensation. The Main Reservoir (Main Reservoir, MR) is tilted, so moisture flows to one of the ends (from where it is drained through the drain valve). Each MR tank has a separate drain valve, which is activated by a drain valve solenoid (Drain Valve Magnet Valve, DVMV) [4].

The safety valve is installed on outlet branch pipe of the first main tank. This valve is designed to protect the compressor and other components of the compressed air system from overpressure. The compressed air flow from the first main tank is divided into two parts. One part of the flow is supplied to the main tank pressure sensor (MR1), which provides a feedback signal on the compressed air pressure to the locomotive control system. The second part of the flow enters the air dryer, in which the compressed air is further purified from moisture. After the dryer, the air enters the second main tank and the auxiliary air filter. A reverse throttling valve with a diaphragm of about 8 mm (5/16 inch) is used to limit the air flow into the auxiliary equipment pipeline and to ensure priority filling of the MR2 tank.

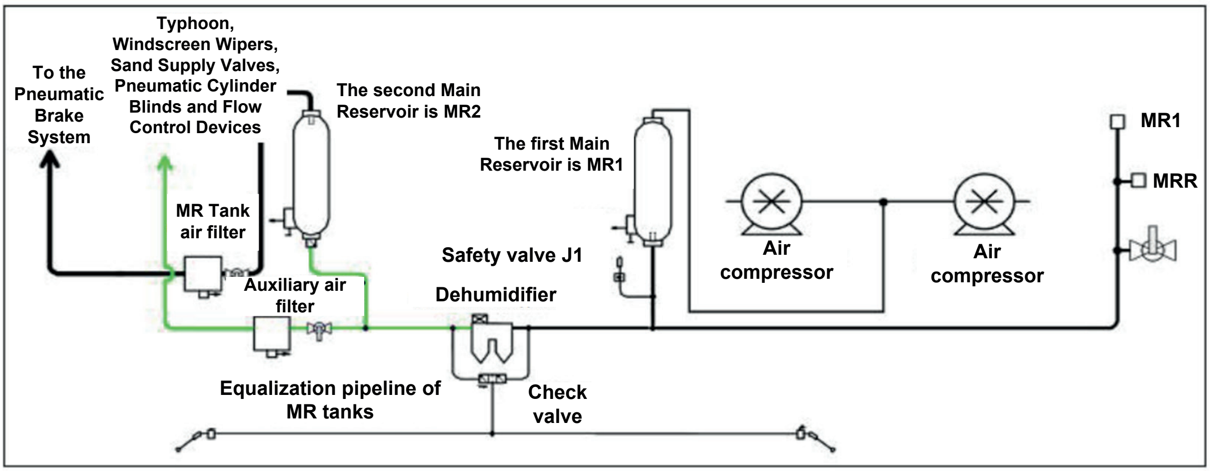

__Figure 3__ Schematic diagram of the location of the braking system main elements

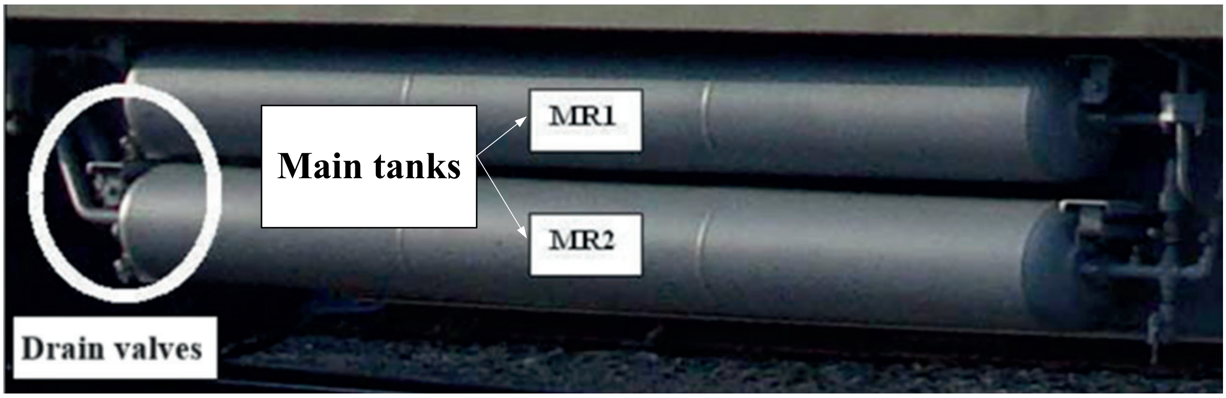

__Figure 4__ Main tanks (MR1 and MR2) typical arrangement

The valve is installed between the outlet of the first main tank and the equalizing pipeline of the MR tanks [5-6].

The second check valve is installed between the outlet of the air dryer and the equalizing pipeline of the tanks MR. This check valve is designed to supply air to the second locomotive of the coupler. This arrangement allows air to enter the compressed air system of the second coupling locomotive only through the air dryer. Air passing into the second tank MR2 through the check valve enters the air filter of the main tanks. The presence of a check valve prevents the return movement of air into the first main reservoir. This is done in the case of air leakage from the first main tank. In such a situation, the air remaining in the second tank will be sufficient to provide emergency braking. The MR air filter and auxiliary air filter are also referred to as final air filters. These devices are used to filter air before it enters the pneumatic brake system and auxiliary equipment. Each filter is equipped with a drain valve. The valves serve to drain moisture from the filters. Filtered air from the auxiliary equipment air filter (auxiliary supply air) is supplied to the typhon, windshield wipers and sand supply valves [6].

Filtered air from the MR tank air filter (make-up air from MR tanks) is distributed among the components of the pneumatic brake system.

2.1 Main tanks of the compressed air system

The main tanks (Figure 4) serve to store compressed air intended for use in a locomotive. The locomotive has two tanks of a diameter of 394 mm and a length of 3950 mm. Two tanks contain 960 liters of air under the pressure of the main tanks 10 MPa. The main tanks are fixed on the locomotive at a slight inclination, which ensures the drainage of moisture to one of the ends of the tank. Automatic blowdown devices (drain valves) are installed at the lower end of each tank to drain the moisture.

