Justification of Efficiency of Heavy Dump Trucks Effectiveness in Open pit Mines According to Operating Life Criterion of the Back Axle

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***Abstract* - Open pit mine dump trucks with different carrying capacity transport more than 80% of overburden and coal from open pit mines of Kuzbass. The universal indicators of vehicles operating conditions are: energy intensity which determines energy consumption for minerals transportation and durability which characterizes operating life of a unit or an element of a vehicle. Constantly changing mining-geological and mining-technological operational parameters lead to significant costs for diesel fuel and repairing works, planned and unplanned downtime for heavy dump trucks. Therefore, the research, aimed at establishing admittible operating conditions of heavy dump trucks operation in open pit mines, is of current concern. The scientific work is done by means of GPS systems digitized data analysis, and by means of processing the results of experimental tests by methods of mathematical statistics and econometrics. The main results are the following: the effect of average size pieces in the face at energy consumption per unit is estimated; the interconnection of mathematical expectation of stress amplitude occurring in metal structures and energy consumption per unit under rock mass transportation is determined; admittible average diameters pieces of blasted rock mass for dump trucks of different capacity according to operating life criterion of a back axle of a vehicle are defined.**

***Keywords* - heavy dump trucks; effectiveness; operation; energy consumption per unit; route inclination; durability; the admittible operating conditions.**

I. INTRODUCTION

Currently Kuzbass coal mines are mostly equipped with dump trucks of various carrying capacities: for example, CJSC "BelAZ", Komatsu, Caterpillar [1]. To evaluate the effectiveness of transportation of mined rock by heavy dump trucks, the value of the energy consumption per unit is accepted (g.s.f. / t m) for the transportation of 1 ton of cargo [2]. It was found that the energy consumption per unit is substantially affected by such factors as overloading of a truck, route inclination on the rise, transportation distance, turning and crossing, the engine power, speed and other (Table 1) [3].

The analysis of the influence of various operating parameters of open pit mine motor transport on energy consumption of the transportation process showed that the longitudinal slope of open pit mine roads and grain size composition of mined blasted rock are the most informative means of assessment of the energy consumption per unit parameters and durability of metal structures [4].

TABLE 1 - Factors influencing auto transport effectiveness

Mining-technological	Technical
1. Roads conditions.	1. The engine power.
2. Rise, slope.	2. The overloading of a truck.
3. Turnings.	3. Speed.
4. Crossings.	4. Mileage since the operational start.
5. Route inclination on the rise.	5. Integrity of fuel system and engine.
6. Transportation distance.	6. Index of back of a truck filling.
7. Grain size composition of mined rock.	
8. Mass of cargo to transport.	

II. MATERIALS AND METHODS

The monitoring of indicators of operating vehicles in open pit mines of Kuzbass in September – December of 2015 allowed to estimate that 60-65% of dump trucks runs were made in overloaded or underloaded condition (Table 2).

Table 2 shows that overloading and underloading condition of a dump truck is a result of unsatisfactory preparation of a face for excavation. In this regard, the establishment of relationship between the quality of the prepared blasted rock mass for excavation and excavator automobile complex efficiency is of great current interest.

The main most important indicator of the quality of rock preparation for excavation is grain size composition of blasted rock mass, which is characterized by an average diameter of a piece in debris. The degree of lumpiness influence affects significantly the effectiveness of dump trucks and it decreases with cargo transport equipment increase. Figure 1 shows the dependence of shift effectiveness of mining shovels from the average diameter of a piece in debris [5].

