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Experimental studies of high-speed grinding rails modes

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ABSTRACT

Introduction. Rails' grinding in the conditions of a railway track is a priority for extending its life cycle due to the timely removal of tread surface defects and formation of required transverse profile. Today, *14 RSHP-48* rail grinding trains are used in Russia. At the same time, most rail grinding trains are ending its service life. Therefore, the development of a fundamentally new rail grinding train with increased efficiency is an urgent task. Siberian transport university is working together with the Kaluga plant "Remputmash" to create a new rail grinding train named *RSHP 2.0*. The rail grinding train *RSHP 2.0* is based on the technology of high-speed rail grinding, which is based on increasing working speed of rail grinding train by increasing rotational speed of grinding wheels and setting the angle of attack. **The aim of this work is** to study rails' grinding modes on a specially designed installation *URSH*, which implements the technology of high-speed grinding rails by increasing speed of grinding wheels rotation up to 5,000 rpm. **Research methods.** Grinding wheel speed control was carried out by *IT-5-ChM* "Termit" electronic tachometer and "*Megeon 18005*" laser tachometer. The angle of attack of grinding wheel was measured by digital, three-axis accelerometer-inclinometer *ATst 90*. The force of pressing grinding wheel to the rail was evaluated by strain-resistive sensors *M50-0.5-C3*. The measurement of head rail transverse profile before and after grinding and evaluation of metal removal were carried out by a *PR-03* rail profiler. The width of grinding track was controlled by *ShTsTs-I-300-0.01* caliper. The surface roughness of rail sample after machining was measured by *TR 200* portable instrument. **Results and discussion.** Based on research results of *CRS*, the parameters of the working equipment of designed grinding rail train, which implements the technology of high-speed rail grinding, the influence of grinding modes on the formation of the quality parameters of the machined rail surface are established, and the optimal values of the forces of pressing the grinding wheel to the rail are determined.

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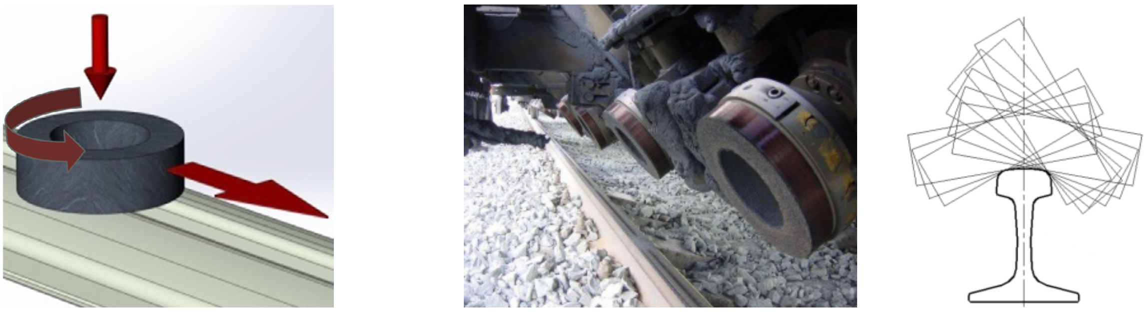
Introduction

The process of rails grinding has been actively used on the Russian railway network since the early 2,000s. The technology has proven itself to be the only one that allows extending the life cycle of the rail [1, 2]. This technology is implemented using rail grinding trains of the *RSHP-48* type, which are a complete copy of the Swiss trains of the *Speno* company (RR modifications), developed in the 1,980s of the XX century [3]. The main functions of rails grinding (fig. 1a) are the creation of the necessary rail profile to ensure the best interaction of the wheel with the rail, as well as the removal of defects that are formed on the wheel thread [4, 5, 6]. To process a complex profile of rails, grinding is performed by tilting the grinding wheels at different angles (fig. 1b).



a *b*

Fig. 1. Schematic representation of rail grinding by a rail grinding train:
a – a schematic representation of flat grinding of rails with the end of the wheel; *b* – the inclination of the grinding heads when processing the rails' profile

It should be mentioned that the rail grinding trains, which are operated on the railway network, have speed limits up to 8 km/h and the speed of grinding wheels up to 3,600 rpm [3]. With such parameters, rail grinding trains have low efficiency, which makes it necessary to close the runways for movement during the work on grinding rails, which leads to significant financial losses [7]. Thus, the issue of increasing the efficiency of rail grinding trains is extremely relevant for the development of the railway industry.

In total, 21 rail grinding trains have been manufactured in Russia for all time. Starting from 2,021, due to the technical condition of the machines and the end of its service life, the retirement of rail grinding trains from operation began. At the end of 2,022, there were 14 *RSHP-48* trains operating on the Russian railway network, which, in the context of its low efficiency, do not meet the needs of railways in rails grinding.

In view of the foregoing, the *Sinara-Transport Machines Holding*, which is the only supplier of rail grinding services for the Russian Railways company, decided in 2,021 to create a fundamentally new machine – the Rail Grinding Train *RSHP 2.0* (fig. 2).

