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Justification of the concept of creating a perspective dump truck

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Annotation. The article carried out a deep technical and economic analysis of existing samples of quarry vehicles. The modern technical level of the mining industry is determined by performing a patent search and review of literature on this topic. The main problems associated with the operation of mining vehicles in mining are considered. The basic requirements for the development of a perspective dump truck have been formed.

The development of the mining industries of the Russian Federation requires the implementation of new cost-effective and safe technologies for extraction and transportation of minerals [1]–[4]. This industry is important national economy and requires improvement. A method of open-cut mining is called if it involves working in open pits. Due to the rapid increase of the depth of open pits it become impossible to use railroad freight activity, scraper or conveying belt due to the complexity of organizing efficient and high-performance transportation of rocks. Wheel vehicle seems to be most suitable for working in open pits, as it is capable of ensuring the proper level of working productivity. One such vehicle is a dumper. A dumper is a self-unloading truck designed to transport running ground and other goods in off-road conditions.

To identify current trends in the development of dumper designs it is necessary to conduct a deep technical and economic analysis of existing samples of mining equipment. The high priority task of feasibility study is to determine the current technical level of the industry by performing a patent search and review of literature on this topic.

An analysis of the patent search gives reason to build a short-time prediction (for 5 years) for the development of career equipment. The main trend in world mining equipment is the course towards increasing energy efficiency, the main indicator of which is the specific fuel consumption. Problem of energy efficiency and control law of dump trucks are presented in [5]–[9]. One of the main ways to reduce specific fuel consumption is to reduce resistance to movement and transfer technology to a parallel hybrid or distributed hybrids.

We give an example of a patent RU 158 664 U1 «The control device for a set of traction electrical equipment for vehicles, mainly dump trucks». This patent describes a control device for electric traction drive (see Figure 1) for vehicles. The kit contains a housing and a liquid cooling system of power converters fixed therein, which are connected by buses.

We give an example of a patent US RE 36152 «Method and apparatus for controlling differentially driven wheel-slip for an articulated machine». This patent describes a Method and apparatus for controlling differentially driven wheel-slip for an articulated machine. The described device includes a brake mechanism, which has the ability to block each of the wheels individually, angular velocity



sensors, a sensor for the mutual angle of rotation of the articulated parts of the frame, and a controller. The application of the traction control system (see Figure 2) on dumper can reduce wheel slip and at the same time reduce power consumption for driving.

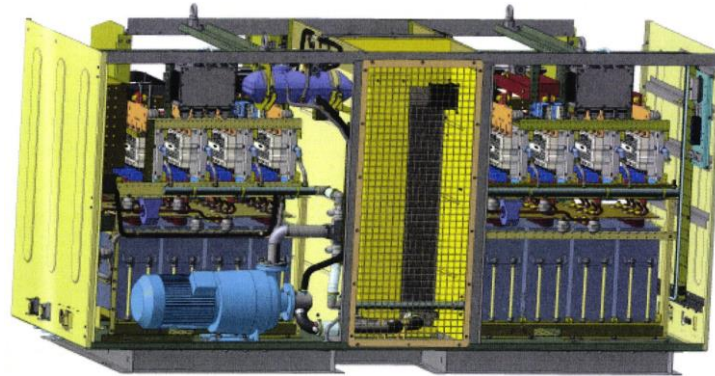


Figure1.Control device for an electric traction drive

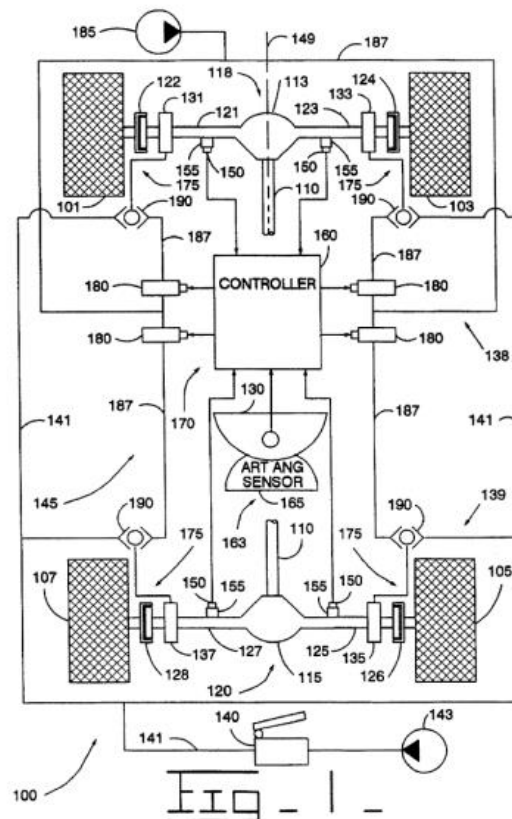


Figure2.Traction control system

After conducting a patent search, it is necessary to proceed to a review of literary sources, as well as sources of the Internet.

The efficiency of using hybrid transmission schemes is shown in [10]–[13]. Ways to reduce fuel consumption and harmful emissions into the atmosphere through the use of dump trucks with a hybrid power plant. Modeling was performed in MATLAB / Simulink of a dump truck transmission with a diesel-generator hybrid power plant. Similar model is presented in [14].

