

METHOD FOR CALCULATION OF THE INFLUENCE OF THE LONGITUDINAL SLOPE OF THE ROAD ON THE TIRE LIFE

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ABSTRACT

This article presents a methodology for studying the effect of each percentage of the longitudinal slope of open-pit roads on tire life. The experiment was carried out at the Muruntau quarry, owned by the Navoi Mining and Metallurgical Combine (NMMC). The experiments were carried out on Komatsu HD785-7 dump trucks with a carrying capacity of 91 tons. According to the results of the experiment, it was found that the life of dump truck tires operated on routes with an average road slope of 6% is reduced by 2 times compared to tires operated on a horizontal road.

Key words: tire life, quarry roads, technological transport, longitudinal slope of the road, rock strength, rock mass transportation

INTRODUCTION

At mining and metallurgical enterprises, special requirements are imposed on the tires of heavy dump trucks transporting rock, since their operation is carried out in difficult road conditions [1 – 2]. The tire life is affected by the following factors: proper loading of the dump truck and uniform distribution of the shipped ore, condition and type of road surface, longitudinal and transverse slope of the road, internal pressure in the tire, driver experience, etc.

At present, the main types of transportation of minerals at mining enterprises are motor vehicles, rail transport and conveyor transport. Road transport has found wider use than other types of transportation of minerals. The advantage of this type of transportation is high maneuverability, overcoming large slopes and mobility. For mining enterprises in the extraction of minerals, one of the urgent tasks is to reduce the operating costs for the transportation of minerals [3 – 5].

Operating costs for tires are 25 – 30% or more of the cost of transporting rock mass by dump trucks. Therefore, increasing tire mileage is essential to reduce costs [6 – 7].

ANALYSIS OF EXISTING STUDIES

According to Michelin, the following decrease in the resource (mileage) of tires has been established depending on the longitudinal slope of the roads: calculation during tire operation - 33% of the service life on the front axle, and 67% - on the rear [8] (table 1).

Table 1 Reduced tire life depending on the slope of the roads

Slope, %	Lift cycle with load, %	Downhill cycle with load, %
8	100	61
10	81	44
12	64	32

Based on the analysis of statistical data, N. A. Tsytchenko recommends using the values of the tire wear increase coefficients given in table 2.

Table 2 Increase in tire wear coefficient depending on the value of the longitudinal slope [9]

Slope, %	0 – 2	3	4	5	6	7	8	9
Tire wear factor, I_t	1	1,1	1,22	1,35	1,5	1,65	1,8	2,0

The studies of S. B. Nikitin revealed the dependence of the average tire wear on the longitudinal slopes when driving an empty and loaded car on ups and downs (Fig. 1).

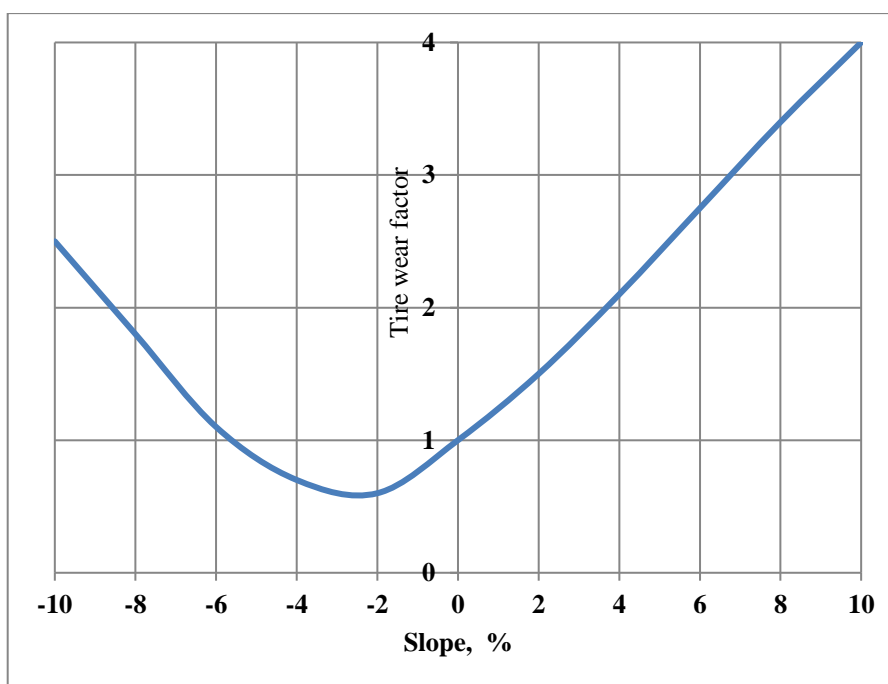


Fig.1. Dependence of tire wear on the value of the longitudinal slope

Taking tire wear as a unit on a horizontal flat area, we obtained the value of the average (half the sum of wear on the ascent and descent) relative tire wear on the value of the longitudinal slope (Fig. 2) [10].