Fig. 2. Rail grinding train *RSHP 2.0*

The operation of the new train is based on the technology of high-speed grinding of rails, which was developed at the *STU* in the late 2,000s [8] and underwent preliminary industrial testing [9]. The new technology was proposed based on the theory of cutting during abrasive processing [10–12], wherein an increase in the working speed of a rail-grinding train is impossible without a proportional increase in the speed of rotation of the grinding wheel. Otherwise, an increase in feed can lead to a significant deterioration in the quality parameters of the processed surface and a decrease in metal removal. Increased wear of the abrasive tool is also possible due to a violation of the optimal modes of its operation [13]. Thus, the following conditions were implemented in the high-speed grinding technology:

1) the first condition is that the abrasive wheel is located at an angle α to the surface of the rail being processed with the opening towards the rail grinding train movement direction ("angle of attack"). Due to this arrangement of the grinding wheel, a uniform allowance is achieved between the abrasive grains, while reducing the wear of the abrasive tool (fig. 3). The highest efficiency in the grinding of rails is achieved with the correct selection of angle α, since its value depends on the metal removal. The angle α is taken with provision for the size of the grinding wheel and the average value of the expected metal removal, and is 0.35 degrees in accordance with the calculations according to the equation:

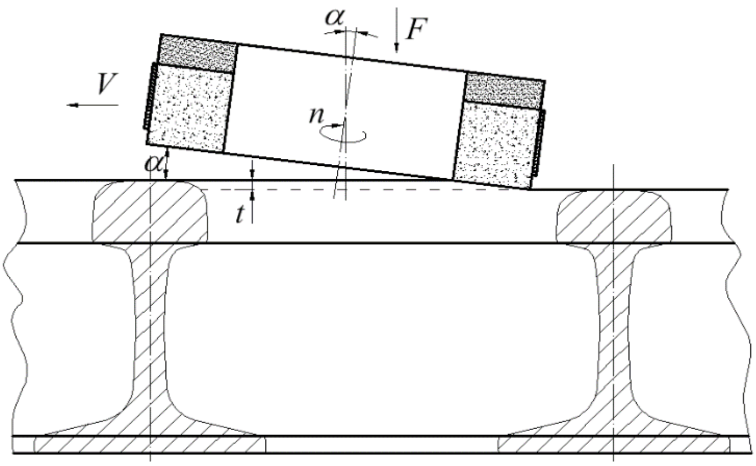


Fig. 3. Schematic representation of interaction of an abrasive tool with a rail during high-speed grinding

$$\sin\alpha = \frac{t}{(D-d)/2} = \frac{0,3}{(250-150)/2} = 0.006,$$

where t is the expected metal removal, mm (t = 0.3 mm); D is the outer diameter of the grinding wheel, mm (D = 250 mm); d is the inner diameter of the grinding wheel, mm (d = 150 mm).

2) the second condition is to increase the rotation speed of the grinding wheel. An increase in the rotation speed leads to an increase in the metal removal rate, while the cutting force decreases, at the same cutting depth. It has been previously established that increasing the rotation speed of the grinding wheel to 5,000 rpm will increase the working speed of the rail grinding train to 15 km/h without reducing metal removal [9].

The practical application of the adopted technological solutions requires the development of grinding modes, which should form the basis for the design of new working equipment for a rail grinding train.

Setting research objectives

Currently, the *Kaluga Remputmash*, together with the *Siberian Transport University*, is conducting design work on a new rail grinding train. Within the framework of the technical project, the corresponding characteristics of all control systems for the rail grinding process are laid down, which depend on the implemented operating modes of the rail grinding train.

The operation of rail grinding trains is characterized by fundamental differences from grinding on machines in stationary conditions [14]. Grinding of rails is carried out due to the force closure of the kinematic pair "abrasive wheel – surface being processed" (fig. 4). Each individual grinding wheel is pressed against the rail head by a pneumatic cylinder through a drive motor mounted on a motor plate. The axes of rotation of the parallelogram suspension are fixed on the end plate of the block of the grinding trolley. This design ensures a constant perpendicularity to the axis of rotation of the circle relative to the longitudinal axis of the rail.

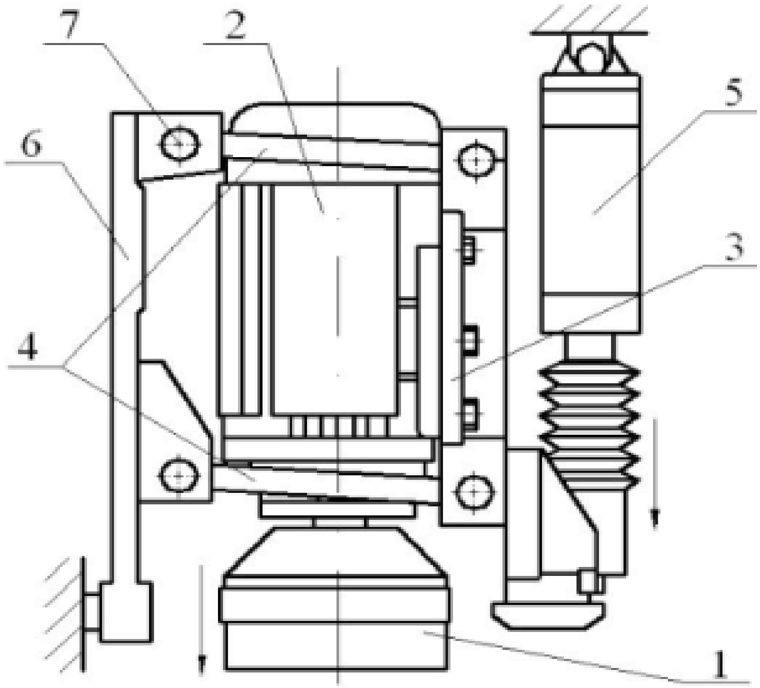


Fig. 4. Grinding head attachment pattern:

1 – abrasive wheel; *2* – electric motor; *3* – under-engine plate; *4* – parallelogram suspension; *5* – pneumatic cylinder; *6* – block plate; *7* – axis

In this case, the force of pressing the grinding wheel to the rail is determined by the pressure in the pneumatic cylinder, which is automatically adjusted depending on the current load on the windings of the electric motor in accordance with the schematic pattern shown in fig. 5.

The specified feature of the rail grinding process does not allow implementing the cutting depth accurately, since metal removal will occur spontaneously depending on a number of factors, and with a high probability will differ from the specified value. Accordingly, the rail profile forming accuracy will

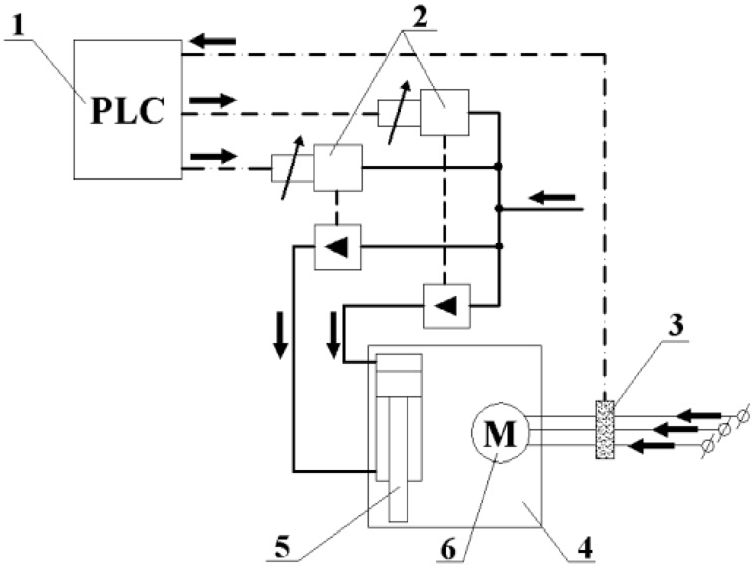


Fig. 5. The pressing force of grinding wheel common control circuit:

1 – grinding modes control unit; *2* – proportional valve; *3* – converter of the adjusting block; *4* – grinding block; *5* – pneumatic cylinder; *6* – grinding wheel drive motor be violated [15, 16], the working conditions of the abrasive tool [17, 18] and the formation of the quality of the treated surface will be changed. In order to minimize deviations of the actual metal removal from the specified (assumed) one, for which the appropriate cutting speed and feed are specified, it is required to obtain empirical dependencies of the entire technological system, which will allow further design of technological processes for grinding rails for various conditions.

In view of the foregoing, the main **purpose of the research** was determination of the optimal modes of rails grinding in the implementation of high-speed grinding technology, providing maximum machining performance with the formation of the specified parameters of the quality of the rail head surface being processed and determination of the main parameters of the technological equipment *RSHP 2.0* specific to these modes, such as pressure in the pneumatic system pressing the grinding wheel to the rail and the current load of grinding motors.

To achieve this goal, the following **tasks** were solved:

determination of the parameters of the pneumatic system, providing the required forces of pressing the grinding wheel to the rail;

determination of the dependence of the current load in the windings of the electric motor on the force of pressing the grinding wheel to the rail;

determination of the rated current load of the electric motor to the specified average values of the grinding wheel pressing force against the rail;

assessment of metal removal and roughness of the processed surface in various grinding modes.

Research methodology

Currently, there are a number of test benches [19, 20] on which it is possible to implement research program tests of rail grinding technology. At the same time, it should be noted that all the installations available today are limited to the standard operating modes of existing rail grinding trains and do not allow it to be changed in a sufficiently wide range.

In order to fulfill the tasks of studying the technology of rails high-speed grinding, a special rail grinding unit – *URSH* – was developed and manufactured.

The *URSH* consists of a separate section of track with a length of 100 m, a standard gauge of 1,520 mm (fig. 6a), on which a rail grinding trolley moves (fig. 6b). The trolley is driven by a winch-type drive containing a motor, a transmission (clutch, brake, single-stage gearbox) and a drum with a single-layer winding (fig. 6b). As an energy source, a diesel generator set (hereinafter referred to as a *DGS*) with a capacity of 200 kW is used (fig. 6d). The operation of the *URSH* in test mode is automatic, controlled by a control system from a personal computer.

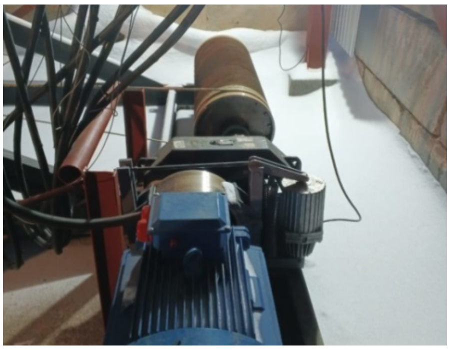
Standard rails *P50*, *P65*, *P75* are used for grinding, which are installed along the axis of the track. In this case, the level of the head of the working rail (test sample) coincides with the level of the rail head of the standard track. The rail is fixed on special brackets, with the possibility of its quick change and the ability to install a working rail with imitation of various defects of the real path. Fig. 7 shows a diagram of the attachment point of the working rail to the standard track.