2.2 Safety valve L

Valve L is designed to protect the compressor and other components of the compressed air system from overpressure (Figure 5). If the air pressure exceeds 1.05 MPa, the valve opens and releases excess air to the atmosphere. Safety valve is arranged between the two main tanks on locomotive A side [3].

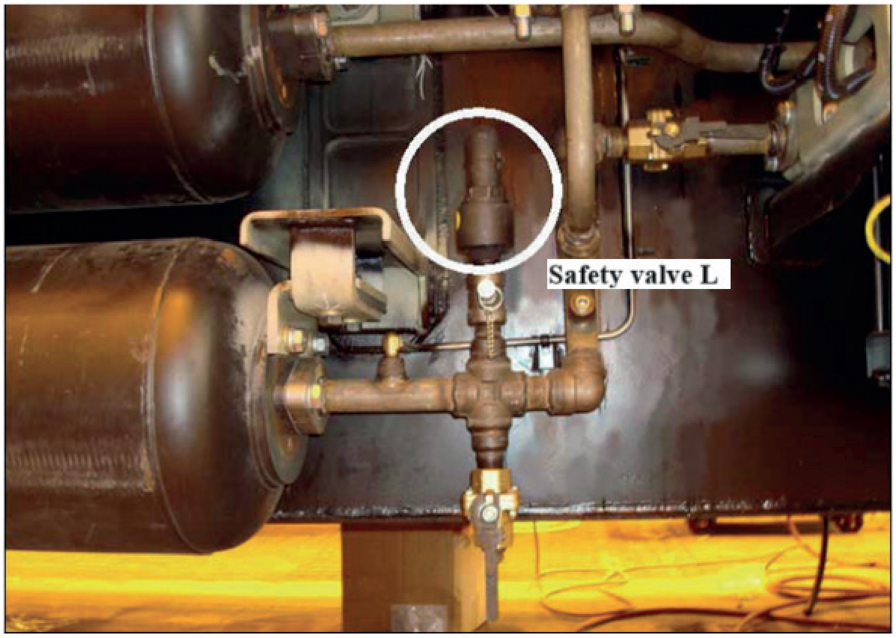

Figure 5 *Safety valve L*

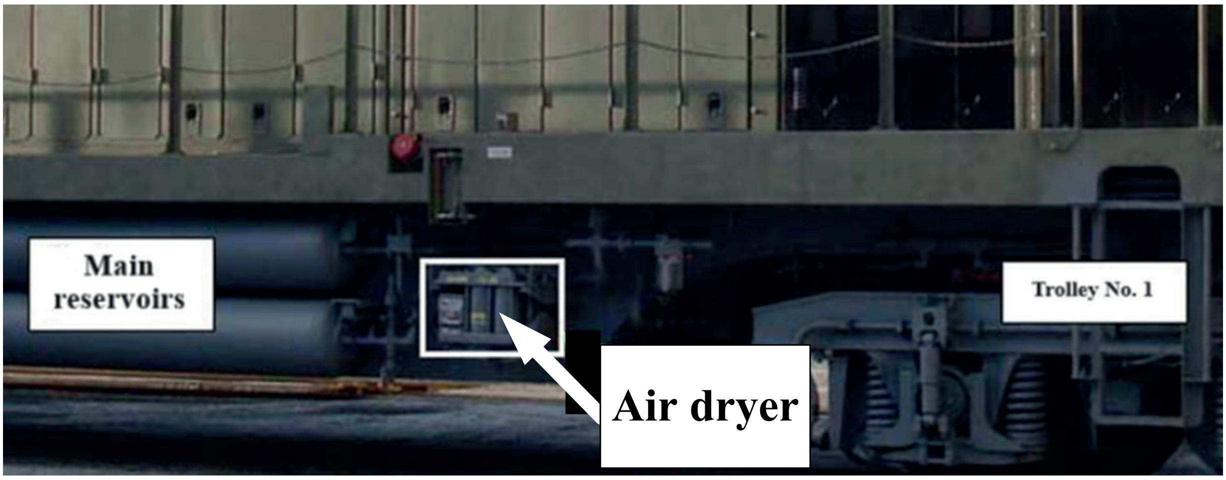

Figure 6 *Air dryer*

2.3 Air dryer

Dryer is designed to separate the compressed air from moisture. When frozen, moisture can damage pneumatically controlled devices (Figure 6). The air dryer is located on the A side of the locomotive between the main tanks and trolley No. 1.

2.4 Main Tank Pressure Transmitter (MR1)

MR1 is used to measure the air pressure at the outlet of the main tank of the compressed air system. In the locomotive control system, this data is used to calculate the moment when the compressor motors are turned on and off, and to monitor its load. The ultimate goal of such monitoring is to maintain a constant pressure in the compressed air system. Pressure information is also displayed on programmable displays to inform the driver [7].

The sensor MR1 is located on the inner wall of the CA9 zone in the refrigeration chamber.

