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RATIONAL PROFILE FOR CAREER ROADS

Purpose. To develop the method for optimizing the longitudinal road profiles of deep horizons through the scientific and technical solutions for the design and practical use of effective trucking systems in opencast mining.

Research methods. Mathematical statistics, axiomatic and hypothetical methods, program-target method, generalization of experience of domestic quarries with the use of statistical data on production and operational characteristics of motor transport equipment, system analysis and simulation using information computer technologies; technical and economic calculations to substantiate effective technical and organizational solutions, mathematical modeling, technical and economic analysis, regression analysis in the study of the influence of the parameters of the road profile on the speed of dump trucks.

Scientific novelty. The experimental-analytical methods for assessing mining and road conditions of technological vehicles based on a comprehensive accounting of physical criteria - loading mode of units of the dump truck, its speed depending on the applied configuration along the longitudinal profile; methods for assessing road operating conditions, the calculation of rational structures of road profiles used to power heavy-duty dump trucks is a contribution to the theory of transport systems formation in quarries.

Practical significance. Boosting operation of motor transport equipment by increasing the average speed of heavy-duty dump trucks through the use of guidelines for optimizing the longitudinal profile of roads and intensificating of opencast mining.

Results. The research results allow to increase the scientific validity and accuracy of operational indicators of quarry vehicles by considering the comprehensive mining and road operating conditions; reduce the cost of transporting rock mass by optimizing the longitudinal profile of roads and achieve an increase in the speed of loaded dump trucks.

Key words: quarry roads, heavy dump trucks, longitudinal profile.

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Problem statement. A career road is a sequence of tracks with different slopes, where the slopes of the travelled tracks affect the driving mode on the following tracks. However, the previous studies have not considered the relationship of the longitudinal profile characteristics of all driving tracks consistently travelled by the vehicles in deep quarries. In this regard, an important issue to be addressed is how to optimize characteristics of a longitudinal profile that integrate with technological and transport factors. This is particularly relevant in the lower horizons of the quarry, where the mining conditions determine the longitudinal profile of roads. The deeper the quarry is, the more convex the longitudinal road profile related to the technological mining conditions becomes. Thus, objective prerequisites exist for further setting and solving the task: what should be the longitudinal profile of roads within the working quarry at a given lifting height until the loaded dump truck reaches the above-horizon-mark in a shortest time - time criterion? Insights into the question can be gained from various perspectives including fuel consumption for the work performed, the transportation cost of 1 t mining rock mass and the total cost of roads and transportation. It should be noted that the slight change in the longitudinal profile affects the distance travelled by the vehicle between the loading and unloading points. The general task is effectively solved by modeling the driving modes of the vehicles.

Analysis of the recent research and publications. Presently, considerable Ukraine's and international competencies in the design, construction and operation of quarry roads under different mining, geological and climatic conditions come from the works by S.O. Arefiev, Yu.A. Monastyrsky, I.V. Kuznetsov, V.O. Vynokurov, V.O. Sistuk, M.V. Dadonov, K.V. Ardeiev, P.V. Artman, E.A. Kreisman, V.O. Zhukov, V.V. Kryvda, A.I. Kosolapov, S.A. Kosolapova, I.A. Luika. Although, the roads are of different parameters and designs, most of them move dump trucks with a capacity of 75-120 tons. Currently, there is no single science-based method of optimizing the parameters of the roads.

Objectives of the article. The following research objectives were formulated in order to achieve the desired goals:

to establish statistical data on real speed modes of dump trucks for long-term operation in the PJSC "Northern GZK" quarries ;

to determine the principles of software engineering for data processing;

to develop a software package for experimental data analyzing including speed modes of heavy-duty dumpers in the quarry under different environmental conditions.

Presentation of the main research and results. Consider the vehicle motion according to the analytical model theory of operational properties. We use the differential equation of vehicle's speed on a route length

$$\frac{dV}{dl} = \frac{\left(D(V) - \psi(l)\right) \cdot g}{\delta(V) \cdot V_{cp}(l)}, \tag{1}$$

where D is the dynamic factor of a vehicle; $\Psi\ (l)$ is the total road resistance; g is the gravitational acceleration; $\delta\ (V)$ is the coefficient of influence of the rotating masses of the vehicle; $V_{cp}\ (l)$ is the average speed of the vehicle on the driving track.

