New working equipment of PXP 2.0 high-performance railway train

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Abstract. The article presents design and technical solutions for the new working equipment of the high-performance rail grinding train PXP 2.0 for the implementation of high-speed rail grinding technology in railway conditions. A description of the design of grinding carts is given, including the drive of the grinding wheels and the mechanism for setting the angle of attack of the grinding wheel. In addition, the article discusses the conditions for moving working equipment along a rail track at high speeds. The presented solutions make it possible to carry out rail grinding work at speeds of up to 30 km/h without reducing the amount of metal removal, which ensures an increase in work productivity by more than 3 times compared to existing analogues of rail grinding trains.

1 Introduction

The rail grinding process is actively used on the railway network in order to extend the service life of rails [1, 2]. The implementation of this technology is carried out using rail grinding trains of the PXP-48 type, which allow processing of rails directly on the road, without dismantling the rails [3]. The processing is carried out by flat grinding with the end of an abrasive wheel (Fig. 1, a) and allows not only to eliminate wave-like irregularities, mechanical damage, crumpling and peeling of metal on the rail head, but also to form the required transverse profile of the rail head to ensure the best interaction with the wheel [4, 5, 6]. This is ensured by removing metal by grinding wheels located at different angles relative to the vertical axis of the rail (Fig. 1, b).

The rail grinding trains used today do not meet modern productivity requirements, since they operate at speeds from 4 to 8 km/h. In this case, the rotation speed of the grinding wheel is constant and amounts to 3600 rpm. Depending on the force of pressing the grinding wheel against the rail, the average metal removal ranges from 0.05 to 0.3 mm per pass [3]. Low-productivity processing modes require the organization of technological windows, since the operating speed of rail grinding trains does not allow work to be carried out within the schedule of passenger and freight trains, which leads to the need to close entire sections to traffic. In this regard, large financial costs arise due to a decrease in the capacity of sections of the railway track and train delays [7, 8]. Thus, the issue of increasing the productivity of rail grinding trains is extremely relevant for the track facilities of the railway industry.

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Fig. 1. Scheme of grinding rails with a rail grinding train: a – scheme of flat grinding of rails with the end of a wheel; b – tilt of the grinding heads when processing the rail profile.

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Based on the above, the Sinara-Transport Machines holding company decided in 2021 to create a fundamentally new machine - the "Rail Grinding Train PXP 2.0" (Fig. 2), characterized by more than three times increased productivity compared to existing analogues.

Fig. 2. PXP 2.0 rail grinding train.

The operation of the new rail grinding train is based on the technology of high-speed rail grinding, which was developed at SGUPS and has undergone preliminary industrial testing [9]. Two principles were implemented in the high-speed rail grinding technology:

1) The use of a new scheme for the interaction of the grinding wheel with the rail (Fig. 3), according to which the abrasive wheel is installed at an angle $\alpha$ to the surface of the rail
being processed with an opening towards the direction of movement of the rail grinding train (angle of attack). This arrangement of the grinding wheel allows the allowance to be evenly distributed between the largest number of abrasive grains, which reduces tool wear and the level of shock loads arising from the unevenness of the rail surface being processed.

![Diagram](https://example.com/diagram.png)

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

2) Increasing the rotation speed of the grinding wheel, which allows you to increase the metal removal rate and lead to a proportional decrease in cutting forces, with the same metal removal. It has been previously established that increasing the rotation speed of the grinding wheel to 5000 rpm will increase the operating speed of the rail grinding train to 15 km/h, and to 30 km/h at 7000 rpm without reducing metal removal [9].

The practical application of the adopted technological solutions requires the creation of new working equipment for the rail grinding train.