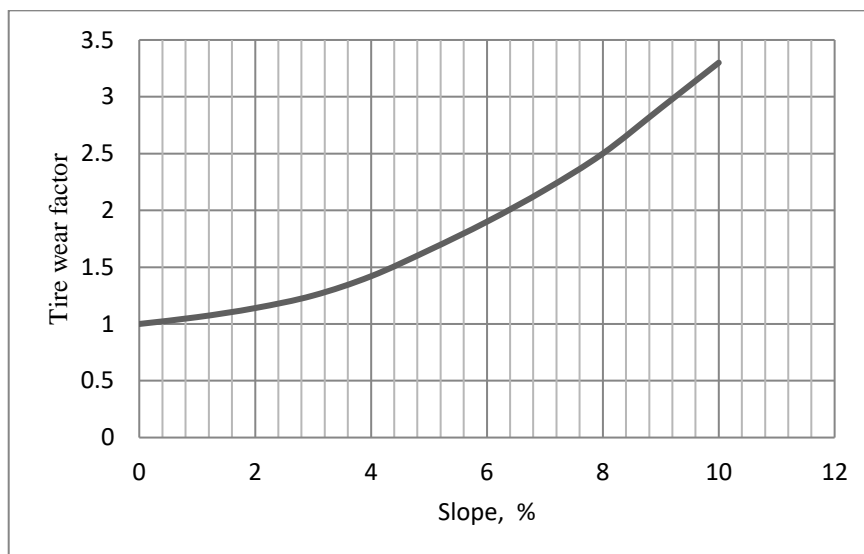


Fig.2. Dependence of the relative wear of tires on the value of the longitudinal slope

All of the previous analyzes have examined the effect of road gradient on tire life in mountainous conditions, i.e. asphalt road at the pass. The influence of the slope of quarry technological roads on the resource of tires has not been studied sufficiently. Based on the analysis of studies, an attempt was made to assess the impact of the slope of the technological road of the Navoi Mining and Metallurgical Combine (NMMC) on the tire resource.

CHARACTERISTICS OF OBJECTS AND SUBJECTS OF RESEARCH

Mining heavy dump trucks are designed to transport rock mass along technological roads in open pit mining with different climatic conditions [11–13]. Experimental studies are being carried out at the Muruntau, Amantai and Turbay quarries, which belong to the Navoi Mining and Metallurgical Complex. The object of the study is tires (27.00R49) of mining dump trucks Komatsu HD785-7 (table 3). The subject of research is the resource of tires.

Table 3 Main technical data of dump truck Komatsu HD785-7 [14]

Load capacity, kg	91000
Operating weight, kg	72300
Gross weight, kg	163300
Mass distribution, kg: unladen:	
-front	33980 (47%)
-rear	38320 (53%)
gross weight: -front	51440 (31,5)
-rear	111860 (68,5)
Tipper body capacity, m ³ :	
-geometric	40
-with a hat (2:1)	60
Maximum travel speed, km/h	65
Ability to overcome the rise,%	35
Minimum turning radius, m	10,1

Dump angle, °	48
Overall dimensions, mm:	
-length	10290
-width	5050
-height	4950
Engine	
Model	Komatsu SAA 12V140E-3
Type	4-stroke, water-cooled, V-shaped, 12-cylinder, with direct injection, turbocharger and aftercooler
Working volume, l (cm ³)	30,5 (30500)
Useful engine power, kW (rpm)	879(1900)
Full engine power, kW (rpm)	895(1900)
Maximum torque, Nm (rpm)	5076 (1350)
Fuel consumption (min), g/kWh	206
Power transmission	
Torque converter: Device Clutch lock	Three element, single stage, two phase Hydraulically actuated wet multi-plate clutch
Gear box: Type Number of gears	Planetary (fully automatic, with electro-hydraulic drive, forced lubrication pump). 7 forward gears, 2 reverse gears
Reducer: Type Gear ratio Differential type	Spiral bevel gear with splash lubrication 3,357 Spiral bevel gear with splash lubrication
Final drive: Type Gear ratio	Planetary gear with splash lubrication 6,333
Tires	27.00R49★★E4
Tire pressure, kPa (kg/cm ²)	686 (7)

Tires must meet basic performance specifications, including tonne-kilometers per hour, tread type, tire pressure, ply rating, etc. [15]. Table 4 describes the tires used in the Muruntau quarry on Komatsu HD785-7 dump trucks.