2.5 Principle of the braking system operation

The air discharged from the air compressor enters the main tank No. 1 (MR No. 1). At the exit of MR No. 1, the air flows are separated: one air flow goes to the safety valve L, the other goes through the air dryer, and the third goes to the MR1 sensor. The safety valve L protects equipment located downstream of MR tank No. 1. The MR1 is used in the feedback loop to control the pressure in the main tanks. The air downstream of the dehumidifier passes through a 2” check valve with a 0.312” bypass [5]. This air is then routed to the

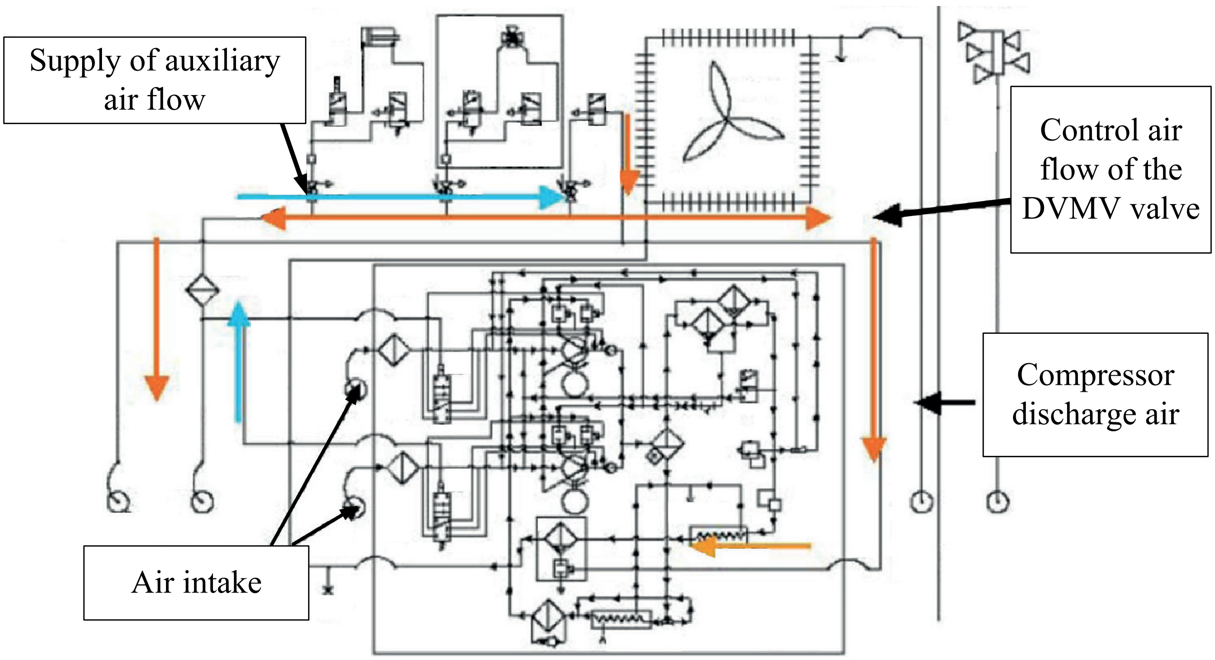

Figure 7 *DVMV and DVMV pneumatic signals for MR drain valves*

main tank outlets located at the four corners of the locomotive (MRE air connections) and enters the main tank No.2 (MR No.2) via a 2» check valve. Each MR tank is provided with a drain valve, which opens to remove moisture at each on/off cycle of the air compressor (Figure 7).

These drain valves are automatically controlled by the DVMV valve located in the compartment above the compressor. (The drain valves in “automatic” mode are opened to remove the moisture or they can be turned to “off” position when they do not perform this function). The normal operation of the locomotive is to work in the “auto” mode to remove moisture from the tanks. When the drain valves move from the “auto” position to the “off” position, or from the “off” position to the “auto” position at increased pressure MR, compressed air is released and a sharp sound is heard. Be careful and protect your eyes and ears when doing this.

The air injected from the main tank No. 1, after the air dryer, has a different path. This is an auxiliary airflow. There is a shut-off valve for venting air to the valve if work is needed, and a built-in filter for further removal of dirt and moisture [8].

The POU, or pneumatic control module, is located in the brake compartment on the A-side of the locomotive. The module consists of control components (electrical, pneumatic, mechanical and electronic) for adjusting the pressure in the brake line pipelines. The POU module is a central device for connecting the air ducts and electrical wiring to the locomotive. It consists of the following replaceable units: brake line control assembly, MC-13 control valve, quick-acting valve assembly, brake cylinder control assembly, idle (cold) towing assembly, and power supply.

Brake main line control unit. Designed to control the brake line pressure, when the automatic brakes are activated in the CUT-IN full control mode, it allows one to adjust the CUT-IN/CUT-OUT full/partial control modes of the automatic brake application via SDIS and provides the possibility of emergency discharge of the brake line.

MC-13 control valve. It is a backup and allows braking in such situations when there is a complete lack of power supply, computers fail, the locomotive is hauled in an inoperative (cold) state in a coupling or as part of a train.

Quick-acting valve assembly. Ensures proper brake cylinder pressure in any automatic brake operation mode.

Brake cylinder control assembly. Provides control of air supply from the main reservoir No.2 to the brake cylinders and release of air from the brake cylinders to the atmosphere in all braking and release modes.

Idle (cold) towing assembly. Used when hauling a completely inoperable locomotive.

Power supply. Provides redundant power supply for the FastBrake controller logic circuits and solenoid valve driver circuits, and is two separate 74 VDC power supplies.

3 Stationary test of a single diesel locomotive TE33A series brake equipment No. 0120

To check for compliance with the requirements of the Instruction on Operation of Rolling Stock Brakes of the Closed Joint Stock Company “National Company Kazakhstan temir zholy” the condition and operation of

***Table 1** Check of the condition and operation of the braking equipment of the diesel locomotive TE33A No. 0120*

No.	Measured parameter	Actual		Standard	
		P	T	P	T
		MPa	s	MPa	s
1.	Brake line density	0.55	75	0.02	>60
2.	Feed line density	0.8-0.78	200	0.02	>150
3.	Capacity of 2 compressors	0.7-0.8	21	0.7-0.8	<45
4.	Turning on the compressor	0.75-0.76		0.75	
5.	Compressor shutdown	0.99-1.0		0.9	
6.	Overpressure in the equalization tank IV position (overlap with the power supply of the brake line) after the first stage of braking	0.45	standard	Not allowed	
7.	Overestimation of pressure in the equalization tank to the IV position (overlap with the power supply of the brake line) after the full-service braking	0.39	standard		
8.	Service discharge rate	0.5-0.4	5.27	0.5-0.4	4-6
9.	Rate of elimination of supercharge pressure	0.6-0.58	87	0.6-0.58	80-120

