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DETERMINING OF THE RATIONAL CAPACITY OF A BUNKER FOR CYCLIC-AND-CONTINUOUS TECHNOLOGY IN QUARRIES

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ВИЗНАЧЕННЯ РАЦІОНАЛЬНОЇ ЄМНОСТІ БУНКЕРА ПРИ ЦИКЛІЧНО-ПОТОКОВІЙ ТЕХНОЛОГІЇ НА КАР'ЄРАХ

Purpose. To determine the rational parameters of reloading points for cyclic-and-continuous technology at open mining operations using dump trucks.

Methodology. The basis of the developed methodology was the modeling of the physical essence of the process of road transportation, which most fully corresponds to the simplest flow in the theory of mass servicing of the Poisson type, and the reloading point from the point of view of bunkering and storage can be considered as an open queuing system in which the waiting time for unloading is approximated by an indicative distribution.

Findings. As a result of the calculations, the rational capacity of the bunker and the rational number of unloading points were determined on the basis of the condition of uninterrupted unloading of dump trucks at the transfer point.

Originality. For the first time, a quantitative assessment of the technological parameters of the reloading points was done, taking into account the journey duration of the dump truck in the cargo and empty ways, the load capacity of the dump truck, the loading time, the total number of dump trucks required for servicing the excavators, and a number of other parameters. Thus, complex analysis of the operation of the quarry transport system was carried out.

Practical value. Based on the proposed methodology, the possibility of increasing the efficiency of the transport system in open mining can be planned in advance, which ultimately will improve the overall productivity of the quarry.

Keywords: *dump truck, cyclic-and-continuous technology, rocks, rational capacity, reloading point*

Introduction. In the development of open-cast mining various transport solutions are used. This could be rail transport, road transport (large capacity dump trucks) or mobile conveyor transport. These modes of transport are considered in the monograph [1] in details. Here it is also noted that the most efficient in financial terms is combined transport (automobile – conveyor). In accordance with this monograph in the article [2] there were published graphs of the dependence of the transportation cost of one ton of rock mass depending on the depth of the quarry (Fig. 1). If the cost of transportation by rail is comparable for medium – depth quarries and even may be less than for combined transport (automobile – conveyor), for deep quarries the last mode of transport is beyond competition.

Thus, the use of combined transport for deep quarries is a common solution. It is widely used in the countries of the former USSR, for example, in Ukraine, Uzbekistan or Russia. For example, article [3] considers CCT conveyors applied to rocks of stripping at Pervomaiskiy quarry of PJSC "Severnyi GOK" (Ukraine). Article [4] is devoted to the use of this technology in Russian quarries. The similar technology was used at the quarry "Muruntau" of Navoi Mining-and-Metallurgical Complex [5] (Uzbekistan). At the loading stations, in addition to the overload itself, crushing of the rock mass is usually carried out with the help of crushing devices (crushers).

Analysis of the recent research and unsolved aspects of the problem. The open pit mining is undergoing the most intensive period of development where some problems arise that threaten the preservation of mining capacity and result in the rise in the operational costs and hence in the increase in the payback period of investments. The growth of development rates of mining operations and primarily the increase in the depth of quarries inevitably lead to the rise in the transportation costs. In addition, the right choice of the transportation process affects the overall slope angles of pit edges and, consequently, the relation of the waste rock volume and useful resources: the overburden ratio. There are advantages and disadvantages in any technology; therefore, it is necessary to mention that the flow technology is rather unsuitable for quarries with low productivity, small transportation distances, ultrahigh sinking speed and short operation life due to high capital costs and semi-mobile

