Group traction drive as means to increase energy efficiency of locomotives of open-pit transport

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Abstract. Questions of possible use of a group drive for locomotives of an open-pit transport are considered. The possibility of a significant reduction of traction costs in the case of a combination of a group traction drive with devices for the non-inertial regulation of the coefficient of friction between the wheel and the rail has been shown, and new patentable solutions have been proposed.

1. Introduction

The main specificity of open-pit railways in mining industry is increased contamination of working surfaces and increased slopes of tracks up to 60 %. According to [1-4], losses of fuel and energy resources for traction in open-pit transport can exceed 30%. In addition, the sand remaining on rails can create resistance to movement up to 12%. This means that when creating traction drives for open-pit locomotives, it makes sense to take the implementation of a stable, wheel-to-rail ratio independent of external conditions as the main priority, while at the same time making a structural complication and increasing the cost of the drive itself.

It is known that a significant increase in the coefficient of friction can be realized by using a group drive (comparative tests of diesel locomotives type TGM6 and TEM2 have shown that a four-axle locomotive with a group drive not abate by traction properties to a six-axle with electrical transmission and individual drive of wheel sets). However, the mechanical pairing of axes does not remove by itself the dependence of friction coefficient on external conditions. It is established that the friction coefficient can be controlled without inertia by the action of an electric current or magnetic field on contacting objects. According to [5-7], transmission of electric current through the contact of wheel and rail allows to increase the friction coefficient of the wheel with the rail in 2 ... 2.5 times, which is confirmed by observations in operation [8], where the friction coefficient was increased from 0.2 to 0.49 . When using the magnetoplastic effect in the rolling of metals, an increase in the friction coefficient was observed from 0.2 ... 0.22 to 0.49 ... 0.57 [9]. Thus, there is a task to create a group traction drive of open-pit locomotive, which is convenient for locating devices for strengthening the traction force and detecting the slippage.

2. Results and Discussion

Until now, the group drive for electric locomotives or locomotives with electric power transmission has been used mainly in passenger or cargo-and-passenger traffic, which led to the use of a scheme with a gearbox connected to the wheels by a pivot drive collar or hollow cardan shaft (electric
locomotive VL40, electric locomotive of French railways). However, for electric locomotives and traction aggregates of industrial transport, increased axial loads (30 tons) at moderate axial power (650 kW) and low speeds (up to 30 km / h in the long-haul mode and a design speed of 65 km / h) are typical. In these conditions, the use of compensating mechanisms on the low-speed side of the drive is inadvisable due to high torque. In addition, on traction units, to increase the coupling weight, the trolleys of several dump cars have been powered, which reduces the permissible dimensions of the drives in height.

On the TEM12 industrial locomotive, a cardan gear was used, similar to that used on diesel locomotives with hydrotransmission, while traction electrical motors (TEM) were placed longitudinally on the locomotive frame. Because of limited dimensions for TEM placement, this drive scheme can be used only on locomotives of small power for industrial transport, in particular, on mine electric locomotives.

Since two-axle bogies are usually used on electric locomotives and wide-track traction units used in open-pits, this allows the use of a two-stage traction drive with axial and gear reducers, in which cardan shafts are located outside and connect the gearbox with axial gears. Such drive was used on the experimental electric locomotive VL83 with electronic traction motors (Fig. 1).

![Diagram of a bogie with group traction drive of an electric locomotive VL83](image)

**Figure 1.** A bogie with group traction drive of an electric locomotive VL83: 1 – TEM; 2 – cross beam of the bogie frame; 3 – thrust of the traction transmission device; 4 – brake cylinder; 5 – horizontal thrust of the axial reduction gear; 6 – thrust attachment; 7 – longitudinal beam of a bogie frame; 8 – axial reduction gear; 9 – wheel pair; 10 – frame reducer.

The disadvantage of the VL83 electric locomotive bogie is high location of the TEM, which prevents its use on motor dump cars. However, it should be taken into account that the hourly power of the TEM of VL83 electric locomotive is 1800 kW, or 900 kW per one axis, and 650 kW for traction units in the 15-minute mode; i.e. 40% lower. In this case, as indicated in [10], the circumferential speed of the rotor of electronic TEM can be brought up to 100 m/s, which makes it possible to obtain a hourly power of 1600 kW with an outer diameter of TEM about 1 m, which corresponds to the diameter of the collector TEM NTK-650 of traction unit NP-1 (1.086 m). This indicates the possibility of linking a group drive with an electronic TEM in dimensions of bogies of traction units. At this, the speed of TEM shaft is 2600 rpm, which, with a wheel diameter of traction unit of 1.25 m, requires a gear ratio of 9.4. Such gear ratio can be realized in the presence of two stages (frame gearbox and axial gears), while axial reduction gears are located outside the dimensions of the TEM, and do not limit its length.
It should be noted that in this case the use of electronic TEMs, allowing the increase the reliability of the traction motors, requires lower costs than the use of asynchronous ones, because the electronic TEM does not require pulse width modulation of the phase voltage, which simplifies the design of the converter and control system. In electronic TEMs, it is also easier to implement electric braking. At this, at the present time, it makes sense to use forced switching in the converter, which makes the operation of electronic TEM more stable and allows to increase the power.