***Table 2** Check of the condition and operation of the braking equipment of the diesel locomotive 2TE10M No. 3628*

No.	Measured parameter	Actual		Standard	
		P	T	P	T
		MPa	s	MPa	s
1.	Brake line density	0.55	72	0.02	>60
2.	Feed line density	0.8-0.78	190	0.02	>150
3.	Capacity of 2 compressors	0.7-0.8	46	0.7-0.8	<50
4.	Turning on the compressor	0.74		0.75	
5.	Compressor shutdown	0.84		0.9	
6.	Overpressure in the equalization tank IV position (overlap with the power supply of the brake line) after the first stage of braking	0.45	standard	Not allowed	
7.	Overestimation of pressure in the equalization tank to the IV position (overlap with the power supply of the brake line) after the full-service braking	0.39	standard		
8.	Service discharge rate	0.5-0.4	5.01	0.5-0.4	4-6
9.	Rate of elimination of supercharge pressure	0.6-0.58	92	0.6-0.58	80-120

the braking equipment of the locomotive was checked [9]. The results of the inspection of the braking equipment of the TE33A locomotive No. 0120 are given in Table 1. Results of the braking equipment check of 2TE10M locomotive No. 3628 are given in Table 2.

3.1 Stationary tests of operation of the locomotive TE33A braking equipment

To carry out the functional tests of braking equipment during the stationary tests, a test train of 100 units of rolling stock (400 axles) was formed on the receiving tracks of station Almaty 1 according to the scheme in Figure 8.

Diesel locomotives TE33A No. 0120 and 2TE10M No. 3628 were delivered from both ends of the train, for testing the braking equipment and for recording the braking processes and pressure in the brake line at the rear of the train.

During the stationary tests, the pressure in the brake cylinders of the diesel locomotive, the spare tank and the brake cylinder of the tail freight car (portable pressure gauges) was checked in various braking modes (brake line discharge stages, full service and emergency braking) [10].

According to the functioning tests of the TE33A locomotive No. 120 braking system - the volume of the main tank is 1900 liters, with a train consisting of 100 units of rolling stock - 400 axles release of tailgate brakes:

1. after the step braking occurs in 1-3 minutes - the train is prepared to turn on the traction with no danger of breaking the train, and charging of spare tanks up to 95% of the charging one (and according to the air flow meter reading on the TE33A) occurs

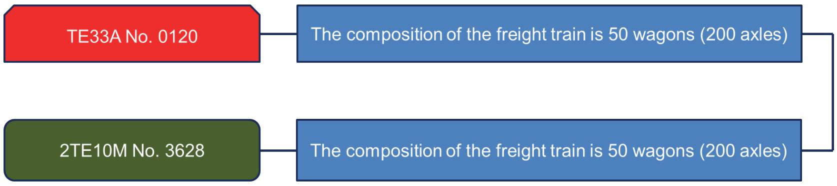

Figure 8 *Test diagram when forming a train of 100 rolling stock (400 axles)*

in 4-5 minutes - readiness of the braking system (95%) for subsequent effective braking;

2. after the full-service braking and deep discharges of the brake line, the decompression takes 1-3 minutes. Even faster than with small stages, since the decompression is carried out with overpressure above the train line - the train is prepared to turn on traction with no danger of breaking the train, and charging spare tanks up to 95% of the charging (and according to the air flowmeter reading on the TE33A) occurs during 5-7 minutes - the brake system is ready (95%) for subsequent effective braking;
3. after the emergency braking, the decompression takes 2-3 minutes. The train is prepared to turn on the traction with no danger of breaking the train, and the spare tanks are charged up to 95% of the charging tank (and according to the air flowmeter reading on the TE33A) takes 8-14 minutes. - the brake system is ready (95%) for subsequent effective braking.

Brake control at train pressure in the brake line 0.50.52 MPa is considerably improved [11]:

- increasing the density of the brake line (reducing the intensity of leaks);
- the pressure difference between the head and the tail of the train decreases;
- reducing the time for releasing the brakes and charging spare tanks.

4 Calculation of diesel locomotive braking system TE33A

The braking system must have high reliability and ensure the safety of train traffic. Automatic brakes of the railway rolling stock should be maintained according to the established standards and have controllability and reliability of action in various operating conditions, provide smooth braking. To determine the performance of the braking system according to the results of the tests performed, it is necessary to assess the braking system. To perform the calculation of the brake system, the main parameters of the main elements of the braking equipment were obtained from the passport data of TE33A series diesel locomotives [12]. The value of barometric pressure in normal conditions is taken as 0.103 MPa. The compressor's capacity and main reservoir's capacity are obtained by measuring the indicators on the control panel instruments in empty and loaded states of diesel locomotives, for the cases of brake release and charging after the full-service braking. To perform the calculation of the main devices, the main parameters of the braking equipment of TE33A diesel locomotive are given in Table 3 [9].

4.1 Compressor unit calculation

Calculation is carried out for the most unfavorable operating conditions of the locomotive (presence of the largest permissible air leaks and air flow rate).

The train braking network volume is determined according to Equation (1). Train Brake Network Volume $\Sigma V_{BN.T}$ consists of the volumes of the brake network of the locomotive $V_{BN.L}$ and rolling stock $V_{BN.RS}$ [13]:

$$\Sigma V_{BN.T} = V_{BN.L} + V_{BN.RS}\,, \tag{1}$$

60 rolling stock - $\Sigma V_{BN.\,T}$ = 20+103.5×60=6230 liter,
71 rolling stock - $\Sigma V_{BN.\,T}$ = 20+103.5×70=7265 liter,
90 rolling stock - $\Sigma V_{BN.\,T}$ = 20+103.5×90=9335 liter,
100 rolling stock - $\Sigma V_{BN.\,T}$ = 20+103.5×100=10370 liter.