Table 4 **Main characteristics and design features of oversized tires**

Tire specifications	Tire brand	
	Michelin 27.00R49 (France)	
Installed on a dump truck	Komatsu HD785-7	
Tire model and type	XDR3 TL	XDR2 TT
Pattern type	E-4R	E-4R
Rubber type	B4	B4
Rim	19.50/4.7[3.2]	19.50/4.0 [3.2]
Outer diameter, mm	2730	2733
Profile width, mm	730	738
Maximum load, kg	27250	27250
Tread depth, mm	90	90
Maximum speed, km/h	50	50
Layering (strength):	★★★	★★
Tire pressure, kg/cm ²	6,5	6,6
TKPH	528	480
Tire weight, kg	1380	1280

TEST EQUIPMENT

During the experimental studies, the following equipment was used:

1. Electronic thermometer for measuring ambient air temperature with an accuracy of ± 0.1 °C.
2. U901 tire pressure monitoring system, wireless TPMS with 6 external sensors.
3. Average cruising speed as measured data.
4. A special inclinometer sensor installed on the basic set of machines to fix the road slope.
5. Electronic depth gauge with an accuracy of 0.1 mm - a device for determining the measurement points of the tread height in order to increase the reliability of the results.
6. Torque, power and wheel speed received from the dump truck ECU using a computer using a special RealDisp program.
7. Pressure sensors on the suspension cylinders of the machine (all 4 sensors), from the parameters of which the mass of the load was recorded.

ROAD TEST METHODOLOGY

Experimental studies begin with determining the degree of strength of the quarry rock. All career routes are divided into 5 groups, based on the average longitudinal slope of the road. The routes of the first group are roads with an average slope from -1 to +1%. The average slope of the route of the second group should be in the range from +1 to +3%, the third group - in the

range from +3 to +5%, the fourth group - in the range from +5 to +7%, the fifth group - over +7% [16 – 17].

Experiments begin with the selection of dump trucks (at least 3, based on the number of the garage) in a group with an average road slope of up to 1%. Qualified drivers with at least 5 years of experience are selected for the experiment.

Then dump trucks are selected for the rest of the routes. A tire model is selected for dump trucks, after which the tires are checked for quality and prepared for testing. Depending on the capabilities of the organization, the dump trucks participating in the experiment will be fitted with new tires.

Experiments are carried out simultaneously on all routes, divided into 5 groups. A separate table is compiled for each group of dump trucks. The table records the distance traveled by the truck, the remaining tread depth of each tire, and the average tire wear rate. The average tire wear rate is calculated using the following formula [18 – 19]:

$$\gamma_{av} = \frac{h_1 - h_2}{S_2 - S_1} \tag{1}$$

where h_1 is the initial tread height, mm; h_2 – tread height at the end of the measured run, mm; S_1 – mileage at the beginning of measurements, thousand km; S_2 – the value of the run at the end of the measured run, thousand km.

Experimental studies are carried out within 3 – 12 months, depending on the change in the length of the routes. Once every two weeks, measurements are taken and entered in the table (table 5).

Table 5 Accounting card for experimental studies of the influence of road slope on the resource of tires of dump trucks Komatsu HD785-7

№	Installation location	Manufacturer	Date of measurement												
			Mileage, km												
			0,00												
			Start height tread, mm	Tread wear, mm	Tread height, mm	Wear tread, mm	Average intensity wear, mm/thousand	Tread height, mm	Wear tread, mm	Average intensity wear, mm/thousand	Tread height, mm	Wear tread, mm	Average intensity wear, mm/thousand		
1	F.L.	Michelin ,	90	0											
2	F.R.														
3	R.L.I.														
4	R.L.O.														
5	R.R.I.														
6	R.R.O.														

Note: Here and in table 17 F.L. - front left tire, F.R. – front right, R.L.I. - rear left inner, R.L.O. – rear left outer, R.R.I. – rear right inner, R.R.O. - rear right outer.

Based on the table (see table 5), graphs are built and the dynamics of tire tread wear is analyzed. For dump trucks of each group, the operational (expected) mileage is calculated using the following formula.

$$L_0 = \frac{1000(h_{in} - h_{res})}{\gamma_{av}} \quad (2)$$

where L_0 – is the distance traveled by the dump truck to maintain the tread height of 1 mm, km; γ_{av} – is the average intensity of tire wear, mm/1000km; h_{in} – begin – initial tread height, mm; $h_{res} = 1$ MM.