We solve the equation of the dynamic factor D related to the velocity V

$$D=(P_k - P_w)/G\ , \tag{2}$$

where P_k is the traction on the drive wheels of a dumper; $P_w = k \cdot F \cdot V^2$ is the air resistance; k is the air resistance coefficient, which depends on the shape and quality of the vehicle's surface, H s^2/m^4; F is the frontal area of the vehicle, m^2; G is the weight of the vehicle.

For dump trucks with electromechanical transmission, the power transmitted from the primary (diesel) engine to the drive wheels of the vehicle is equal to

$$N_{\text{к}}=N_e \cdot \eta_{всп} \cdot \eta_c \cdot \eta_p \cdot \eta_{д}=N_{г} \cdot \eta_{д} \cdot \eta_p=10^{-3} \cdot I_{г} \cdot U_{г} \cdot \eta_{д} \cdot \eta_p, \tag{3}$$

where $N_{\text{к}}$ is the power on the drive wheels of the dumper, kW; N_e is the engine effective power, kW; $\eta_{всп}$is the engine power loss coefficient of the auxiliary equipment drive; $\eta_{\text{с}}$ is the electrical network efficiency; $\eta_{\text{р}}$ is the motor-wheel reducer efficiency; $\eta_{\text{д}}$ is the traction motor efficiency; $N_{г}\ , I_{г}\ , U_{г}$ are power, current and generator voltage.

The power consumed by the generator of the BelAZ-7549 dumper is equal to $N_{\text{св}}$ = 630 kW - free power. Another power diesel engine (142 kW) consumed to drive the vehicle's auxiliary equipment and power transmission losses from a diesel to generator, kW

$$N_{г}=U_{г} \cdot I_{г}=N_{св} \cdot \eta_c=630 \cdot 0{,}92=580,$$

where $\eta_{\text{с}} = \eta_{\text{г}} \cdot \eta_{\text{в}}$ = 0,945 × 0,975 = 0,92; $\eta_{\text{г}}$ is the generator efficiency; $\eta_{\text{в}}$ is the rectifier efficiency.

The external characteristic of the generator $U_{\text{г}}=f(I_{\text{г}})$ considering the losses in the generator and rectifier is shown in Fig. 1.

Traction motors implement the specified limit and partial traction characteristics of the vehicle according to the expression

$$N_{к}=0{,}272 \cdot \times\ 10^{-3} \cdot P_{\text{к}} \cdot V. \tag{4}$$

Equating expressions (3) and (4), we obtain the dependence of the traction force $P_{\text{к}}$ of the drive wheels on the vehicle's speed V at nominal free power $N_{\text{св}}$

$$0{,}272 \cdot 10^{-3} \cdot P_{к} \cdot V=10^{-3} \cdot I_{г} \cdot U_{г} \cdot \eta_{д} \cdot \eta_p\ ;$$

$$P_{к}=3{,}68 \cdot I_{г} \cdot U_{г} \cdot \eta_{д} \cdot \eta_p\ /\ V, \tag{5}$$

where V is the vehicle's speed, km / h.

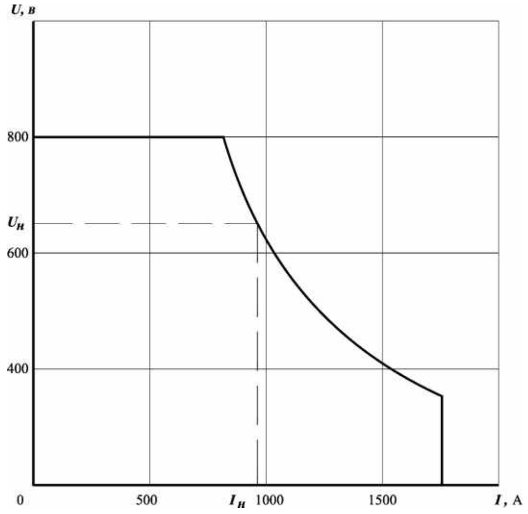

Fig. 1. External characteristic of the generator ($N_{г}=I_{г} \cdot U_{г}$=const) of the BelAZ-7549 dumper

The generalized limit traction characteristic of the

BelAZ-7549 dumper is shown in fig. 2. This characteristic shows that all operation modes of the vehicle are within the three main sections of the dependence *Pк (V)*, corresponding to the maximum traction force$P_{к.\text{мах}}$ (line $0_1 0_2$), maximum power $N_{св}$ (curve $0_2 0_3 0_4$) and the maximum speed $V_{\text{мах}}$ (curve $0_4 0_5$). The section $0_2 0_4$ consists of two zones: long-term mode (curve $0_3 0_4$) and short-term mode (curve $0_2 0_3$). The points 0_2 and 0_4 of the dependence *Pк (V)* are the limit and correspond to output of the vehicle with electromechanical transmission in modes of maximum power $N_{св}$ and speed *V*.