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TABLE 2. The data from satellite monitoring system of operating auto trucks BelAZ -75306

	A	D	E	F	G	H	X	Y	Z
1	Run resport								
2	#	Model	Number	№ n/n	Period	Shift	Loading zone	Unloading zone	Cargo mass, t
3		01.11.2015							6684,53
4									196,6
5		Shift 1							3173,06
6									186,65
7	1	BelAZ 75306	551	1	01.11.2015	Shift 1	P&H 2300	North dump	249,35
8	2	BelAZ 75306	551	2	01.11.2015	Shift 1	P&H 2300	North dump	235,5
9	3	BelAZ 75306	551	3	01.11.2015	Shift 1	P&H 2300	North dump	230,61
10	4	BelAZ 75306	551	4	01.11.2015	Shift 1	P&H 2300	North dump	231,19
11	5	BelAZ 75306	551	5	01.11.2015	Shift 1	P&H 2300	North dump	248,37
12	6	BelAZ 75306	551	6	01.11.2015	Shift 1	P&H 2300	North dump	0,
13	7	BelAZ 75306	551	7	01.11.2015	Shift 1	P&H 2300	North dump	249,42
14	8	BelAZ 75306	551	8	01.11.2015	Shift 1	P&H 2300	North dump	225,91
15	9	BelAZ 75306	551	9	01.11.2015	Shift 1	P&H 2300	North dump	170,86
16	10	BelAZ 75306	551	10	01.11.2015	Shift 1	HITACHI 1	South dump	183,41
17	11	BelAZ 75306	551	11	01.11.2015	Shift 1	HITACHI 1	South dump	229,41
18	12	BelAZ 75306	551	12	01.11.2015	Shift 1	HITACHI 1	South dump	0,
19	13	BelAZ 75306	551	13	01.11.2015	Shift 1	HITACHI 1	South dump	201,81
20	14	BelAZ 75306	551	14	01.11.2015	Shift 1	HITACHI 1	South dump	261,75
21	15	BelAZ 75306	551	15	01.11.2015	Shift 1	HITACHI 1	South dump	0,
22	16	BelAZ 75306	551	16	01.11.2015	Shift 1	HITACHI 1	South dump	230,9
23	17	BelAZ 75306	551	17	01.11.2015	Shift 1	HITACHI 1	South dump	224,55

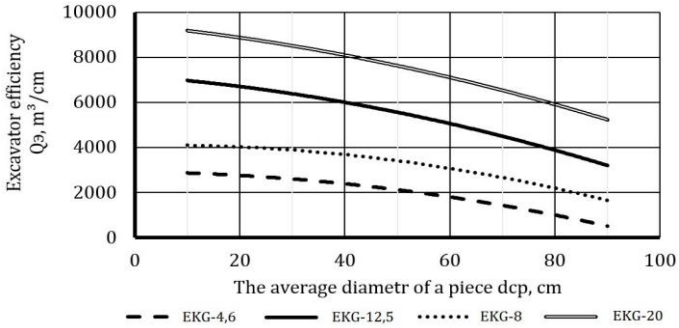

Fig. 1. The dependence of shift effectiveness of a mining shovel from the average diameter of a piece in debris

As a result of dump trucks "BelAZ" with different carrying capacity operation monitoring in open pit mines of Kuzbass (Kedrovskiy, Bachatskiy, Tomusinskiy) with route inclination from 10 ‰ to 100 ‰ the influence of the average diameter of a piece in debris to the effectiveness of open pit mine vehicles was estimated (Fig. 2).

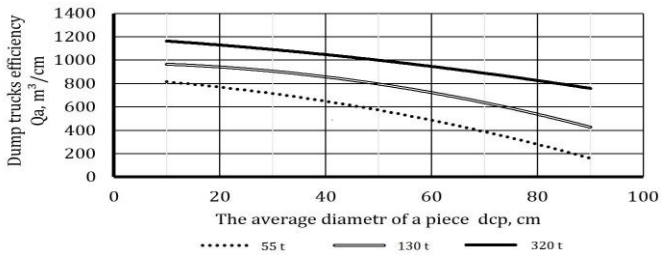

Fig. 2. The dependence of dump truck effectiveness on the average diameter of a piece in a face

If to use more powerful excavators with bucket capacity of 20 m^3 or more the increase in diameter of an average piece to 0.7 m leads to decrease in effectiveness of heavy dump trucks.