For one wagon unit the volume of the braking network is equal to:

$$V_{BN} = V_{LINE} + V_{ST} + V_{OT} = 13.5+78+12=103.5 \text{ liters}, \tag{2}$$

where: V_{LINE} - brake line volume, 13.5 liter,
V_{ST} - spare tank volume, 78 liters,
V_{OT} - volume of operating tanks, 12 liters.

4.1.1 Determination of the total hourly air flow rate

The total hourly air flow rate in the train at frequent adjustment braking is determined by the equation:

$$Q_{GEN.T} = Q_{L.\,T} + Q_{BRAKE} + Q_{O.\,L}, \tag{3}$$

where: $Q_{L.\,T}$ - consumption of compressed air to replenish leaks from the brake line and braking devices in the train, l/h,
Q_{BRAKE} - air flow rate for braking, l/h,
$Q_{O.\,L}$ - other air consumption, for electric locomotives and diesel locomotives can be accepted $Q_{O.\,L}$ = 12000 l/h,
60 rolling stock:
$Q_{GEN.T} =$ 72 583+48 388+12 000= 132 971 l/h;

***Table 3** Initial data for calculation*

Basic parameters	Empty	Loaded	Empty	Loaded
Number of rolling stocks, units	100	90	70	60
Locomotive main line volume, l	20.0	20.0	20.0	20.0
Car main line volume, l	13.5	13.5	13.5	13.5
Spare tank volume, l	78.0	78.0	78.0	78.0
Volume of working tanks of air distributors, l	12.0	12.0	12.0	12.0
Barometric pressure, MPa	0.103	0.103	0.103	0.103
Allowable pressure decrease in the brake line, MPa per minute (leak)	0.02	0.02	0.02	0.02
Required compressor capacity, m³/min	4.80	4.36	3.49	3.06
Required minimum volume of the main tank, l.	1688	1909	1181	1273
Selected volume of the main tank, l	1900	1900	1000	1000
Checking the performance of the compressor and the capacity of the main tank for cases of release and charging of brakes after the full-service braking				
Decompression time, min	3.0	3.0	3.0	3.0
Pressure drop in working tanks, MPa	0.15	0.15	0.15	0.15
Charging pressure in the reserve tank, MPa	0.49	0.54	0.49	0.54
Pressure in the reserve tank after braking, MPa	0.34	0.39	0.34	0.39
Value of pressure decrease in TM (full-service pressure), MPa	0.15	0.15	0.15	0.15
Permissible pressure drop in the main tank	2.5	2.0	2.5	2.0
Selected compressor capacity, m³/min	5.8	5.8	5.8	5.8
Required compressor capacity, m³/min	5.0	4.7	3.8	3.3

70 rolling stock:
$Q_{GEN.T}$ = 84 641+56 427+12 000 = 153 068 l/h;
90 rolling stock:
$Q_{GEN.T}$ = 108757+72505+12 000 = 193 262 l/h;
100 rolling stock:
$Q_{GEN.T}$ = 120 816+80544+12 000 = 213 359 l/h.

The air flow rate in the main air duct is determined according to the Equation (4):

$$Q_{MAD} = \frac{60 \cdot \Delta P_{MAD} \cdot V_{TBN}}{P_{BAR}} \quad (4)$$

where: ΔP_{MAD} - permissible pressure reduction in the main air duct in 1 minute through leaks in the absence of its supply (0.02 MPa is accepted),
ΣV_{TBN} - the volume of the train's braking network, l,
P_{BAR} - barometric atmospheric pressure, P_{BAR} = 0.103 MPa,

60 rolling stock:

$$Q_{MAD} = \frac{60 \cdot 0.02 \cdot 6230}{0.103} = 72583$$

l/hour,
70 rolling stock:

$$Q_{MAD} = \frac{60 \cdot 0.02 \cdot 7265}{0.103} = 84641$$

l/hour,
90 rolling stock:

$$Q_{MAD} = \frac{60 \cdot 0.02 \cdot 9335}{0.103} = 108757$$

l/hour,
100 rolling stock:

$$Q_{MAD} = \frac{60 \cdot 0.02 \cdot 10370}{0.103} = 120816$$

l/hour,

The air consumption for braking is determined by the equation:

$$Q_{BRAKE} = \frac{\Delta P_{BR.L.} \cdot \Sigma V_{TBN} \cdot K}{P_{BAR}}, \quad (5)$$

$\Delta P_{BR.L.}$ - reduction of air pressure in the brake line during braking (in the case of adjustment braking, it is accepted $\Delta P_{BR.L.}$ = 0.08 MPa),
K - the number of adjustment brakes per 1 hour (in the most unfavorable case for a mountainous area with long descents K = 10/h),
60 rolling stock:

$$Q_{MAD} = \frac{0.08 \cdot 6230 \cdot 10}{0.103} = 48388$$

l/hour,
70 rolling stock:

$$Q_{MAD} = \frac{0.08 \cdot 7265 \cdot 10}{0.103} = 56427$$

l/hour,
90 rolling stock:

$$Q_{MAD} = \frac{0.08 \cdot 9335 \cdot 10}{0.103} = 72505$$

l/hour,
100 rolling stock:

$$Q_{MAD} = \frac{0.08 \cdot 10370 \cdot 10}{0.103} = 80544$$

l/hour.

4.1.2 Determination of the compressor performance

The compressor performance is determined by the equation:

$$Q_{COM} = 1.3 \cdot \left(\frac{Q_{GEN.T}}{60} + Q_{LOK.L}\right), \quad (6)$$

where: 1.3 - a coefficient that takes into account the need to turn off the compressor for cooling,
$Q_{LOK.L}$- air consumption to compensate for locomotive leaks (take 135 l/min),
60 rolling stock:

$$Q_{COM} = 1.3 \cdot \left(\frac{132971}{60} + 135\right) = 3060$$

l/min,
70 rolling stock:

$$Q_{COM} = 1.3 \cdot \left(\frac{153068}{70} + 135\right) = 3490$$

l/min,
90 rolling stock:

$$Q_{COM} = 1.3 \cdot \left(\frac{193262}{90} + 135\right) = 4360$$

l/min,
100 rolling stock:

$$Q_{COM} = 1.3 \cdot \left(\frac{213359}{100} + 135\right) = 4800$$

l/min.

