Adaptive control system of dump truck traction electric drive

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Abstract. The paper describes the operational factors that determine the accident rate of a quarry motor vehicle and assessment of their impact on the choice of the operation mode of the traction drive control system.

1. Introduction

The current state of the mining industry tends to increase the share of minerals produced by the open cast method. Throughout the world, the share of minerals extracted by the open cast method is about 73%. In Russia today, 65% of coal is mined by open cast and according to current forecasts this share will increase to 75% by 2020 [1, 2].

The main advantages of extracting minerals by the open cast method, in comparison with the underground mining, are:

- less capital costs for the construction of a mining enterprise;
- the possibility of providing a greater degree of automation and mechanization of work;
- higher labor productivity;
- lower production costs;
- a greater percentage of minerals extraction.

Recently, there has been deterioration in mining conditions, due to an increase in the depth of open cast mines. One of the measures aimed at eliminating this problem is to increase the volume of rock mass transported by road. At the same time, the main growth was achieved due to an increase in the load capacity of dump trucks. The share of dump trucks with the carrying capacity of 220 tons in the volume of the executed works has increased more than 3 times [3, 4]. Experience shows that applying the non-contact electric transmission on heavy-duty dump trucks is the most efficient decision.

![Figure 1](https://via.placeholder.com/150)

**Figure 1.** The change in accidents on the quarry (A) depending on the speed of the dump trucks (V) during descent (1 - ice, 2 - wet coating, 3 - dry coating) and the tire adhesion coefficient (ψ) with the...
road (4).

On the other hand, one of the main disadvantages of open cast mining is the dependence on weather conditions, which leads to a decrease in the tire adhesion coefficient of the dump truck with the road surface. A decrease in the tire adhesion coefficient from 0.6 to 0.2 leads to an increase in the accident rate 6-7 times (Figure 1), while accidents of career vehicles caused by unsatisfactory mining and road conditions account for 39.2% of the total number of accidents [5].

2. Operational factors that determine the accident rate of the dump truck
During the movement of the dump truck, the most dangerous intervals are the ascent and descent, as the dump truck wheels can start uncontrolled slippage due to unfavourable road conditions, which will lead to reduction in the tire adhesion coefficient (Figure 2a), vehicle skid and loss of control. Therefore, the actual task is the development of an algorithm for controlling the traction electric drive of the dump truck, which ensures a stable mode of the dump truck movement and prevents a transition to an unstable movement mode of drive wheels.

![Figure 2](image)

**Figure 2.** a – dependence of the tire adhesion coefficient ($\psi$) on the speed of the wheels (V) of the dump truck, where Vmax is the maximum speed of the wheels without slippage; b – traction characteristics of the dump truck drive, where Vmax is the maximum speed limit, Vem, Vlo – the speed of the empty and loaded dump truck respectively, Fem, Flo – the motive force produced for moving the empty and loaded dump truck, respectively, Fmax – the maximum possible motive force of the drive.

Forces acting on the dump truck, during travelling uphill (Figure 3) are: Fm– the motive force of the dump truck; P – the weight of the dump truck; Fa – the adhesive force of the dump truck wheels with the road surface; W – the total resistance to motion; Wo – the basic resistance to motion of the dump truck; Wi – the resistance of bias.

![Figure 3](image)

**Figure 3.** The movement of loaded dump truck during the ascent.
The movement of the dump truck will be carried out without slippage if the motive force will be less than or equal to the adhesive force of the dump truck wheels with the road surface:

\[ F_m \leq 10^3 \cdot F_a. \]  (1)

The motive force of a dump truck for a driving mode is:

\[ F_m = \frac{3600 \cdot N_e}{V} \cdot \eta_{tr} \cdot \eta_w \cdot \eta_{to}, \]  (2)

where \( N_e \) is the prime engine power, \( \eta_{tr} \) – the transmission efficiency; \( \eta_w \) – wheel efficiency; \( \eta_{to} \) – coefficient that takes into account the power take-off for powering auxiliary systems.

The adhesive force of the dump truck wheels with the road surface can be determined as:

\[ P_a = \xi \cdot (m_a + q_a) \cdot g, \]  (3)

\[ F_a = P_a \cdot \psi \cdot \cos \alpha, \]  (4)

where \( P_a \) is the adhesion weight, \( m_a \) – the mass of the dump truck; \( q_a \) – the mass of the load in the dump body; \( \xi \) – the coefficient that takes into account the part of the dump truck weight falling on the driving wheels; \( \psi \) – the tire adhesion coefficient; \( \alpha \) – the angle of the longitudinal roll of the dump truck.