The rail grinding trolley is a non-self-propelled structure on wheels (fig. 8a), for moving along a standard gauge rail track. The trolley consists of a main frame, a frame of transverse displacement, a frame of transverse inclination. A mobile compressor station is located on the main frame to power the pneumatic cylinder pressing the grinding wheel to the working rail. A grinding head control system is implemented on the grinding trolley as on a rail grinding train, in accordance with the patterns in figs. 4–5 (fig. 8b).

A transverse tilt frame with a mechanism mounted on it allows for the possibility of tilting the frame of the grinding unit (electric motor with a circle) in the range from +70° to –20° in accordance with the pattern (fig. 1b). The tilt is carried out using a stepper motor and a screw-nut transmission, the accuracy of setting the required angle is ± 0.5°, which is provided by the kinematics of the transmission itself.

a

b



c

d

Fig. 6. General view of the *URSH*:
a – section of the railway track; *b* – rail grinding trolley; *c* – drive; *d* – *DGS*

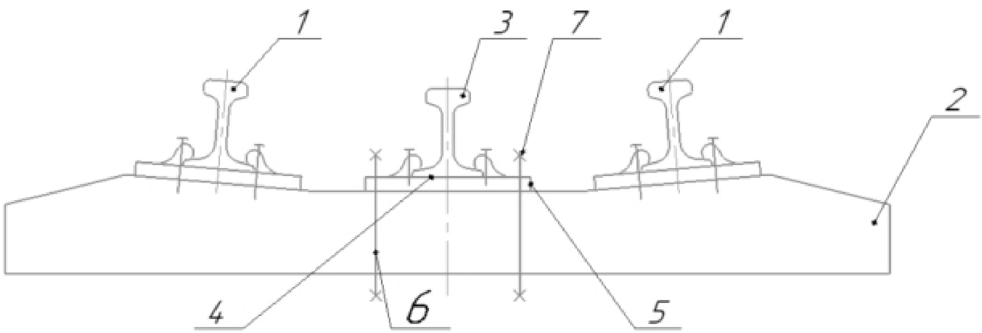


Fig. 7. Mounting unit of the working rail:
1 – rail for moving the sanding trolley; *2* – sleeper; *3* – test sample (working rail);
4 – spacer; *5* – lining; *6* – mounting studs; *7* – nut

As the drive of the grinding wheel, a standard *RSHP* electric motor is used, upgraded to be able to realize the shaft rotation speed of 5,000 min^{-1} with the torque on the shaft of the electric motor necessary to ensure the operation of the grinding wheel. The modernization was as follows:

1) increasing the nominal rotation speed of rolling bearings from 4,000 min^{-1} to 6,700 min^{-1} by replacing the rolling bearing brand;

2) changing the stator winding circuit from Δ (440 V, 60 Hz) to *Y* (380 V, 50 Hz) for connecting the stator windings to Δ to provide increased power on the motor shaft. The actual, calculated technical characteristics of the modernized grinding motors are presented in Table 1.

The frame of the grinding block is mounted on axle in a movable frame of transverse displacement. A lever mechanism with a pneumatic drive is located in the frame, which provides pressing of the grinding wheel with the required force up to 3 kN. Also, this mechanism allows setting the angle of attack of the grinding wheel equal to 0.35°.

a

b

Fig. 8. Rail grinding trolley device:

a – grinding trolley with transverse displacement frame; *b* – a grinding cradle with an installed grinding head and the possibility of transverse inclination

Table 1

Technical characteristics of modernized electric motors

Switching scheme	Mode	Current frequency, Hz	Voltage, V	Current, A	Rotation speed, min^{-1}	Shaft torque, N·m	Power, kW
Δ	Idling	85	254	24	5100	0	0
	Nominal mode	85	254	45	5029	49.8	26.2
	Increase of the torque by 1.15 times from the nominal	85	254	56	5019	57.3	30.1
	Increase of the torque by 1.5 times from the nominal	85	254	66	4994	74.7	39.1
	Increase of the torque by 1.63 times from the nominal	85	254	70	4985	81.2	42.4
	Increase of the torque by 2 times from the nominal	85	254	80	4958	99.6	51.7

Pressing the grinding wheel to the rail surface being processed is carried out on the basis of the pressure difference in the rod and piston cavities of the pneumatic cylinder. Pressure adjustment in the cavities of the pneumatic cylinder is carried out by a proportional pressure regulator based on data on the current load in the windings of the grinding motor.