Using the formula (2) and the dependences *Pк = f (V), PW = f (V)* we obtain the dependence of the dynamic factor for the loaded BelAZ-7549 dumper, as shown in Fig. 3.

Alignment of the curve *D = (V)* is performed precisely on the hyperbola

$$D = \frac{A}{B + C \cdot V}, \tag{6}$$

where *A*, *B*, *C* are the dump truck's empirical constants determined from the condition that the resulting curve must coincide with the leveling curve at three points: $D_{\max}$ $(V=V_0)$, $D_{cp}(V=V_{cp})$, $D_{\min}=(V=V_{\max})$

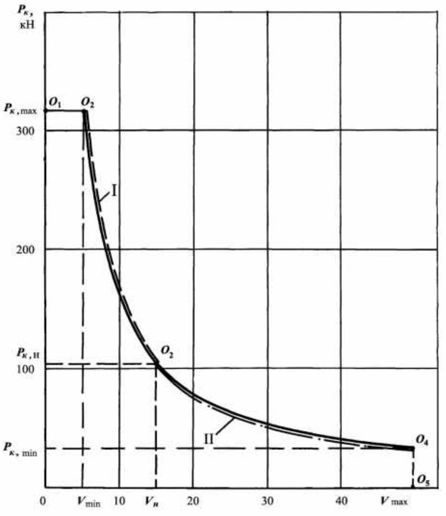

Fig. 2. Traction characteristics of the BelAZ-7549 dumper: *I* is for the first transmission; *II* is for the second transmission

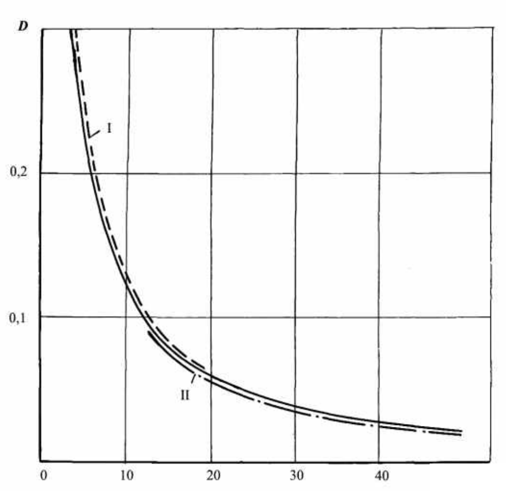

Fig. 3. Dependence of the dynamic factor for the loaded vehicle *D* on the motion speed *V* of the BelAZ-7549 dumper: *I* is for the first transmission; *II* is for the second transmission

Solve a system of equations

$$D(V)\begin{cases} D_{max} = A/(B + CV_0) = A/B & V_0 = 0, \quad D_{max} = 1/2; \\ D_{cp} = A/(B + CV_0) & V_{cp} = 15 \quad D_{cp} = 0{,}08; \\ D_{min} = A/(B + CV_0) & V_{min} = 50 \quad D_{min} = 0{,}02, \end{cases}$$

we obtain the expression to determine constants

$$A = \frac{D_{\max}^2 \cdot D_{cp} \cdot V_{cp}}{D_{\min}^2 \cdot \left(D_{\max} - D_{cp}\right) \cdot V_{\max}}; \tag{7}$$

$$B = \frac{D_{\max} \cdot D_{cp} \cdot V_{cp}}{D_{\min}^2 \cdot \left(D_{\max} - D_{cp}\right) \cdot V_{\max}}; \tag{8}$$

$$C = \frac{D_{\max}}{D_{\min}^2 \cdot V_{\max}}. \tag{9}$$

When substituting the values of the vehicle speed *V* in m / sec, the hyperbolic function *D (V)* is

$$D = 77{,}14/(69{,}29+216\ V).$$

The total resistance of the road is determined

$$\Psi = f_к \pm i, \tag{10}$$

where $f_к$ is the rolling resistance coefficient; *i* is the slope of the longitudinal road profile.

The rolling resistance coefficient on all tracks is to be relatively constant since the quarry vehicles travel on well-stiffened gravel roads treated with mineral or liquid binders. The total resistance of motion depends mainly on the geometric elements of the road longitudinal profile, which differ in size, alternation and length of slopes. To determine the dependence $\Psi = f(l)$ consider the geometric elements of the longitudinal road profile Pershotravnevyi in the PJSC "Northern GZK" quarry, which is presented in Fig. 4. Each element of the longitudinal profile is designed in the following values: the slope *i* expressed in ‰, with a plus sign on the rise and a multiple of 10 ‰; the length of the constant slope track *l* expressed in kms.