In the works [15]–[18] it was revealed that there is a tendency to deepen the career depth. Increasing depth leads to a deterioration in operating conditions. Gas contamination is increasing, especially in the lower part of the career. In the main works, the need to reduce harmful emissions from the operation of mining equipment is noted. In some works, it is proposed to use trolley cars that are powered by a contact network. The advantages of trolley cars over the classic diesel-electric circuit are examined in detail. Transfer to electric traction will reduce the level of harmful substances in the air, noise and vibration. The complete transition to the use of trolley cars is complicated by the lack of flexibility in moving the contact network. This approach requires the organization of fixed loading and unloading sites. To solve the problems of flexibility and mobility, it is proposed to use diesel trolley vehicles (see Figure 3).



Figure 3. BelAZ-7524-3792

After analyzing the mining conditions for the use of trolley vehicles, the following operating conditions suitable for the use of trolley vehicles in open mines are distinguished: the remoteness of the trolley lines from the production site, the presence of a stationary loading and reloading point, the distance of transportation of the rock mass is 3–30 km, the gradient of roads is from 0 to 10%. However, with the development of technologies of electric batteries manufacturing, it became possible to create fully electric dump trucks [19]–[21].

The use of all-electric drivetrain in addition to reducing the cost of operating the transport allows manufacturers to significantly save on production due to the smaller number of transmission units and other elements. In addition, the electrified mining transport allows you to get the following advantages: 10–15% reduction in the mass of the dump truck, the exclusion of diesel exhaust and, therefore, the absence of gas contamination of the mine and the formation of fog, eliminating the costs of the purchase, storage and transportation of diesel fuel, reduction in the cost of the truck due to the exclusion of the diesel engine, reduction in tire costs due to the lower dead weight of the electric truck, ease of maintenance of the power unit, and immunity of the electric engine to frost, which especially distinguishes it in the northern regions from diesel (strong negative temperatures have a negative effect mainly on batteries).

One such example is the eDumper electric dump truck (see Figure 4). For several years, the Swiss government has been equipping heavy industry with electric-powered machinery. The largest in size is the eDumper electric dump truck weighing 45 tons, developed by Kuhn Schweiz AG, which has a length of 8.5 meters, a width and height of 4.2 m. Power is supplied by 600 kWh batteries which weighs 4.5 tons.



Figure 4. Electric dump truck eDumper

Like all electric vehicles, eDumper recuperates the energy generated by braking. While braking occurs, the electric motor goes into reverse mode, producing electricity that charges the batteries. The eDumper is used in a mine near Biel (Switzerland). It transports 65 tons of rock to a cement factory down the mountain with a slope of 13%. When descending from the mountain, the dump truck has a large inertia, due to which the regenerative braking system charges the batteries. As a result, eDumper charges itself and does not require frequent network connections. Battery charge measurements were taken after ascending with a fully loaded body and after descending to the loading point in the quarry. At the beginning of the rise, the battery charge was 90%, after the rise it was 80%. After the descent due to the recovery of power, the batteries were charged up to 88%, which is almost equal to the initial charge of the batteries. A dump truck carries out about 20 descents and ascents daily.

The result of the implementation of electric transmission and engines is the saving of 50 tons of diesel fuel annually, which significantly increases the energy efficiency of work and makes mining dump trucks environmentally friendly.

Thus, a review and analysis of publications shows that development and research are currently focused on increasing the efficiency, reliability and safety of mining transport systems through the use of hybrid and electric transmissions.

Currently, autonomous vehicles are widely used in various fields [22]–[27]. The use of autonomous vehicles in industry can be dictated by dangerous working conditions, as well as the need to increase productivity by reducing vehicle downtime during rest and driver shifts, as well as working in the dark. The creation of autonomous mining dump trucks is one of the priority tasks in the development of mining equipment. This is primarily due to the safety when working in quarries, often accompanied by accidents associated with crashes, and the danger posed by harmful gases, especially radioactive radon. Also, the use of autonomous dump trucks provides increased energy efficiency associated with the use of hybrid and electric transmissions.

Creating fully autonomous cars is a complex task that has not yet been completely resolved at the current level of technology development. Mining trucks operate in limited areas on repeating routes. These features of their operation allow to create autonomous mining equipment using currently available tools.

At the moment, several autonomous mining equipment have been created by the leading companies BelAZ, Volvo, Komatsu, Caterpillar, Hitachi.

BelAZ autonomous mining dump truck.

The Russian company VIST Robotics together with BelAZ created a prototype of an autonomous mining dump truck based on the BelAZ-7513R model, shown in Figure 5. The dump truck has a loading capacity of 130..136 tons, can operate both in autonomous mode and in telecontrol mode, has an electromechanical transmission, and an 1194 kW engine.



Figure 5. Autonomous mining dump truck BelAZ-7513R

BelAZ-7513R works as follows: the dispatcher issues a shift task to the system, allocates the required number of pieces of equipment and the production route. Trucks leave the parking lot for the site and begin continuous operation - loading, road, unloading. The operator can reassign the machine to another route or send it to the parking lot: the robot will finish the current cycle and head to a new task.