The performance of the Garden Denver compressor is 5800 l/min, it satisfies the calculation results.

4.1.3 Determination of the volume of the main reservoirs

The approximate volume of the main tanks is determined from the filling condition of the main air pipeline (without powering the spare tanks) after emergency braking [11].

$$V_{MT} \frac{\Delta P_{BR.L} \cdot V_{BR.L}}{\Delta P_{MT}}, \quad (7)$$

where: ΔP_{MT} - permissible pressure drop in the main reservoirs during the emergency braking in accordance with the Instructions for operation of railway rolling stock brakes [9]:
for loaded rolling stock ΔP_{MT} = 0.9 - 0.55 = 0.35 MPa,
for empty rolling stock ΔP_{MT} = 0.9 - 0.5 = 0.4 MPa,
$V_{BR.L}$ - the volume of the train's brake line, l,
$\Delta P_{BR.L}$ - reduction of air pressure in the brake line from charging to 0 MPa,
60 rolling stock (loaded):

$$V_{MT} = \frac{0.55 \cdot 60 \cdot 13.5}{0.35} = 1273$$

liters,

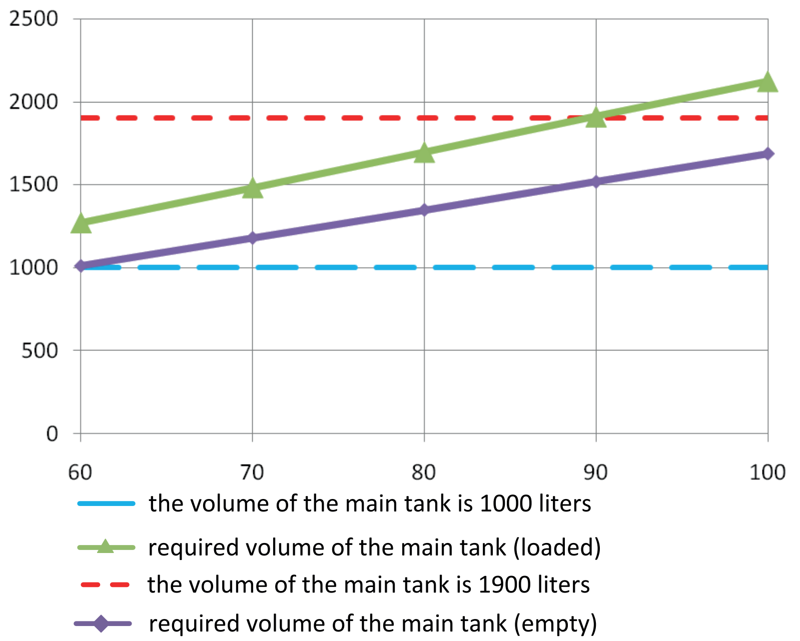

***Figure 9** Dependence of the volume of the main reservoirs on the number of axes*

70 rolling stock (empty):

$$V_{MT} = \frac{0.5 \cdot 70 \cdot 13.5}{0.4} = 1181$$

liters,
90 rolling stock (loaded):

$$V_{MT} = \frac{0.55 \cdot 90 \cdot 13.5}{0.35} = 1909$$

liters,
100 rolling stock (empty):

$$V_{MT} = \frac{0.5 \cdot 100 \cdot 13.5}{0.4} = 1688$$

liters.

The volume of the main tanks on locomotive TE33A No. 120 is 1,900 liters, which satisfies the calculation results for both loaded and empty trains with a length of up to 400 axles, whereas the serial locomotives with a volume of 1000 liters of main tanks (Figure 9) do not satisfy even for trains with a length of 280 axles (70 rolling stock) [8, 14].

4.2 Checking the compressor performance and the capacity of the main tanks

The calculated values of the compressor capacity and the volume of the main tanks must be checked for the cases of release and charging of the brakes after the full-service braking (FSB) [10]. The check is performed based on the compressed air flow balance equation according to:

$$Q^{I}_{COM} \cdot t_{R.BR} + \frac{\Delta P_{MT}}{P_{BAR}} \cdot V_{MT} = \frac{\Delta P_{BR.L}}{P_{BAR}} \cdot \sum V_{LINE} + \\ + \frac{\Delta P_{WT}}{P_{BAR}} \cdot \sum V_{ST} + \frac{\Delta P_{ST} - \Delta P^{I}_{ST}}{P_{BAR}} \cdot \sum V_{ST} + \\ + \frac{\Delta P_{MAD}}{P_{BAR}} \cdot \sum V_{ST} \cdot t_{R.BR},$$

where: $t_{R.BR}$ - estimated time to release the brakes and recharge the reserve tank to full charging pressure.

In calculating, the following values were taken:
for trains with a length of less than 200 axles $t_{R.BR}$ = 1.5 min,
for trains with a length of more than 200 axes $t_{R.BR}$ = 3.0 min,
V_{MR} - the total volume of the selected main reservoirs, V_{MR} = 1900 liters,
ΔP_{WT} - pressure drop in the working tanks (for FSB with air distributors, conl. No. 483-000- ΔP_{WT} =0.15 MPa,
P_{ST} - pressure in the spare tanks (freight train P_{ST} = 0.54 MPa),
P_{ST} - pressure in the spare tanks after braking (freight train - P_{ST} = 0.39 MPa),
$\Delta P_{BR.L}$ - the amount of pressure reduction in the brake line (with full service braking), $\Delta P_{BR.L}$ = 0.15 MPa,
ΔP_{MT} - permissible pressure drop in the main tanks (with full service braking ΔP_{MT} = 0.75 - 0.55 = 0.2 MPa).