Grain size composition of blasted rock mass, estimated by the average diameter of a piece in debris affects not only the effectiveness of mining machines, but also the energy consumption during transportation.

To assess the criterion of energy efficiency of transport systems of deep open pit mines, the value of the specific energy consumption was accepted, which is determined according to the formula proposed by professor Yu. I. Lel,

$$P_{ф} = \frac{g}{i} \cdot k_{пер} \cdot k_{уТ} \cdot k_{д}, \quad (1)$$

where $P_{ф}$ – the energy consumption per unit for transportation of 1 ton of rock mass by 1 m, g.s. f./t·m (grams of specific fuel/t·m); g – specific consumption of diesel fuel of dump truck, g/t·m; i – route inclination, ‰; $k_{пер}$ – processing coefficient, reflecting the energy consumption to obtain diesel fuel from oil ($k_{пер}$=1,18÷1,20); $k_{д}$ – coefficient taking into account the energy consumption to produce and transport the fuel ($k_{д}$=1,04÷1,10) [6]; $k_{уТ}$ – coefficient taking into account the difference of the specific heat of combustion of diesel and specific fuel ($k_{уТ}$=1,5).

Specific consumption of diesel fuel of a dump truck was calculated from the expression

$$g = \frac{Q}{m \cdot l}, \quad (2)$$

where Q – fuel consumption, g; m – transported cargo mass, t; l – transport distance, m.

Energy consumption per unit is a multi informative index of effectiveness and technical readiness of heavy dump trucks. According to the analysis of operation of open pit mine motor transport of different carrying capacity in open pit mines of Kuzbass, the influence of the average diameter of a piece in debris on the value of energy consumption per unit under rock mass transportation was estimated (Fig. 3).

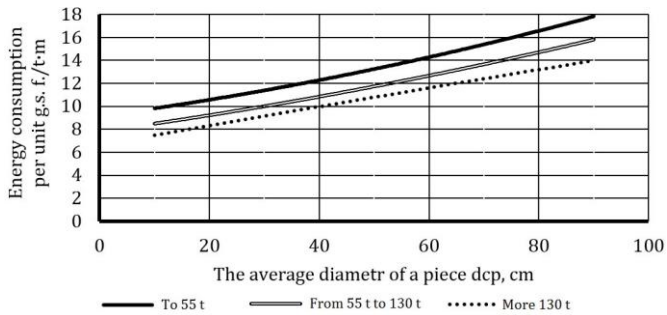

Fig. 3. The dependence of energy consumption per unit of heavy dump trucks on the average diameter of a piece of blasted rock mass

Figure 3 shows that the energy consumption per unit increases with the lumpiness rise in a face, characterized by an average diameter of a piece, which leads to the significant increase in fuel consumption during transportation of rock mass, the decrease of truck body filling ratio and, consequently, the effectiveness of a dump.

The increase of an average piece to 0.7-0.8 m reduces not only productivity of excavator - automobile complex, but is the consequence of non-stationary distribution of loads and increasing stresses in the basic elements and components of a machine (body, frame, front and back axle), it leads to reduction of the service life and operation deadline. In order to establish the relationship of stresses and energy consumption per unit during transportation of rock mass, taking into account the route inclination changing, stress state of the back

axle of a dump truck BelAZ-75131 was assessed, when the inclination angle of the route (20-70 ‰) and distance transportation (2-5 km) were changed; the assessment was done by means of recording the amplitude frequency cycle at different sections of the road with the help of strain test station A17-T8 and laptop AcerAspire 5630 [6].

Calculation of energy consumption per unit, characterizing the energy consumption of transportation process was carried out with the use of GPS-navigation.

III. Results

To get the empirical relationship between the energy consumption per unit and mathematical expectation of stress amplitude under different operating conditions the approximation methods were used.

The area of distribution of the experimental data is presented in Figure 4.