### 2 Problem statement

Currently, the Kaluga plant “Remputmash”, together with the Siberian State University of Transport, is developing a new rail grinding train. As part of the research and development work, the implementation of new PXP 2.0 work equipment is required. The equipment must be able to carry out rail grinding work at a rail grinding train speed of 1 to 30 km/h. At the same time, based on the required and experimentally confirmed grinding modes [9, 10], the following technical parameters must be provided for new grinding carts:

- Raising and lowering of working equipment when transferring it from transport to working position must be carried out by hydraulic cylinders. In this case, the lowering/raising time of the grinding cart should be no more than 5 seconds.
- The accuracy of processing the transverse profile of the rail head using new working equipment should be ± 0.3 mm.
- The working equipment must allow the angle of attack of the grinding wheel to be set and changed depending on the direction of movement of the rail grinding train.
- The design of the working equipment must ensure a minimum radius of traversable curved sections of the railway track in operating mode of 200 m.
- The rotation speed and pressing force of the grinding wheels must be adjustable and depend on the grinding modes.
- After installation on the rail grinding train in transport mode, the working equipment...
should not extend beyond the 1T railway clearance.
- The weight of the sanding trolley should not exceed 5.5 tons.
- The thickness of the removal of the metal layer of the rail in one pass, depending on the speed of the train, should be at 10 km/h - at least 0.3 mm, at 15-30 km/h - at least 0.2 mm.

In addition to the specified technical requirements, the design of the grinding cart must be of a closed type to enable the implementation of an aspiration and dust absorption system and removal of combustion products during abrasive processing.

3 Results and discussion

The working equipment of the PXP 2.0 rail grinding train includes six grinding carts, two for profiling at the beginning and end of the train and four for smoothing in the middle; this arrangement allows the PXP to work in both one and the other direction equally effectively. A general view of the grinding cart is shown in Figure 4.

![Fig. 4. General view of the sanding trolley.](image)

Smoothing carts are designed primarily for the operation of grinding wheels on the rolling surface of the rail, as a result of which the transverse angles of inclination of the grinding heads in carts of this type are ± 20 degrees. In profiling carts, the grinding heads can have a transverse inclination from 0 to -70 degrees and their task is to process the working fillet of the rail. Each sanding trolley includes 8 sanding heads, 4 for each rail. To ensure transverse inclination of the grinding heads, they are installed in separate blocks - grinding cradles, which are mounted on rotary axes.

There are four cradles installed in the profiling cart (Fig. 5, a), each cradle has two grinding heads. The smoothing cart contains two grinding cradles (Fig. 5, b), each including 4 grinding heads. Each cradle can rotate independently of the others to an individual value of the transverse angle of inclination (Fig. 6).

![Fig. 5. Grinding cradles of PXP 2.0 working equipment: a – cradle of the profiling trolley; b – cradle of the smoothing trolley.](image)
Each sanding cart, regardless of type, is equipped with:

- Pneumatic cylinders for raising and lowering grinding electric motors, as well as for pressing the grinding wheel against the rail;
- Hydraulic cylinders for tilting the grinding cradles in the transverse direction (Fig. 6);
- Mechanism for setting the angle of attack, installed on one pair of motors, providing longitudinal inclination of the grinding electric motors in the range of ±0.35°;
- Pneumatic system for removal of grinding products. This system must be integrated into the PXP 2.0 aspiration system and must remove at least 85% of grinding products;
- A spark extinguishing system, which is a movable protective screen with a pneumatic drive, which, when lowered, protects the external space relative to the trolley from sparks and possible fragments of the grinding wheel if it ruptures;
- A limiting device that prevents contact of the faceplate with the rail in the event of extreme wear of the grinding wheels.

![Fig. 6. Transverse inclination of PXP 2.0 sanding cradles.](image)

### 3.1 Grinding head of working equipment

The grinding head of the working equipment of the PXP 2.0 rail grinding train consists of an electric motor with a faceplate mounted on its shaft, into which the grinding wheel is fixed.