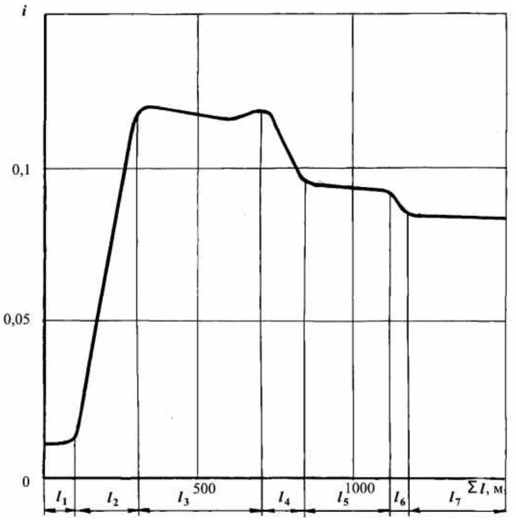

Fig. 4. Dependence of the slope longitudinal profile *i* on the length *l* Pershotravnevyi quarry road in the PJSC "Northern GZK" low horizons

The interpolating function $\Psi = f(l)$ is represented by a Newton polynomial

$$\Psi(1) = \sum_{i=0}^{n} a_i \cdot l^i = a_0 + a_1 \cdot l + a_2 \cdot l^2 + ... + a_n \cdot l^n. \quad (11)$$

The researchers experimentally established the dependence of the change in the coefficient of rotational masses inertia on the speed of the loaded vehicle of quarry dump group (up to $V_{\max} = 15$ m /s)

$$\delta = 0{,}00046 \cdot V^2 - 0{,}0152 \cdot V + 1{,}188. \quad (12)$$

The presented dependence $\delta = f(V)$ can numerically solve the differential equation (1) and determine the dependence $V = f(l)$

$$dV = \frac{[D(V) - \Psi(l)] \cdot g}{\delta(V) \cdot V_{cp}(l)} \cdot dl.$$

The initial limitations of the design model of the dump truck in the quarry are the following prerequisites. The longitudinal profile of quarry roads is presented as broken vertical lines, whose parameters are expressed by the dependence of the total resistance to the distance of transportation $\Psi = f(l)$. The motion of the loaded dumper on rise and on horizontal sites is considered at calculations. The motion of the vehicle on the rise is characterized by two modes related to uneven motion, when accelerating $P_{\mathrm{j}} = P_к - P_f - P_i - P_w$, or when slowing down $P_{\mathrm{j}} = P_к - P_f - P_i - P_w$, where P_j is the inertia force of the vehicle*;* P_f is the rolling resistance; P_i is the resistance force of the rise of the road. The equation corresponding to uniform motion is $P_к - P_f - P_i - P_w = 0$ The condition of the sufficient traction is that acceleration of the vehicle should be with the maximum possible acceleration and at the highest possible speed not exceeding the limit and safe. The condition of the sufficient stability and traction is determined by the fact that the model does not consider wheel slippage, redistribution of reactions on the axles and wheels, oscillating processes in the transmission and chassis, and reducing the effectiveness of the brakes.

The methodological construction of a model, which reproduces the motion modes of a loaded dumper in order to study and optimize its technical and operational performance, is to simulate the conditions of quarry roads. Computational calculations of traffic in individual phases are performed in a sequence depending on the specific traffic conditions on a track. The traffic condition is determined by the numerical values of the geometric elements of the road, various limitations and the alternation of both. When simulating the longitudinal profile of quarry roads, a definite deterministic motion is modeled. The modes of the dumper motion are determined by a combination of technical and geometric parameters of the road.

Conclusions and direction of further research. As a result of modeling the traction mode of dumpers with a capacity of 75-130 tons, we found that the rational longitudinal profile of roads on deep horizons is concave. That provides the speed of loaded trucks by 3-9% higher than convex and 2-4% higher than straight sloping. A higher speed on the concave longitudinal profile relies on the use of a profile that provides a more favorable loading mode of units of the dump truck and contributes to the rational use of inertia of the moving vehicle. Thus energy expenses of the dumper on the concave-longitudinal-profile road are less than on the straight sloping and convex profile. The rational use of the inertia force of the dumper moving on the concave-profile road provides a higher speed when entering areas with slopes of the longitudinal profile of more than 90-100 ‰.

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