Taking into account the foregoing, authors proposed variants of traction drive with magnetic (Fig. 2a) and electric (Fig. 2b) traction amplifiers, in the form of a monomotor drive of a two-axle locomotive bogie with frame and axial reduction gears. To predict the deterioration of friction of wheel to the rail under the influence of external factors, the redistribution of the traction force along the axes of the monomotive bogie is used, depending on the elastic slip of the axis, as determined by the longitudinal force sensors in the extension rods of axial reducers. If the coupling of one of wheelsets with the rail deteriorates, the thrust force transmitted to it decreases, which leads to a reduction in the rod of the axle gearbox. The difference in traction forces is detected by a control system that feeds the inductor on the axle of the wheel pair with less traction or passes the current through the wheel contact with the rail of this wheel pair. In order to prevent simultaneous slippage of both wheelsets, the subordinate control system compares the total tractive effort, determined by forces in both extension rods, to the specified by locomotive control system. When the force is reduced in comparison with the target, the current is supplied to both inductors or passed through the contact of both wheels with the rail.

Using a group drive with axial reduction gears makes it possible to conveniently position inductors when exposed to a magnetic field, and allows the wheel pair to be isolated from the frame of the bogie when exposed to electric current. The proposed technical solutions do not have world analogues, the variant of Fig. 2a received a patent for a utility model [11].

The disadvantage of the traction drive in Fig. 2a, b is the absence of control over the heat release at the point of contact between the wheel and the rail. With the coupling of the wheel, the rail deteriorate and the traction forces are below the maximum under the TEM heating conditions. It is possible that the traction force is realized when the wheels slip substantially along the rail [12,13], which is not

![Figure 2](image-url)
detected by the system either because the traction force matches the specified or due to the fact that with a significant amount of elastic slip, the traction force on both axles in motion will be equalized. High values of slip can lead to an increase in the temperature of the wheel surface and rail and to decrease in their strength.

This disadvantage is eliminated in the drive variant of Fig. 3a. Infrared thermometers are located near one of wheels of the wheel pair on opposite sides. When the level of a signal from one of infrared thermometers assumes a value corresponding to a temperature of 300 °C in the contact “wheel-rail”, the monitoring unit sends a signal to “or” blocks, and from their outputs to current regulators, which supply voltage from the current source to the inductors of wheel pairs, and the magnetic flux created by inductors increases the friction coefficient. The termination of wheels sliding along the rails reduces the release of heat in the contact of wheels with rails, and, as a result of cooling of wheels and rail by transferring heat to the surrounding air, the surface temperature of the wheel and rail becomes less than 300 °C.

Another option involves the use of a magnetoboabrasive powder to increase the friction (Figure 3b). Tests of the system [14, 15], which feeds, doses, distributes and retains on the rolling surface an abrasive magnetic powder (scrap waste) was carried out on a full-scale stand manufactured at the Lugansk Machine-Building Institute and the testing ring of the Lyudinovsky Diesel Locomotive Plant (locomotive TGM4A). The use of an abrasive magnetic powder increased the friction coefficient by 20 - 30%. However, the introduction of this system is constrained by the higher cost of the abrasive powder and the lack of its local resources compared to sand. The use of a system of inertial-free adjustment of friction coefficient allows one to drastically reduce the consumption of abrasive powder and to limit its use only in places where a strong contamination of the surfaces of rails can disrupt the operation of friction amplifiers.

In the proposed drive (Fig. 3b), pairs of collector hoppers are located above wheel pairs, each of hoppers is located in the plane of each wheel of the wheel pair near the surface of the wheel. Each hopper contains a control unit for supplying abrasive material in the form of a polarized electromagnetic trap from a magnetic circuit with a control winding and a shunting gap above which a permanent magnet is mounted. The collecting hopper is filled with a magnetic abrasive powder.

Figure 3. Modified traction drive options: 1,2 – axle gears; 3,4 – rods; 5 – bogie frame; 6 – frame gear; 7,8 – cardan shafts; 9,10 – inductors; 11,12 – wheel pairs; 13,14 – force sensors; 15 – comparison unit; 16 – key; 17 – setup unit; 18,19 – “or” blocks; 20,21 – current regulators; 22 – current source; 23 – switch;24 – adder; 25,26 – infrared thermometers; 27 – control unit; 28,29 – pairs of collector hoppers; 30 – magnetic circuit; 31 – permanent magnet; 32 – abrasive powder; 33 – winding.
A permanent magnet creates a magnetic flux that keeps the magnetic abrasive powder inside hoppers. When applying voltage to the inductor from the current source, the voltage is also applied to the control windings of a pair of hoppers of the same wheel pair. Sections of the magnetic circuit near holes for the control winding are saturated, the magnetic flux becomes less than the residual induction of each wheelset of the wheel pair, and the magnetic abrasive powder is distributed along the circle of the rolling of each of bands. With the rotation of the wheels, the magnetic powder is entrained by the magnetic field of the band and falls into the place of contact of wheel with rail, destroying the contamination films. Further, the abrasive magnetic powder remains on the wheel. After the inductors are disconnected, the magnetic flux caused by the residual magnetization of the wheel pairs acts on the abrasive powder on rolling surfaces of wheel pairs and keeps the magnetic powder on rolling surfaces. When the magnetic powder approaches pairs of hoppers, the magnetic flux generated by the magnet in each of hoppers becomes stronger than the magnetic flux of wheel and the abrasive magnetic powder is drawn into hoppers.

3. Conclusion
The group drive makes it possible to reduce energy losses by 15-20% for traction by reducing the sliding of the wheel along the rail, both due to the mechanical joint of axles, and by the convenience of placing on the crew part of devices of noninertial adjustment of friction coefficient of wheel to rail by electric current or magnetic field on the contact area of wheel with rail.

In traction aggregates of industrial transport, the group drive can be realized according to the scheme with frame and axial reduction gears.

Variants of designs are offered, the patent for useful model is received.

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