In accordance with the previously established characteristics of the technological process of high-speed grinding of rails, the URSH has the following technical characteristics:

– the range of rotation speed of the grinding wheel is 3,600–5,000 rpm;

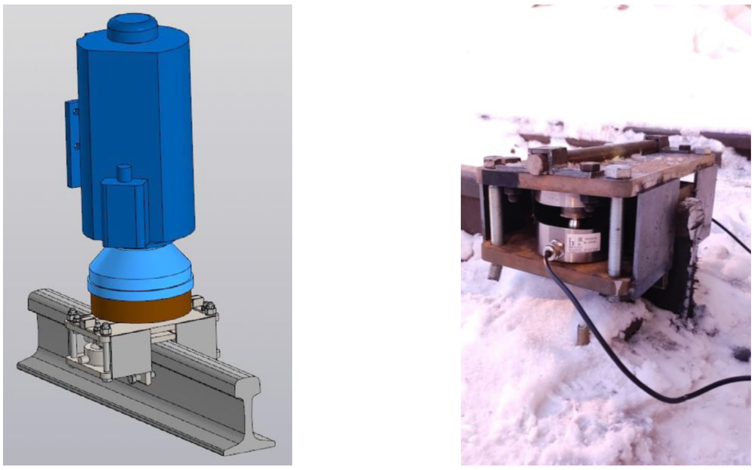
– the range of change in the trolley movement speed is 4–30 km/h;

– the range of the angle of inclination of the grinding motor from + 20° to – 60° from the vertical;

– the angle of attack of the grinding wheel is 0.35° and is provided with the opening to meet the working movement of the trolley;

– the range of change in the pressing force of the grinding wheel to the rail is 0–5 kN without taking into account the mass of the grinding motor.

URSH is equipped with a special device for the pressing force calibration (fig. 9). The device allows determining the actual force of pressing the grinding wheel to the rail (in Newtons) depending on the current load in the windings of the electric motor. This dependence is further used to determine the actual cutting forces during operation based on the values of the current loads of the electric motor. The force of pressing the grinding wheel to the rail is measured by means of two force sensors.



a *b*

Fig. 9. Device for calibrating the pressing force of grinding wheel to rail:

a – 3D-model of the device; *b* – general view of the device

Taking into account the requirements for high-speed grinding wheels [21], research on the technology of high-speed rails grinding was carried out using grinding wheels "*Machaon*", designed for a maximum grinding speed of 75 m/s (5,000 rpm). The tests were carried out with a grinding wheel angle of attack of 0.35°, at rotation speeds of 5,000 rpm. The roughness of the processed surface was estimated by the parameter *Ra*.

During the research, the following measuring instruments were used: the control of the rotation speed of the grinding wheel during the grinding process was carried out by an electronic tachometer *IT-5-FM* "*Termit*" and a laser tachometer "*Megeon 18005*"; the installation of the transverse angles of inclination of the grinding motor and the angle of attack of the grinding wheel was carried out in accordance with measurements by a digital, three-axis accelerometer-inclinometer *ATST 90*, the pressing force was determined using a strain gauge sensor *M50-0.5-S3*, and the corresponding pressure in the pneumatic system was controlled using pressure converters *ARIES PD100I-DI1,6-111-0,5*; a rail profiler *PR-03* was used to measure the transverse profile of the rail head before and after grinding and to assess the metal removal after processing; the width of the grinding track was monitored with a caliper *SHCC-I-300-0.01*; the surface roughness of the rail sample after processing was measured with a portable *TR200* device.

Results and its discussion

Before conducting the research, the electric drive of the grinding head was adjusted, during which the dependence of the current load in the windings of the electric motor on the force of pressing the grinding wheel to the rail was established.

The dependence of the power parameters on the pressure in the pneumatic system of pressing the grinding wheel to the rail was established to determine the parameters of the pneumatic system that provide the required force of pressing the grinding wheel to the rail and to assess its effect on the operating modes of the high-speed electric drive (fig. 10).

It can be seen from the graph (fig. 10) that the greater the pressure in the pneumatic system, the greater the force pressing the grinding wheel to the rail. At the same time, it was found that the nominal pressing

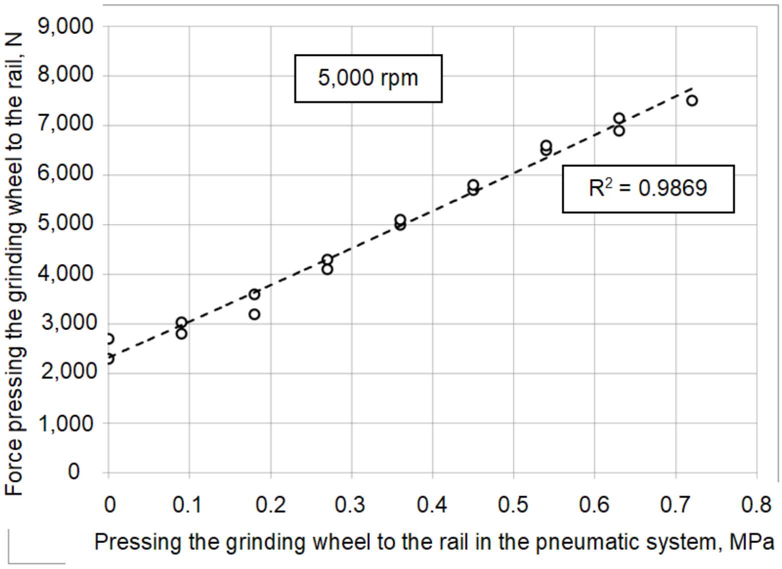


Fig. 10. Dependence of the pressing force of grinding wheel to rail on pressure in the pneumatic pressing system

force is realized at a pressure in the pneumatic system up to 0.2 MPa, regardless of the rotation speed of the grinding wheel.