The grinding wheel is driven by a high-speed asynchronous electric motor with permanent magnet excitation, which is controlled by a frequency converter. As a whole, the new electric drive has the following characteristics:

- Electric motor rotor speed – 5000…7000 rpm;
- Rated power on the electric motor rotor – 46.5 kW;
- Nominal operating mode of the electric motor according to GOST R 52776 ~ S1;
- Electric motor efficiency in nominal mode is at least 95%;

The lifting and releasing of the grinding electric motor is carried out using a pneumatic cylinder. To ensure verticality when raising and lowering the electric motor, it is installed in a lever mechanism made according to the parallelogram principle (Fig. 7). The mechanism performs the function of pressing the grinding electric motors and lifting them into the transport position. The mechanism is driven by a pneumatic cylinder, the body of which is fixed by means of a hinge to the cradle frame, and the rod is fixed to the sub-motor frame. To ensure protection against contact of the faceplate with the rail, a mechanical stop is provided on the submotor frame. To automatically control the stopping of the pneumatic cylinder, inductive sensors are provided that turn off the drive when lifting and lowering in the required positions.
3.2 Mechanism for setting the angle of attack of the grinding wheel

To set the angle of attack of the grinding wheel in accordance with the high-speed rail grinding technology, the grinding electric motors must be tilted at an angle of 0.35° on both sides of the vertical, depending on the direction of movement of the PXP 2.0. This tilt is carried out due to the eccentric shaft (Fig. 8), which allows you to change the upper arm of the parallelogram mechanism for raising and lowering the grinding electric motor. The eccentric shaft is driven by a mechanical, screw, self-braking transmission (actuator).

The mechanism is a lever system with a self-braking electric drive (actuator). In Fig. Figure 8 shows the mechanism installed on the cradle. For both types of cradles, the mechanism has the same design and is interchangeable. A special feature of the mechanism is the presence of two degrees of mobility and the asymmetry of the operation of both parts of the mechanism. The principle of operation of the mechanism is as follows. When actuator 3 is turned on to extend (retract) the rod, it displaces the longitudinal rod of mechanism 1, which at its ends is connected to eccentric levers 2 and 4. The rod itself moves in the longitudinal direction relative to the cradle frame and, through a hinge joint, turns the eccentric levers to a certain angle.

When turning the eccentric levers, the size of the upper arm of the lever mechanism for raising/lowering electric motors changes. In this case, one shoulder increases, the second
3.3 Calculation of the fit of grinding carts into curved sections of the path

Of particular importance is the process of moving grinding carts in curved sections of the railway track. According to technical requirements, the minimum radius of curves that the grinding cart must pass in operating mode is 200 meters. In this case, all requirements relating to rolling stock when passing curves must be met, and technological requirements are also added - that is, that all grinding wheels have contact with the processed surface of the rail head when passing curved sections of the railway track.

Calculations were performed based on well-known methods of dynamic fitting into curves and stability of track machines. It is known that when moving in a curve under the influence of horizontal forces (wind, centrifugal force, horizontal component of weight, etc.), the wheel flanges are pressed against the rails. When the ridge hits the rail, a reaction called a guiding shear force occurs, which turns the cart. The biaxial bogie rotates under the action of a guiding force from the outer rail to the front wheel pair, and the flange of the rear wheel does not exert lateral pressure on the inner rail thread. In this connection, we consider the movement of the cart as complex, consisting of a translational motion tangential to the axis of the path and a rotational rotation around the pole. Figure 9 shows a calculation diagram of the process of fitting into the curve.

![Fig. 9. Scheme for calculating forces when passing curves.](image)

The forces acting on the cart are determined by the following dependencies:
- Cart weight, $G_r$, H:
  \[ G_r = \rho \times g \]  
  \[ (1) \]
- Trolley weight per wheel, H:
  \[ G_{tk} = \frac{G_r}{4} \]  
  \[ (2) \]
- Wind force directed from the center of rotation, H:
  \[ F_{bet} = S_k \times p \]  
  \[ (3) \]
  where $S_k$ - side area, m$^2$ (3 m$^2$); $p$ - pressure of 500 Pa
- Centrifugal force $F_c$, H:
  \[ F_c = \frac{m \times v^2}{R} \]  
  \[ (4) \]
  $V$ - curve speed, m/s; $R$ - curve radius, m; $m$ - cart mass, kg.

