Automated control of unmanned truck for transport complex of mining industry

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Abstract. The article is devoted to the development of robotized control mining-and-transport complex systems. The description of modern control mining-and-transport complex systems shows that operator control is currently used. During the replacement with robotic control systems, automatic and automated mining-and-transport complex control can be used. It is demonstrated that automated control can be considered the most promising control system. The article presents the advantages of automated control and the disadvantages of operator and automatic control, deals with electric drives of electric propulsion systems, which allows realizing automated mining-and-transport complex control. This electric propulsion system can be built on two or four motor wheels. In the article the authors review the advantages and disadvantages of the two electric propulsion systems, the utility of using the electric drive of all wheels of mining trucks for the implementation of automated control is proven.

1. Introduction
Nowadays to control the machines of the mining-and-transport complex, which includes mining excavators and dump trucks of open pit mining, an operator control method is used [1-7]. This method of control implies the use of manual control of the SCC machinists and operators. The scheme of the operator control method is presented in Figure 1.

The main disadvantage of this method is the significant impact of the human factor on the performance and safety of mining operations [8-11]. For example, the mistake of the operators of mining dump trucks can lead to overturning of the cars from the pit walls or their collision, and the mistakes of mining dump trucks may cause over- or underload of dump trucks.

This article represents other ways controlling the machines of the mining-and-transport complex, namely automatic and automated control. The most advanced controlling system can be assumed automatized control. Moreover, excavator propulsion's electric drives in automated control of the mining-and-transport complex is considered.

2. Materials and methods
The promising methods of automatization of the open pit mining include the following systems:
– an automatic method controlling machines;
– an automatized method controlling machines with a remote control dump truck.

Schemes of these methods automatization are shown in Figure 1.

The automatic method does not require person's presence in a mining truck for the safety of minerals transportation. However, there is some difficulty in placing the dump truck at a convenient point in the
loading area.

The automatized method controlling machines with a remote control dump truck implies that operator maneuvers during the loading process for adjusting its position. According to that, the second method is more safe and has the highest performance.

The dump truck movement is carried along the route using infrared sensors and cameras installed on it and mirror beacons.

a) operator control method

b) automatic control method

c) automatized method using a remote dump truck control system

Figure 1. Methods of automatization of the mining-and-transport complex

3. Results and Discussion

The disadvantages of the operator method of controlling the mining-and-transport complex:
- reduced safety
- human factor;
- reduced performance;
- cabin availability.

The disadvantages of the automatic method of controlling the mining-and-transport complex:
- difficulties in the position dump truck adjustment in the loading area;
- performance is larger than in the previous method.

The advantages of the automatized method of controlling the mining-and-transport complex:
- increased performance;
- increased safety;
- refined control dump truck traffic.

Equipment for the organization of automatized movement

Dump track movement using the automatized method of controlling the mining-and-transport complex is performed by:
- mirror beacons, which are necessary for following the dump truck route (if the infrared sensors do not fix the reflector, the dump truck will instantly stop; for increasing accuracy it is recommended to install mirror beacons every 150 meters);
- a fiber-optic gyroscope, which is used for adjusting the dump truck position on the route / in space,
does not allow the dump truck to drive up onto the hill and overturn;

- watching cameras, which are intended for recognition, detection and identification of other objects located on the dump track route, i.e. to find out a "computer vision", which is necessary for adjusting the dump truck movement;
- infrared sensors, which are also necessary for adjusting the route, one of them can scan the space within a radius of 15 m because of sudden interferences, others – within a radius of 150 m to adjust the speed during the route.

**Path of the automatized movement**
According to the automatic method, the dump truck occupies a fixed point in the loading area recorded in the satellite system. The point changes will cause the whole route changes, which takes a lot of time. Consequently, performance decreases, the downtime of the SCC machines increases.

In the loading area the dump truck location is determined by the excavator driver, because the excavator during the mineral loading, moves according to the groove. In this method, the dump truck is under the excavator driver control. The driver corrects location for convenience; the last loading point is remembered and the next dump truck will arrive at this point until the driver will change it again.

In the unloading area the dump truck follows the already defined route in the navigation system. The dump truck is able to pass a given route in the loading area without any deviations using precision guided navigation systems. Characteristics of the various navigation systems are represented in Table 1.

| Navigation system | Error of navigation definitions |
|-------------------|---------------------------------|
|                   | Latitude, m | Longitude, m | Height, m |
| GLONASS           | 6.2         | 6.7          | 14.7      |
| GPS               | 5.9         | 5.7          | 14.9      |
| EGNOS (GPS+ GLONASS) | 4.3     | 4.8          | 11.2      |

Routes can be built in two ways with oncoming traffic of dump trucks (Figure 2):

- dump track’s route will be shifted to the right / left regarding the route to the loading area, if the truck moves in the unloading area direction (Figure 3);
- dump track will shift to avoid collisions when meeting using infrared sensors and the GLONASS system (Figure 4).

![Figure 2. The movement of robotic dump trucks in a career.](image-url)
Figure 3. Trajectory of the dump trucks movement in oncoming traffic.

Figure 4. Trajectory of the dump trucks movement in oncoming traffic.

Dump truck electromotive system

Let us consider the systems of electric propulsion, which are installed on most dump trucks in conjunction with an operator control method [12-17]. Their electric propulsion systems consist of a diesel generator, a frequency converter, a motor-wheel. The electrical propulsion system type diagram is shown in Figure 5. The diagram has the following notation:
- brushless synchronous generator (SG);
- twelve-pulse rectifier (R);
- smoothing filter (SF);
- two two-level inverter (AI);
- two motor-wheels (consist of an asynchronous motor and gearbox).

For using automatized mining-and-transport control, changing the system of electric movement of a career excavator increases the maneuverability of the machine [18-20]. The type diagram of the electric propulsion system is illustrated in Figure 6. The following notations are used in the diagram:
- asynchronous generator (AG);
- three-level active rectifier (AR);
- smoothing filter (SF);
- four brake devices (BD);
- four two-level inverters (AI);
- four motor-wheel (MW).

The robotic dump track with four motor-wheels is shown in Figure 7.
4. Conclusion

The comparison of the main characteristic of the two type of the electron propulsion-mining excavator with an operator control system (two motor-wheels) and automatic control (four motor-wheels) has been carried out.

The advantages of the four motor-wheels: there is no need for dump track to turn around in the loading / unloading area; the movement speed can increase up to 65 km / h in both directions, even in the laden condition; there is improved traction possibility.

Asynchronous generators of the electric propulsion system with four motor-wheels:
\- maintain the output voltage at a constant level;
\- simplify the design of the electric propulsion system;
\- are almost independent of harmonic effect;
\- have an inconsiderable rate of uneven rotation;
\- their generator heats up slightly.

For instance, the synchronous generators have a coefficient of nonlinear distortion up to 15% compared to 2% using the asynchronous counterparts. In addition, these solutions have almost no rotating winding and electronic parts, which always fail first. According to that, asynchronous generators are distinguished by high reliability and long lifespan.

Problems of diode rectifiers are as follows:
they function using non-sinusoidal voltages and currents;
there is consumption with low power factor;
there is unilateral rectifier conductivity (impossibility to recover).
Solution of these problems in the application of inverter active rectifiers allows providing the following functions:
function using sinusoidal currents and voltages;
adjustment of the power factor of the ED;
recuperation;
voltage control in the DC bus of the inverter.
Thus, increasing the efficiency of mining deposits, during a simultaneous safe rise, manufacturability and development speed can be proven by the automatized dump track with the four-wheel electric propulsion system.

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