According to the test results, the dependence of the change in the current load in the stator windings of the electric motor on the pressing force was obtained. Graphically, the dependence is shown in fig. 11.

The graph shows that the change in the current load in the stator windings of the electric motor has a linear dependence on the forces arising during grinding. At the same time, it is established that for the tested electric drive, to ensure the design range of the rated current load of 45 A (Table 1), it is required to ensure the pressing force of the grinding wheel to the rail in the range of 2,500–2,800 N.

The obtained dependences make it possible to adjust the force of pressing the grinding wheel to the rail and ensure the nominal operating modes of the high-speed grinding electric drive.

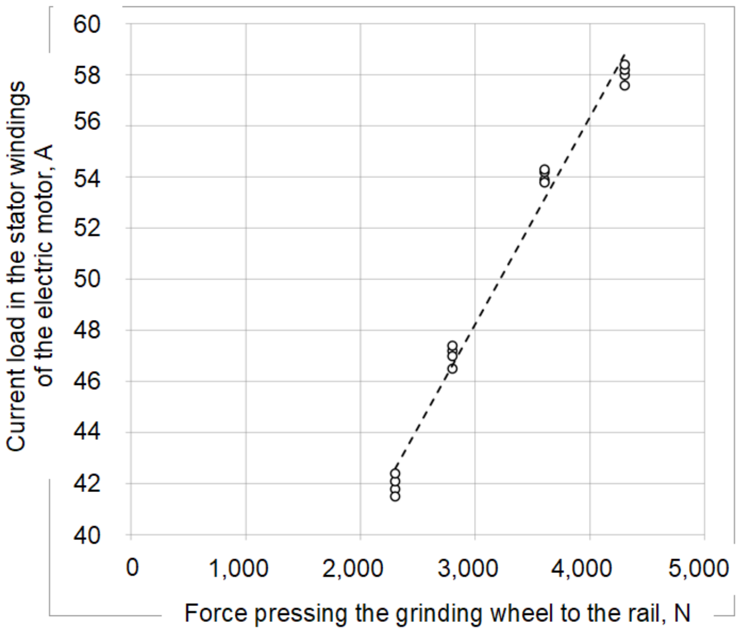


Fig. 11. Dependence of current load change in the stator windings of the electric motor on the force of pressing the grinding wheel to rail

To ensure the required modes of high-speed grinding of rails, the force of pressing can vary in the range 0.8–1.2 of the nominal value of the current load (45 A). That is, the technological modes of operation of the high-speed electric drive for current load range 37–53 A, which corresponds to the range of forces pressing the grinding wheel to the rail 2,200–3,100 N.

The test results of the high-speed rail grinding technology are presented in Table 2. Graphically, the test results are presented in figs. 12–15.

Table 2

Test results of high-speed rail grinding technology

Passage No.	The speed of the grinding trolley movement, km/h	Speed of the grinding wheel rotation, min^{-1}	Angle of transverse inclination of the grinding motor, degree	The pressing force of the grinding wheel on the current load, A	The actual pressing force of the grinding wheel, N	Metal removal, mm	Average metal removal, mm	Roughness of the processed surface, μm	The presence of cauterization (+/–)
1	10	5,000	–60	51	2,706	0.41	0,37	5.8	+
2		5,000	–40	51	2,704	0.4		5.4	+
3		5,000	–20	53	2,785	0.37		4.5	+
4		5,000	0	55	2,827	0.35		4.4	–
5		5,000	10	55	2,835	0.34		4.8	–
6		5,000	20	53	2,788	0.32		4.6	–
7	15	5,000	–60	51	2,712	0.49	0,28	6.2	+
8		5,000	–40	51	2,710	0.36		5.5	+
9		5,000	–20	53	2,786	0.25		4.6	–
10		5,000	0	55	2,832	0.19		3.2	–
11		5,000	10	55	2,836	0.21		3.8	–
12		5,000	20	53	2,790	0.20		4.8	–
13	20	5,000	–60	51	2,706	0.33	0,20	6.6	–
14		5,000	–40	51	2,704	0.28		5.8	–
15		5,000	–20	53	2,785	0.22		4.5	–
16		5,000	0	55	2,827	0.18		3.1	–
17		5,000	10	55	2,835	0.09		4.2	–
18		5,000	20	53	2,788	0.12		5.1	–
25	30	5,000	–60	51	2701	0.21	0,11	7.1	–
26		5,000	–40	51	2,698	0.19		5.7	–
27		5,000	–20	53	2,783	0.11		4.9	–
28		5,000	0	55	2,819	0.05		3.6	–
29		5,000	10	55	2,821	0.07		5.0	–
30		5,000	20	53	2785	0.03		5.3	–