Solving Equation (8) with respect to Q_{COM}, the compressor performance is determined [15]:
60 rolling stock:

$$Q_{COM} = 1.3 \cdot \left(\frac{132971}{60} + 135 \right) = 3300$$

l/min,

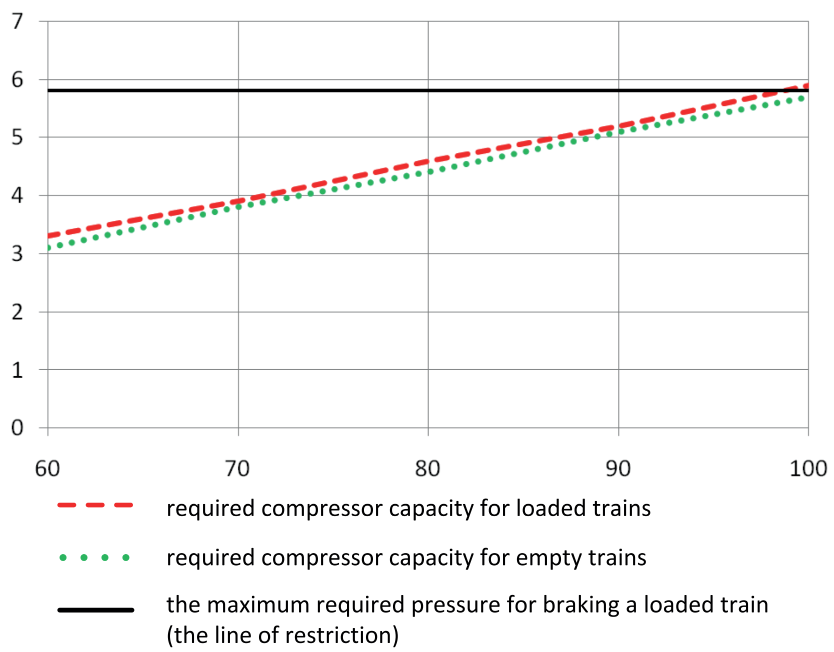

***Figure 10** Curve of required compressor capacity versus number of axes*

70 rolling stock:

$$Q_{COM} = 1.3 \cdot \left(\frac{153068}{70} + 135 \right) = 3800$$

l/min,
90 rolling stock:

$$Q_{COM} = 1.3 \cdot \left(\frac{193262}{90} + 135 \right) = 4700$$

l/min,
100 rolling stock:

$$Q_{COM} = 1.3 \cdot \left(\frac{213359}{100} + 135 \right) = 5000$$

l/min.

Compressor capacity on a locomotive is 5.8 m^3/min= = 5800 l/min. The resulting dependences of the required compressor capacity on the number of axles are shown in Figure 10.

5 Discussion of results

On Western European railways, slow-acting brakes are used on freight cars with a weak screw coupling in short trains, which can switch to accelerated braking in passenger trains. The design and research (study) of brakes are mainly carried out by the companies Knorr-Bremse (Germany) and Oerlikon (Switzerland), DACO (Czech Republic). The highly sensitive braking systems developed by them with valve-diaphragm design air distributors with stepped release and with a braking wave speed of 250-280 m/s, have been adopted by the UIC as uniform on all the railways in Western Europe [16-17].

The braking devices and equipment manufactured in the USA are characterized by the lower braking efficiency and a longer braking distance compared to the braking devices of Western European railways. In the USA, Westinghouse brakes are used, which supplies brakes to all countries of North and South America and has branches in England, Germany, Italy, Spain and France [17]. These brakes have an air distributor that provides stepless accelerated release in long-length freight trains formed from the rolling stock with a powerful automatic coupling. The most common non-direct exhaust air distributors are air distributors of types AB, ABD, ABDW [18].

In the high-speed passenger trains, the creation of which is currently receiving the great attention in Kazakhstan and abroad, disc and magnetic rail brakes in combination with pad brakes, as well as electronic anti-skid devices to protect the wheels of wheelsets from damage (the appearance of sliders, metal shear on the surface of the wheels) are widely used in sections railway tracks with a low coefficient of wheel-to-rail coupling [18].

6 Conclusions

1. According to the results of the brake tests, it was established that the modifications carried out to increase the volume of the main tanks to 1900 liters showed the operation of the brake system in accordance with the standards of the “Instructions for the operation of rolling stock brakes, National Company, Kazakhstan temir Zholy” dated 17.10.2002 No. 120-TsZ.

2. According to the results of stationary tests with trains on the site, it was revealed:

a. The operation of the brake system in braking modes complies with the operating conditions and the standards of the “Instructions for operating the brakes of rolling stock of the Closed Joint Stock Company, National Company, Kazakhstan temir Zholy” dated 17.10.2002 No. 120-TsZ.

b. The operation of the brake system in the release modes for a train of 400 axles (flat mode) complies with the operating conditions and standards of paragraph 19.2.7 “Instructions for operating the brakes of rolling stock of the Closed Joint-Stock Company, National Company, Kazakhstan temir Zholy” dated 17.10.2002 No. 120-TsZ. With a decompression time rate of 80 seconds, the actual tail car decompression time was 57-60 seconds.

c. Comparative stationary brake tests for the release of the train brakes in 400 axles by control from the diesel locomotive of the 2TE10M series No. 3628AB showed that at a rate of 80 seconds, the actual time of the tail car release was 75-80 seconds (volume GR 2000 L), and with the diesel locomotive TE33A (volume GR 1900 L) 57-60 seconds.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Rules of technical operation of railway transport of the Republic of Kazakhstan. Approved by the Order of the Minister of Investment and Development of the Republic of Kazakhstan dated 30 April 2015 No. 544 [online]. Available from: https://adilet.zan.kz/rus/docs/V1500011897