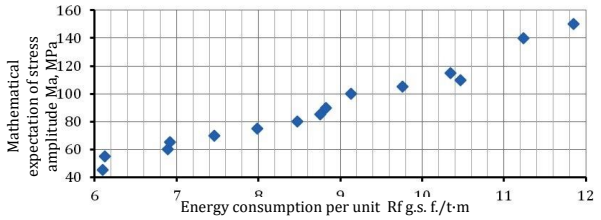

Fig. 4. The dependence of mathematical expectation of stress amplitude on the energy consumption per unit

Figure 4 shows that the stresses in metal structures of the back axle of a dump truck correlate quite well with the energy consumption per unit, consumed by transportation of rock mass.

To test the hypothesis of equality of the mathematical expectations of two independent experimental samples, two-sample t-test with different dispersions was carried out. [7] The calculation results are shown in Table 3.

TABLE 3. The results of two-sample t-test with different dispersions

1. Hypothetical mean difference	0
2. The number of degree of freedom (df)	14
3. The meaning of criterion statistics (t-statistics)	-10,28
4. Probability P (T<=t) one-sided	$3{,}30 \cdot 10^{-8}$
5. The value of quantile t critical one-sided	1,76
6. Probability P (T<=t) two-sided	$6{,}60 \cdot 10^{-8}$
7. The value of quantile t critical two-sided	2,15

Table 3 shows that the value of probability of random occurrence of analyzed samples is sufficiently small and constitutes P (T <=t) = $6{,}60 \cdot 10^{-8}$, which is less than the significance level equal to 0.05. This means that the differences between the samples cannot be accidental.

To study the effect on the measured random value (stress amplitude) of the independent value (energy consumption per unit), the one way univariate dispersion analysis was performed. The analysis results are shown in Table 4.

TABLE 4. The results of one way univariate dispersion analysis

1. Intergroup sum of squares (SS)	49173,5
2. The number of degree of freedom between groups (df)	1
3. Intergroup dispersion (MS)	49173,5
4. The probability value (P value)	$5{,}2 \cdot 10^{-11}$
5. The meaning of criterion statistics (F)	105,8
6. F- critical	4,2

The analysis of Table 4 shows that the impact of the investigated variable can be regarded as proved, since P-value is less than the significance level equals to 0.05.

The results of the analysis of the relationship of mathematical expectation of stress amplitude, energy consumption per unit and continuous monitoring of heavy vehicles loading parameters contribute to the adoption of operational decisions to provide efficiency of dump trucks for a long period of their operation.

The results of selection of a mathematical model to describe the experimental dependence $M_{\sigma a} = f(P_{\phi})$ are shown in table 5.

TABLE 5. The results of selection of a mathematical model to describe the experimental dependence

Function type	**Functional dependence**	**Coefficient of determination (R^2)**
Linear	$M_{\sigma a} = -54{,}72 + 16{,}62P_{\phi}$	0,969
Parabolic	$M_{\sigma a} = 1{,}13P_{\phi}^{\,2} - 3{,}25P_{\phi} + 29{,}45$	0,982

According to the result of analysis of the equations it was found that a linear dependence between stress amplitude and energy consumption per unit cannot be used to calculate the relationship of stresses and the angle of route inclination on the rise, since under the range of inclination from 10 to 30 ‰ negative stress occurs in metal structures, and physical meaning is lost as a consequence. Therefore, parabolic dependence is taken for further calculations.

To describe the experimental dependences between stress and the range of a route inclination angle, the model of the relationship of mathematical expectation of the stress amplitude and energy consumption per unit was taken, as well as the formula obtained earlier was applied [8]

$$F(i,q) = i^2(0{,}007q^2 - 0{,}003q + 0{,}0006) + i(1{,}144q^2 - 0{,}674q + 0{,}094) - 39{,}374q^2 + 22{,}032q + 0{,}167.$$

The law of distribution of the mathematical expectation of the stress amplitude from the route inclination of each dump

truck is parabolic. The determination coefficient of dependency varies from 0.98 to 0.99, which allows obtaining the generalized equation for dump trucks with certain capacity. The equation coefficients are the average value of the dependencies of respective dump truck group. The results are shown in Table 6.