The force generated by the operation of the grinding wheels and their pressing against the rail head:

\[ F_{p0} = \frac{4 \times F_{pr}}{\cos(\alpha)} \]  
\[ (5) \]

$F_{pr}$ - pressing force of the grinding wheel against the rail, H; $\alpha$ - maximum angle of inclination of sanding cradles ($\alpha = 70^\circ$)

Friction force on a cart wheel, H:
Total force acting on the cart wheel, \( H \):
\[
\sum F = F + F + F + F
\]

Figure 10 shows a design diagram for the condition that the trolley does not derail.

The plane of running of the trolley on the rail

\( \mu \) - coefficient of friction in the contact zone

\( \beta \) - The outer front wheel of the trolley when moving in a curve

The position of the trolley in the curve

The elevation of the outer rail is 150mm

\( F_{TPK} = \mu \times G_{TK} \)

**Fig. 10.** Calculation scheme for the condition of non-derailment.

The forces \( P_1 \) and \( P_2 \) are vertical, pressing the cart to the rail, the force \( Y_p \) is lateral, tending to move the cart off the rail. The stability condition is as follows:

\[
\frac{\tan(\beta) - \mu}{1 + \mu \times \tan(\beta)} \geq \frac{Y_p + G_{TK} \times \mu}{G_{TK}}
\]

The recommended value of the stability coefficient \( K_y = 1.5 \).

The results of calculations using formulas 1-6 are presented on the graph of the values of the stability coefficient for various values of the influencing parameters (Fig. 11).
Fig. 11. Dependence of the stability coefficient of the trolley at an angle of inclination of the approach plane of 70º.

Based on the data presented in the graph, the following conclusions can be drawn:

1. When passing curves in the most unfavorable design conditions, the trolley tends to derail at speeds
   - at R=200m from 20km/h,
   - at R=380m from 30km/h.
2. Of significant importance is such a parameter as the angle of inclination of the approach plane, which has an unpredictable value that depends on many parameters. Based on the above, it is recommended to reduce the working speed to the following values: at $R=120$ m, speed no more than 20 km/h (at $\alpha=70^\circ$, $K_r=1.5$).

4 Conclusion

Based on the results of research and development work, a design of a grinding cart has been developed that allows rail grinding to be carried out at speeds of up to 30 km/h. At the same time, the implementation of rail grinding technology is ensured through the following technical solutions:

- Possibility of ensuring the rotation speed of grinding wheels in the range of 5000...7000 rpm and its change depending on the speed of movement of the rail grinding train. This is achieved through a new high-speed electric drive controlled by a frequency converter. The increased speed of the abrasive tool allows you to increase the operating speed of the rail grinding train without reducing metal removal.

- The design of the grinding cart makes it possible to set the angle of attack of the grinding wheel due to a mechanism that allows the electric motor to be tilted in both directions from the vertical axis, depending on the direction of movement of the rail grinding train, at an angle of 0.35 degrees. The value of the angle of attack is taken taking into account the dimensions of the grinding wheel and the average value of the expected metal removal.

The possibility of using the new design of the grinding cart at operating speeds of up to 30 km/h has been established. To avoid the trolley leaving the track, recommendations are
given to reduce the operating speed to 20 km/h with a curved section of the railway track with a radius of 120 meters.

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References
2. W Schoch, Rail Engineering International 36, 1, 6-8 (2007)
5. V.V. Krishna, S. Hossein-Nia, C. Casanueva, S. Stichel, Wear 460–461, 203462 (2020)