3. Proposals for the modernization of the traction electric drive control system

The profit of the mining enterprise directly depends on the operation efficiency of the quarry motor vehicles, therefore the most effective mode of operation of the dump truck electric drive will be such mode which ensures the minimum voyage time [6], i.e. maintains the maximum possible motive force and satisfies the condition of motion without slippage (1).

From (1), (2), (3), (4) it can be seen that the ability of maintaining the maximum motive force without sliding of the drive wheels depends on two variable components, the values of which can vary in a certain range - the weight of the load in the dump body and the tire adhesion coefficient.

From the rules of dump trucks operation, it is known that overload of dump truck by more than 10% of their passport load capacity is prohibited. The error of the "Quarry" system, used in domestic dump trucks for load control, is 2.5% of the maximum dump body load, which does not allow obtaining accurate information on the load weight in the dump body [7, 8, 9].

Reducing the measurement error can be achieved by calculating the load weight according to the average pressure value in the pneumohydraulic suspension cylinders during movement:

\[ M = \frac{1}{\tau} \int_0^\tau S_f [p_{fr}^f(t) + p_{fr}^r(t)] + S_r K [p_{pr}^f(t) + p_{pr}^r(t)] \cos \alpha(t) dt, \]

where \( p_{fr}^f, p_{fr}^r, p_{pr}^f, p_{pr}^r \) are the pressure of the gas-oil mixture in the front left, front right, rear left, rear right suspension cylinders; \( S_f, S_r \) – the area of the rods of the front and rear cylinders; \( K \) – constructive coefficient, taking into account the effect of the reactive levers of the rear suspension; \( \tau \) – the integration time; \( \alpha \) – the angle of a dump truck longitudinal roll.

Tests on load weighing, carried out at the Tomusinsky motor depot with the involvement of the enterprise metrological services, allowed one to fix the weighting error from 0.47% to 1.01% [10].

Unlike the weight of the load in the truck body, the tire adhesion coefficient cannot be determined directly. The control system of the traction electric drive must be adaptive (Figure 2b), i.e. it should limit the maximum motive force, depending on the actual value of the tire adhesion coefficient, avoiding slippage of the drive wheels, i.e. work at the boundary of the steady mode (Figure 2a). As the tire adhesion coefficient decreases, the wheels begin to slip, the traction motor current decreases, and the speed of the wheels increases, when the traction force decreases, the speed decreases, the tire adhesion coefficient increases, and the wheels engage with the ground.

Thus, the actual task is to create an electric drive control system that provides the maximum value of the motive force without slippage of the drive wheels.
Figure 4. Functional diagram of the motor-wheel drive control system, where D is the motor, M – the mechanical part of the drive, Pr – the power reference, Cp – the power controller, Ct – the torque controller, Mr – the resistance moment, Sv – the vibration sensor, speed sensor, St – the torque sensor, Ss – the speed sensor, CU – the corrector, $\omega$ – the angular velocity.

The following structure of the electric drive control system for the motor-wheel of the dump truck is proposed (Figure 4). Power demand Pr is given at the input of the control system, while current and vibration acceleration are measured on the traction motor. The moment of the beginning of the driving wheels slippage is proposed to be determined by the rate of current variation and the vibrational acceleration of the traction motor. After detecting the slippage, the correcting device CU set the motive force limitation depending on the slippage intensity.

4. Conclusion
In the article, the operational factors determining the accident rate of the quarry motor transport were considered and their impact on the choice of the operation mode of the traction electric drive control system was evaluated. The functional scheme of the motor-wheel drive control system, which provides correction of the traction characteristic of the traction electric drive during the external conditions change, was proposed.

5. Acknowledgments
The presented results were obtained as a part of scientific researches according to contract № 13.3746.2017/8.9 within the scope of the State task “The designing on the base of systematic and logic probability evaluations of rational and economically proved structure of centralized, autonomous and combined power supply systems with high reliability and stability level with usage of alternative and renewable power sources for uninterrupted power supply of enterprises with continuous technological cycle”.

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