TABLE 6. Generalized equations of dependence of the mathematical expectation of stress amplitude on the route inclination for each group

Cargo capacity of a dump truck, t	**The equation of dependence of the mathematical expectation of stress amplitude ($M_{\sigma a}$, МПа) on the route inclination (i, ‰)**
To 55	$M_{\sigma a} = 0{,}024i^2 - 1{,}07i + 39{,}1$
55 - 130	$M_{\sigma a} = 0{,}012i^2 - 0{,}5i + 33{,}9$
More 130	$M_{\sigma a} = 0{,}006i^2 - 0{,}23i + 32{,}7$

The obtained dependences of the mathematical expectation of the stress amplitude in metal structures of the back axle of the route inclination angle allow making of a rapid and efficient selection of the dump truck groups for their operation in complex mining conditions.

The most significant mining technology factor influencing the performance of dump trucks operation is the angle of inclination of the route. According to the results of the analysis of open pit trucks operating conditions the joint diagram was made; the diagram shows the dependences of mathematical expectation of the stress amplitude ($M_{\sigma a}$) and energy consumption per unit of the route inclination for BelAZ dump trucks of three major groups with carrying capacity (up to 55 t, 55-130 t and 130 t) (Fig. 5).

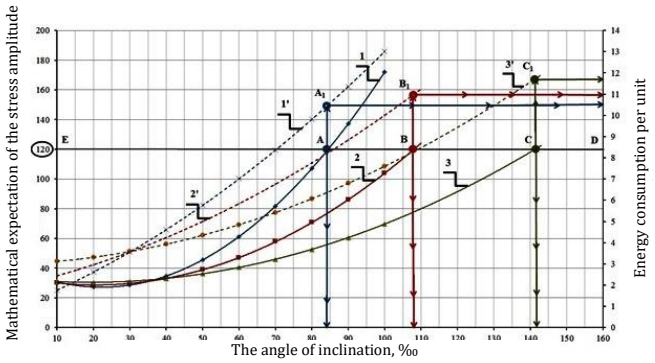

Fig. 5. The joint diagram of dependences of the mathematical expectation of the stress amplitude (1, 2, 3) and energy consumption per unit (1', 2', 3') of the route inclination for BelAZ dump trucks with carrying capacity less than 55 t, 55-130 t and more than 130 t respectively

The safety factor coefficient (n) for the majority of metal structures is adopted in the range of 1.2-2. When adopting n = 2 horizontal black (permissible) line ED in the diagram corresponds to the allowable stress of 120 MPa. The abscissa of the intersection points of this line with the curves of the charts 1, 2, 3 (A, B, C) characterizes the route inclinations for each of these dump trucks types; the growth of cracks is encouraged by stresses in metal structures of a support under inclination increase, the durability and service life of the elements of the back axle beam is reduced.

The values of energy consumption per unit correspond to the values of inclination points A_1, B_1, C_1 calculated by the diagram.

IV. Conclusions

According to the analysis of Figures 3 and 5, the admittible values of parameters of heavy dump trucks operating on the criterion of durability of the back axle of metal structures were estimated, if these parameters decrease substantially the efficiency, performance and service life of vehicles decrease (table 7).

TABLE 7. The admittible parameters of heavy dump trucks operation

Cargo capacity, t	**Energy consumption per unit, g.s. f./t·m**	**Route inclination on the rise, ‰**	**The average diameter of a piece in debris, cm**
less 55	10,5	85	18
from 55 to 130	11	108	43
more 130	11,9	149	62

Under preparation of rock for excavation by blasting, it is recommended to take into account the admittible operating parameters of heavy dump trucks, which contribute to the rational allocation of open pit mine vehicles with account of durability of the back axle of dump metal structures.

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