The results of the experiment are due to the analysis of the mileage of dump trucks moving along the routes of the first group. On roads with an average longitudinal slope from -1 to 1%, the impact on tire wear is assumed to be $K_{s0} = 1$. According to formula (2), we calculate L_0 for each of the 5 groups L_{01} , L_{02} , L_{03} , L_{04} , and L_{05} .

After that, the calculated coefficients of the average slope of the road, affecting the resource of tires K_{s2} , K_{s4} , K_{s6} , K_{s8} are determined by comparing L_{01} , L_{02} , L_{03} , L_{04} and L_{05} with each other.

$$K_{s2} = \frac{L_{01}}{L_{02}}; K_{s4} = \frac{L_{01}}{L_{03}}; K_{s6} = \frac{L_{01}}{L_{04}} \text{ and } K_{s8} = \frac{L_{01}}{L_{05}}$$

For routes with an average longitudinal slope of the road 1, 3, 5, 7%, the coefficients affecting the tire life K_{s1} , K_{s3} , K_{s5} , K_{s7} , are determined by the prediction method. With the help of these correction factors, it is possible to predict the life of tires for mining trucks operating on any road slope.

Experimental studies were carried out in accordance with the requirements and methods of the international standard "GOST 28169-89. Tires are pneumatic. Methods for determining the wear resistance of tires during road tests.

EXPERIMENT

Experimental studies were carried out at the Muruntau quarry, owned by the Navoi MMC. First, the operating conditions of the quarry were studied and the following was established:

1. Quarry depth: 630 m, on average – 450 m.
2. Makes and models of dump trucks CAT-777 (90t.) and Komatsu HD 785-7 (91t.).
3. Road surface and its percentage at the transportation distance: hard rock, 20 – 30%.
4. Access roads to excavators and to the place of unloading of the total transportation distance: approximately 15 to 25%.
5. Width of technological roads, m: maximum 22 – 26 m, average – 18 m.
6. The number of turns on the entire transportation arm: 2 – 10 and their radii, m: maximum – 60 – 80; minimum – 26 – 30.
7. Evaluation of slopes, %: maximum – 12, average – 5 – 7.
8. Shoulder transportation (one way), m: maximum – 10000 – 14400; minimum – 250 – 1000; medium – 4300 – 5800.
9. Operating time (cycle), h: 0,5 – 0,8.
10. Dump truck speed, km/h: maximum: – 40 – 45, average – 14 – 17.
11. TKPH for tires 27.00R49 – TKPH >415.
13. Type of transported rock, loosening coefficient, weight of rock, kg/m³: overburden – hard rock with a density of 1.8 to 2.2; ore – hard rocky rock with a density of 2.2 to 2.8.

14. Coefficient of rock strength according to the scale of M. Protodyakonov: 10 – 12.
15. Loading equipment (model, bucket volume): ECC-15, bucket volume - 15m³, EC-20, EC-25, bucket volume 20 and 25m³.
16. Load control system: on BelAZ-7513,75307 dump trucks, the load and fuel control system (LFCS) was installed, on CAT-789 dump trucks - the VIMS system and on Komatsu HD 785-7 was recorded from the parameters of pressure sensors on the vehicle suspension cylinders (all 4 sensors).
17. Determined how many days with bad road conditions due to weather conditions. The roads are serviced daily by the road service, periodically 3 – 4 days.
18. Maximum seasonal temperature: in winter - maximum -25°C, average -0 – -10°C, in summer – maximum +45°C, average +30 – +40°C.

ALL ROUTES OF DUMP TRUCKS IN THE MURUNTAU QUARRY HAVE BEEN STUDIED AND ANALYZED. MORE THAN 90 DUMP TRUCKS AND 27 EXCAVATORS ARE USED AS TECHNOLOGICAL TRANSPORT AT THE MURUNTAU QUARRY.

Experiments for the first group of dump trucks began on february 3, for the second – on february 7, for the third – on march 4, for the fourth group on march 11 and for the fifth – on april 7.

Once every 2 weeks, the distance traveled, the residual tread height, air temperature, and tire pressure were measured. In addition, the condition of the tires was checked. In case of mechanical damage, cuts in the tread or sidewall, etc. repairs were made after which they were again used in the experiment. If the tires were damaged, an act was drawn up and they were removed from the experiment.

The dynamics of tire wear of each dump truck included in the group was studied, graphs were built and compared with other dump trucks of the same group. Along with this, the average mileage of the tires installed on them was calculated and entered into the graph. This was realized in all five groups.

Calculations of wear intensity were carried out according to the method of determining the expected operating time by establishing the intensity of tire wear.