[2] LANIGAN, J., KRIER, P., LEWIS, R. Field trials of a methodology for locomotive brake testing to assess friction enhancement in the wheel/rail interface using a representative leaf layer. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* [online]. 2020, **235**(9), p. 1053-1064. ISSN 0954-4097, eISSN 2041-3017. Available from: https://doi.org/10.1177/0954409720973135

[3] ABDULLAYEV, S., BAKYT, G., KAMZINA, A., SARSANBEKOV, K., ABDULLAYEVA, A. Interaction of the TE33a diesel locomotive and the railway track on curved section with radius 290 m. *Communications - Scientific Letters of the University of Zilina* [online]. 2023, **25**(4), p. B315-326. ISSN 1335-4205, eISSN 2585-7878. Available from: https://doi.org/10.26552/com.C.2023.069

[4] WHITE, B. T., NILSSON, R., OLOFSSON, U., ARNALL, A. D., EVANS, M. D., ARMITAGE, T., FISK, J., FLETCHER, D. I., LEWIS, R. Effect of the presence of moisture at the wheel-rail interface during dew and damp conditions. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* [online]. 2018, **232**(4), p. 979-989. ISSN 0954-4097, eISSN 2041-3017. Available from: https://doi.org/10.1177/0954409717706251

[5] PFAFF, R., ENNING, M., SUTTER, S. A risk-based approach to automatic brake tests for rail freight service: incident analysis and realisation concept. *SN Applied Sciences* [online]. 2022, **115**(4), p. 1-14. eISSN 3004-9261. Available from: https://doi.org/10.1007/s42452-022-05007-x

[6] SUCHANEK, A., KURCIK, P., STASTNIAK, P. Design of a testing equipment for experimental research of railway brake systems. *AIP Conference Proceedings* [online]. 2019, **2198**(1), 020015. ISSN 0094-243X, eISSN ISSN 1551-7616. Available from: https://doi.org/10.1063/1.5140876

[7] GERLICI, J., LACK, T., RAILBCOT test stand dynamics properties analysis. In: 22nd International Conference Current Problems in Rail Vehicles - PRORAIL 2015: proceedings. Part I. 2015. p 329-343.

[8] ABDULLAYEV, S., BAKYT, G., ABDULLAYEVA, A., DUISEMBAYEVA, B., ASKENOV, Y., ASHIRBAYEV, G., BESEKENOV, R. Testing of railway equipment for the impact on the track and turnouts. *Communications - Scientific Letters of the University of Zilina* [online]. 2024, **26**(2), p. B99-B107. ISSN 1335-4205, eISSN 2585-7878. Available from: https://doi.org/10.26552/com.C.2024.020

[9] Instructions on operation of brakes of rolling stock' of the Closed Joint Stock Company "National Company Kazakhstan Temirzholy". Approved by the order of the President of the Closed Joint Stock Company "National Company Kazakhstan Temir zholy" from 17.10. 2002 No. 120-TsZ.

[10] STRAZOVEC, P., GERLICI, J., LACK, T., HARUSINEC, J. Innovative solution for experimental research of phenomena resulting from the wheel and rail rolling. *Transportation Research Procedia* [online]. 2019, **40**, p. 906-911. ISSN 2352-1457, eISSN 2352-1465. Available from: https://doi.org/10.1016/j.trpro.2019.07.127

[11] MUSSABEKOV, M., BAKYT, G., OMIRBEK, A., BRUMERCIKOVA, E., BUKOVA, B. Shunting locomotives fuel and power resources decrease. *MATEC Web of Conferences* [online]. 2017, **134**, 00041. eISSN 2261-236X. Available from: https://doi.org/10.1051/matecconf/201713400041

[12] KUANYSHEV, B. M., ABDULLAYEV, S. S., BAKYT, G. B. Diesel locomotive TE33A produced by JSC "Locomotive Kurastyru Zauyty". Device, purpose of units and assemblies: manual. Almaty: KazATC, 2015.

[13] HAUSER, V., NOZHENKO, O., KRAVCHENKO, K., LOULOVA, M., GERLICI, J., LACK, T. Impact of three axle boxes bogie to the tram behavior when passing curved track. *Procedia Engineering* [online]. 2017, **192**, p. 295-300. ISSN 1877-7058. Available from: https://doi.org/10.1016/j.proeng.2017.06.051

[14] DIZO, J., BLATNICKY, M., STEISUNAS, S., SKOCILASOVA, B. Assessment of a rail vehicle running with the damaged wheel on a ride comfort for passengers. *MATEC Web of Conferences* [online]. 2018, **157**, 03004. eISSN 2261-236X. Available from: https://doi.org/10.1051/matecconf/201815703004

[15] AZILKIYASHEVA, M. M., SHAYAKHMETOV, S. B., BAKYT, G. B., KOPENOV, B. T., BAUBEKOV, Y. Y., ZHAUYT, A. Development of a method for calculating the degree of use of the plasticity resource (Dupr) when rolling on a new continuous mill. *Metalurgija-Metallurgy*. 2021, **60**(3-4), p. 362-364. ISSN 0543-5846.

[16] RAKIPOVSKI, E., MILCIC, D. Validation testing of an innovative braking system for freight wagons. *Transactions of Famena* [online]. 2020, **44**(3), p. 81-92. ISSN 1333-1124, eISSN 1849-1391. Available from: https://doi.org/10.21278/TOF.44307

[17] SMILESKI, T., VRTANOSKI, G. Development of innovative brake system for rolling stock. *Mechanical Engineering Scientific Journal* [online]. 2019, **37**(1-2), p. 17-27. ISSN 1857-5293, eISSN 1857-9191. Available from: https://doi.org/10.55302/MESJ19371-2614017s

[18] GUNAY, M., ERDI KORKMAZ, M., OZMEN, R. An investigation on braking systems used in railway vehicles. *Engineering Science and Technology, an International Journal* [online]. 2020, **23**(2), p. 421-431. eISSN 2215-0986. Available from: https://doi.org/10.1016/j.jestch.2020.01.009