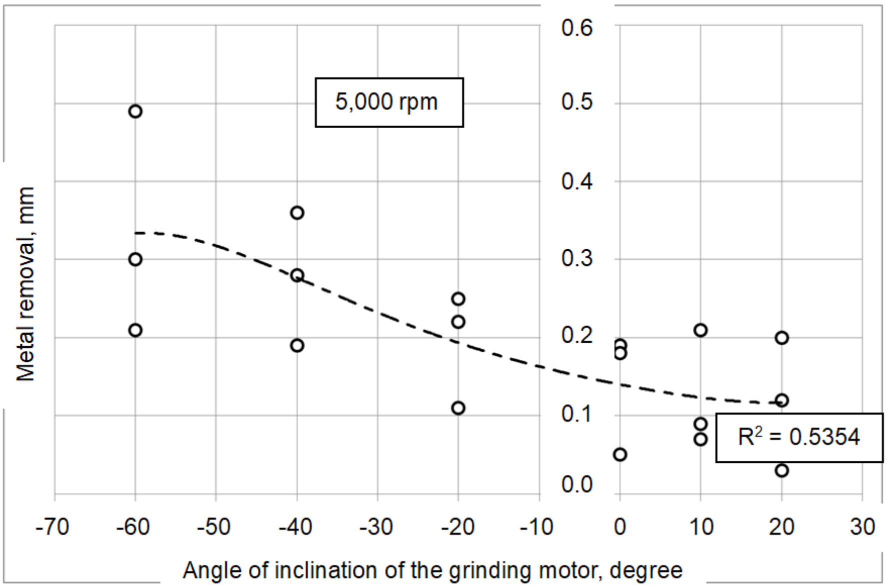


Fig. 12. Removal of metal at the angles of inclination of grinding motor

It can be seen from the graph (fig. 12) that the maximum metal removal is achieved at the maximum angles of inclination of the grinding head, where the width of the grinding track is minimal.

The effect of the longitudinal feed of the grinding wheel (the speed of movement of the grinding trolley) on the metal removal can be seen in fig. 13. With an increase in the longitudinal feed, the difference in the values of metal removal increases, which can be seen on the graph. For a grinding wheel rotation speed of 5,000 rpm, the speed of grinding trolley movement equal to 15 km/h is maximal, after which, with an increase in the longitudinal feed, a decrease in metal removal begins. Also it can be seen from the graph (fig. 13) that at 5,000 rpm, it is possible to achieve the target for metal removal of 0.2 mm at speeds of *RSHP* not exceeding 20 km/h. Approximating the data obtained by the average values of metal removal, we can make a conclusion about the possible modes of operation of the *RSHP* at high-speed grinding according to the performance criterion: 5,000 rpm – 15 km/h; 6,000 rpm – 20 km/h; 6,500 rpm – 25 km/h and 7,000 rpm – 30 km/h.

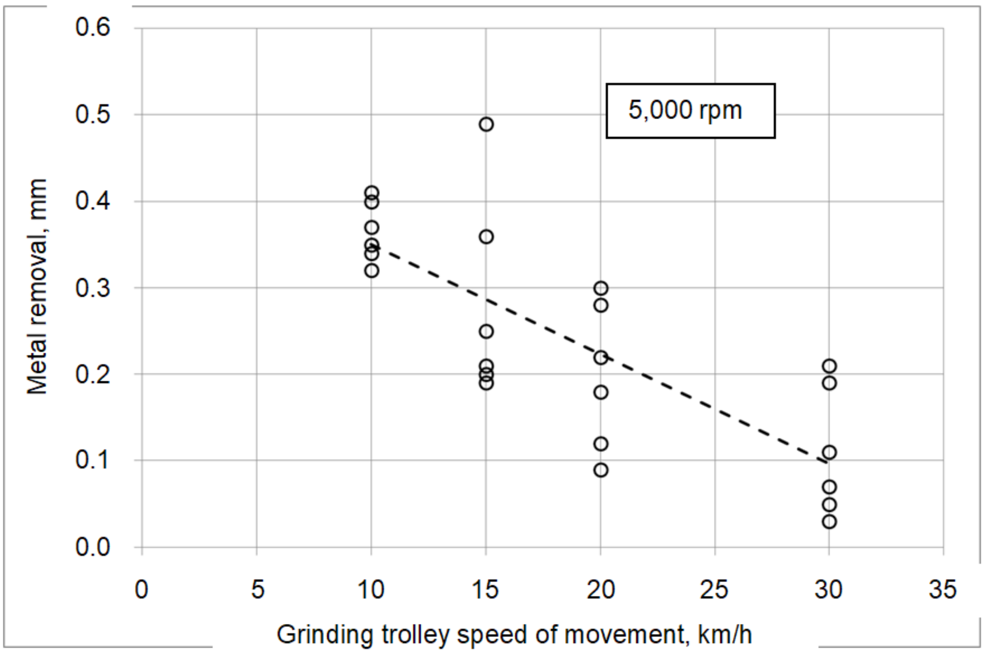


Fig. 13. Dependence of metal removal on grinding modes

These values are valid for nominal values of the grinding wheel pressing force for the range of current loads in the motor windings 37–53 A. In the future, when testing prototypes of industrial electric motors, these dependencies need to be clarified.

Evaluation of the quality of the polished surface by the roughness parameter (fig. 14) showed that the nature of the curve is similar to the dependence of the metal removal at the angles of inclination of the grinding motor (fig. 12). This is natural because the greater the angle of inclination of the grinding motor, the smaller the width of the grinding track, and the specific load on a single grain is greater. As a consequence, the introduction of abrasive grains into the surface being processed is greater, which gives greater metal removal and, accordingly, surface roughness.