In the event of difficult conditions, the operator takes over the remote control, who can simultaneously control several vehicles at once.

The system of autonomous traffic control of the BELAZ-7513R dump truck includes an on-board control unit located in front of the car next to the driver's cab. On the left and right sides of the car there are two receivers of satellite navigation systems.

For visual control, 11 video cameras are used, which are installed around the perimeter of the vehicle. The car uses Orlaco EMOS series security cameras with an Ethernet interface. Several Delphi ESR radars operating in the medium and long range are responsible for detecting people and other objects along the route. Three-dimensional and two-dimensional lidars are installed on the dump truck, which are responsible for scanning space in the horizontal and vertical planes, as well as for monitoring the safety zone around the car. Along the perimeter of the car, Banner QT50U ultrasonic sensors (sonars) are used to detect obstacles at short distances, the sensor detection range is 0.2 ... 8 m.

Komatsu unmanned dump truck.

Komatsu started testing autonomous vehicles at the Codelco copper mine in Chile in 2005 and three years later, in January 2008, in the same place, the first commercial use of AHS (Autonomous Haulage Systems), which increases safety, commercial and economic efficiency, began. In September 2017 on one of operating mining enterprises of Rio Tinto company were conducted successful tests of the AHS upgrade kit for electric powered dump truck Komatsu 830E with a diesel-electric transmission, 1835 kW engine and carrying capacity 231 tons.

The fleet management system AHS works without participation of truck driver. Information about their route and speed is sent wirelessly to the Central control room. The exact location is determined by GPS navigation.

The fleet management system controls all equipment through GPS and wireless network, including other equipment and vehicles that are man-operated, to prevent collisions. Integrated analysis system of environment helps trucks themselves to react on suddenly appearing objects and obstacles.

Japan manufacturer presented a prototype of the dump truck Komatsu IAHV (figure 6), which is part of the autonomous cargo complex management system, in 2016 at the Mine Expo in Las Vegas.



Figure 6. Komatsu IAHV dump truck

The main features of this model — are the ability to move forward and backward with a same speed, and steering of all four wheels. Thanks to these options the time for setting the dump truck for loading and unloading is reduced, as well as space in bottomhole and unloading zones is saved, since there is no need to turn the truck. Komatsu IAHV can move sideways. The center of mass is located in the middle part of the truck, what allowed to evenly distribute load on the wheels and to equalize grip coefficient to the road of all wheels. Today, the design is in a trial operation.

Volvo unmanned dump truck.

Volvo HX unmanned dump trucks are the part of the Volvo Electric Site project of development electrified mining company with a minimal harmful emission. The first Volvo HX1 prototype (figure 7) was used to refine the concept of unmanned electric dump truck. Volvo chose the concept that uses a large number of small dump trucks instead of several with a large carrying capacity and which allows to reduce losses in the event of failure of one of the dump trucks [28]–[30].



Figure 7. Volvo HX1 dump truck

The second prototype Volvo HX2 uses more of Volvo's serial parts such as traction electric motors, batteries and power electronics. Three-dimensional lidars were added in the motion control

system to detect people and obstacles. Dump truck has four-wheel drive and all-wheel steering, which allows to increase maneuverability and gives the possibility of sideway moving. The maximum speed is 40 km/h, both forward and backward. The dump truck is equipped with three electric motors. Two electric motors are used as traction, the third motor drives a hydraulic pump. High pressure hydraulic is used for steering and drives unloading cylinders.

Charging of the traction batteries of Volvo HX2 dump truck occurs due to pantograph, located on a special base below ground level. When truck stops, the pantograph rod rises above it and connects contacts to the dome, located under the bottom of the truck.

Conclusion.

Based on review of existing vehicle developments in the mining sphere, as well as patent researches, it is possible to reveal main tendencies of technology development in this sphere. These include hybridization or the complete electrification of power point and transmission of dump trucks, using of unmanned technologies and complete absence of cabs in the developed technique samples. Accordingly, two ways of development autonomous vehicles are formed: retrofitting of existing vehicles with a necessary aggregates or designing new vehicles taking into account the possibility of autonomous movement up to refusing manual control and excluding the cab from the vehicle construction, similar to the Volvo and Komatsu dump trucks.

Also diesel-trolley trucks are the one of the perspective directions of hybrid dump trucks. A contact network is used for movement along the main sections of the routes, and a diesel generator set is used to access loading and unloading areas.

The use of unmanned systems in dump trucks compared to road vehicles is simplified due to the following factors: the absence of many lanes, other road users, a variety of environmental objects, low speeds along standard routes. However, there are also negative factors, affecting on operating of unmanned dump trucks. These include lack of marking, deformability of the soil, uneven supporting surface at an angle to the horizon, lack of high-quality communication for GPS operation.

Cab-free design of dump trucks is the most perspective and preferred and can significantly increase the size of the loading platform, as well as to provide movement in both directions on the basis of a “push-pull” principle.

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