All tire wear resistance research data were summarized in special “Tire Life Experimental Research Record Cards”. They also provide the results of calculations of the predicted tire mileage until the tread is completely worn out, which is the basis for normalizing the operational mileage of controlled oversized tires.

The initial tread height of the new Komatsu HD785-7 tires installed on february 3, 2022 was 90 mm. All calculations were made on tires that had natural wear, without taking into account tires that were prematurely removed from service due to mechanical damage or tread separation.

ANALYSIS OF THE RESULTS OF EXPERIMENTAL STUDIES

During the experiment, the intensity of tire wear of the front and rear axles of the dump truck was separately studied and analyzed.

We assumed that the average slope of the first group is 0%, the average slope of the second group is 2%, the average slope of the third group is 4%, the average slope of the fourth group is

6%, and the average slope of the fifth group is 8%. On the routes of the first group, the influence of the longitudinal slope of the road on the tire life is taken equal to 1.

As a result of the experiment, the average operating mileage of dump trucks in each group was determined. The average mileage of 5 dump trucks in the first group was 120,000 km, in the second group – 98,400 km, the average mileage of 12 dump trucks in the third group was 78,000 km, the average operating mileage of 5 dump trucks in the fourth group reached 62,400 km, and the average dump trucks in the fifth group – 46,800 km. The correlation of the found values was expressed by the following formula:

$$y = e^{0,113x} \tag{3}$$

Using this formula, by predicting, coefficients are found that reduce tire life, corresponding to each percentage of the longitudinal slope of the route. These values are shown in table 6.

Table 6 Tire life reduction coefficients corresponding to each percentage of longitudinal slope

Average slope of the road, %	Coefficients taking into account the influence of the average road slope on the tire life K_s	Operational mileage of tires, km
0	1	120000
1	1,10	109090
2	1,22	98400
3	1,39	86330
4	1,54	78000
5	1,74	68965
6	1,92	62400
7	2,24	53570
8	2,56	46800

According to this table 6, graphs were built (fig.5).

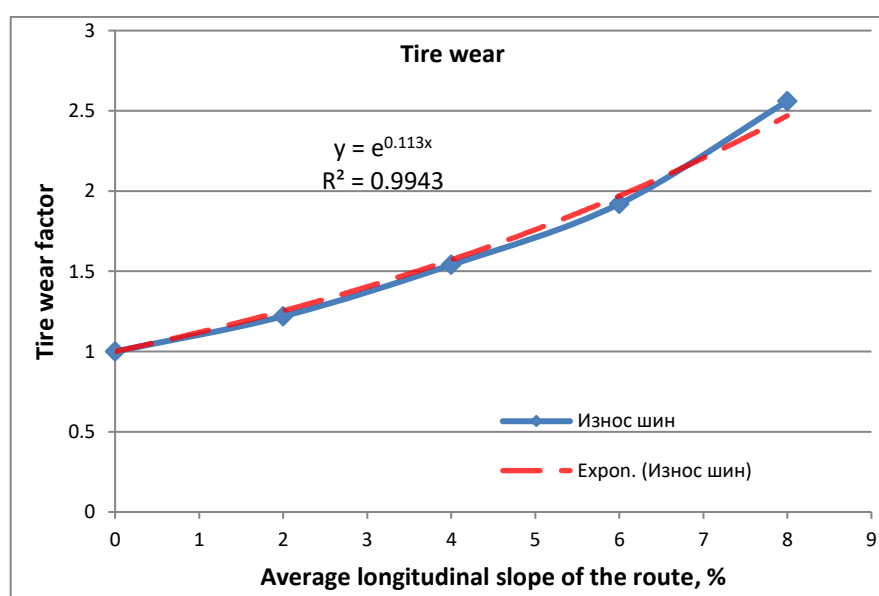


Fig.5. Influence of the longitudinal slope of quarry roads on the resource of tires

CONCLUSIONS

1. The loading control system on Komatsu HD 785-7 dump trucks was fixed from the parameters of the pressure sensors on the machine's suspension cylinders (all 4 sensors). The mass of cargo loaded into dump trucks ranged from 87 to 94 tons (95 – 105%).
2. The coefficient of rolling resistance in quarry conditions was approximately $f=0.05 – 0.06$. In such road conditions, on routes with a slope of 6%, a 2-fold decrease in tire life was observed.
3. The average speed of Komatsu HD785-7 dump trucks in the Muruntau quarry was 14 – 16 km/h when loaded, and 35 – 40 km/h when empty.
4. The experiment involved 30 dump trucks and 180 tires. Of these, 24 (13.3%) tires were withdrawn from service due to mechanical damage and delamination.

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