The effect of the speed of grinding trolley movement on the formed surface roughness can be seen in the graph shown in fig. 15: with an increase in the working speed of movement, the surface roughness increases. This is also due to the influence of the number of abrasive grains passing through the elementary surface of the rail being processed. The higher the speed, the fewer such abrasive grains will be and, consequently, the roughness will be greater. In addition, it should be noted that in all ranges of grinding modes used in the tests, the roughness of the formed surface did not exceed the values established by the regulatory documentation for *Ra* – 6 μm.

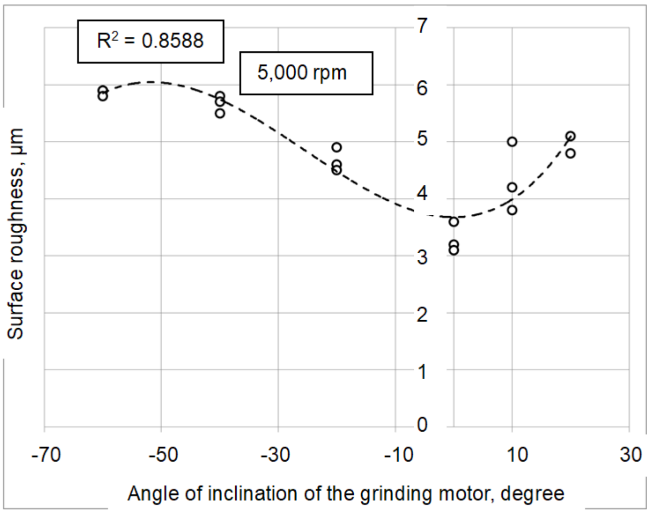


Fig. 14. Surface roughness at the angles of inclination of grinding motor

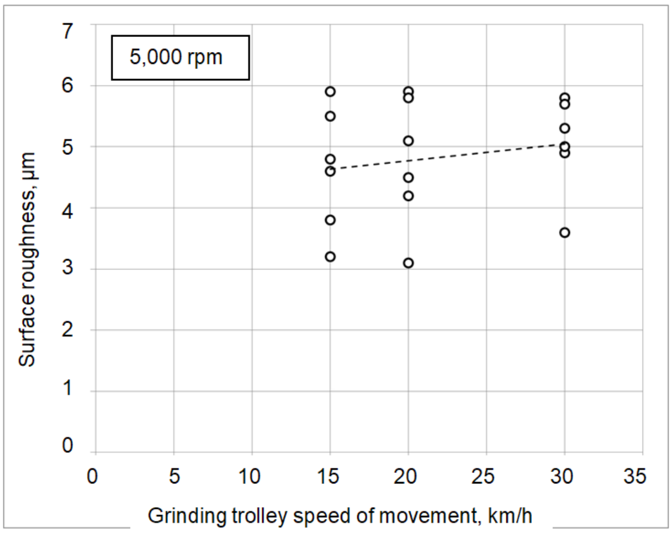


Fig. 15. Dependence of roughness of the machined surface on grinding modes

Also in the tests, the presence of cauterization on the polished surface was visually assessed. The passages after which the cauterization is fixed are marked with a “+” sign in the corresponding column of Table 3. According to the marked passages, it can be established that the occurrence of cauterization occurs when the maximum loads that occur during grinding are exceeded. This is typical for metal removal exceeding 0.35 mm.

Conclusions

According to the test results, the following parameters of the working equipment of the rail grinding train being designed, implementing the technology of high-speed rail grinding, are established:

1. The pneumatic system of the rail grinding train should implement a pressing pressure in the range of 0.8–1 atm per grinding head to ensure the necessary pressing force of the grinding wheel to the rail 2,800–2,900 N.

2. The range of current loads during operation of the electric drive of the grinding head is 37–53 A. Taking into account the long-term operation of the electric drive, the parameters of the diesel generator set,

the cooling system of electric motors and the wiring should be designed for a maximum current load with a 1.5-fold factor, i.e. 80 A.

3. When manufacturing and testing an abrasive tool for the implementation of high-speed rail grinding technology, possible dynamic shock loads of up to 3,500 N. should be taken into account.

Experimentally determined parameters will make it possible to make an appropriate choice of components for the control systems of the rail grinding drive and working equipment.

The results of research on the technology of high-speed grinding of rails allow us to draw the following conclusions:

1. The tests carried out confirmed the fulfillment of the requirements of the technical specification for the rail grinding train *RSHP 2.0* in terms of efficiency. The average thickness of the rail metal layer removing in one pass at maximum grinding power should be:

- 0.3 mm at an operating speed of 10 km/h;
- 0.2 mm at the operating speed of the *RSHP* – 15 km/h.

2. The possible range of the formed roughness of the processed surface of the rails is determined depending on the grinding modes and the angle of inclination of the grinding head. The possible values of the formed roughness according to *Ra* are 3.1–5.9 µm, which meets the requirements of the regulatory documentation on the maintenance of rails.

3. The permissible values of grinding modes are determined, taking into account the exclusion of the occurrence of cauterization on the processed surface of the rail. The presence of cauterization is typical when removing metal with a thickness of more than 0.35 mm, at speeds of movement of the grinding trolley up to 15 km/h.

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Conflicts of Interest

The authors declare no conflict of interest.