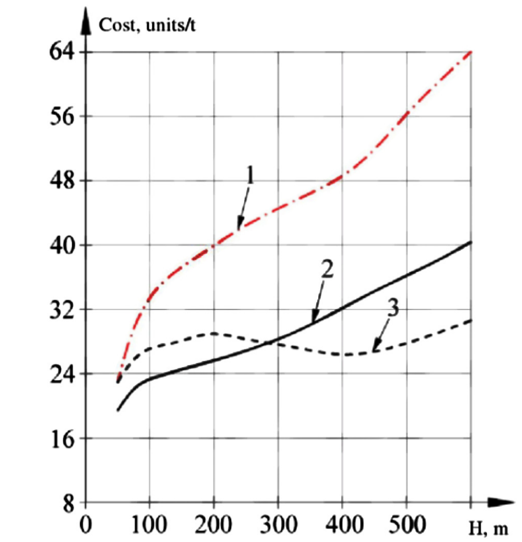

Fig. 1. Dependence of economic indicators on the opencast depth:

1 – automotive transport; 2 – railway transport; 3 – automotive-conveyer transport; C – cost price of ton of material transportation; H – depth of opencast

properties. The adopted practice of trying to minimize the costs by means of selective development of the field, the disorderly change of development directions is of little use for the semi-stationary crushing conveyor complex which is unable to change its location as the excavating railway reloading stations. In the conditions of intensively increasing depth of quarries and growth of costs for hydrocarbon fuel the open mining efficiency increase for many mining companies can be achieved due to the implementation of the cyclic-and-continuous technology (CCT). The dislocation of crushing and reloading stations ensures considerable reduction in the operation costs due to the replacement of a part of expensive vehicle fleet with cheaper conveyor transport. Depending on the work flow and installation place the crushing and reloading stations are divided into the semi-propelled, semi-stationary (mobile, portable) and stationary ones (Fig. 2) [6]. To load the crushing and reloading station it is possible to apply the option of a reloading station in the form of a collecting scoop that alternately takes in cargo from trucks and then unloads the rocks lifted by hydraulic cylinders into the crusher (Fig. 3) [7].

Such a model describes the operation of the mining transport chain of the quarry at cyclic-and-continuous flow charts with conveyors and vehicles, and the mathematical technique used ensures the accounting of accidental variations of the "excavator-truck-reloading station" system and determination of its quantity characteristics.

It is impossible to apply the known recommendations on the selection of rational parameters of the reloading stations at the application of the cyclic-and-continuous technology with trucks due to the design and process particularities of the motor transport system [8, 9].

The article contains the method of calculation of rational process parameters of reloading stations at the

Fig. 2. Two-point stationary crushing reloading station [6]

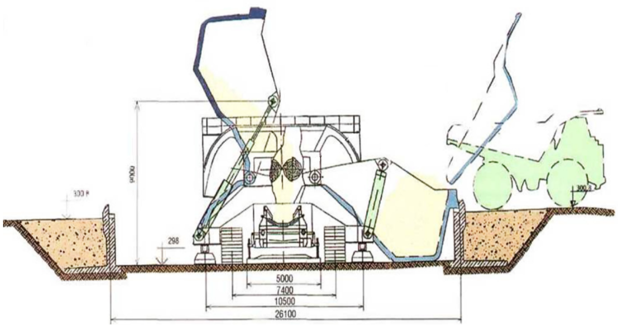

Fig. 3. The scheme of the crushing reloading station with a reloading mechanism in the form of collecting scoops

cyclic-and-continuous technology with the use of dump trucks. Let us assume that the Poisson flow comes into the bunker reloading point with parameter λ, the time of servicing each dump truck t_{serv} is a random value which is governed by the exponential distribution law with parameter μ, and all unloading points at the reloading station are of equal productivity [10, 11].

Presentation of the main research. Based on the condition of continuous work of loading equipment in the quarry, the traffic flow Q_{dt} (capacity of dump trucks) coming to the reloading point must equal the quarry productivity Q_q, i.e. $Q_{dt} = Q_q$.

With due account for irregularity of load-haul-dump machines, the quarry productivity (t/hour) can be represented in the following way

$$Q_q = N_e Q_e^{tech} K_e K_{uf} K_{irr}^{e} K_{irr}^{dt},$$

where N_e is the number of working excavators in the quarry, pc.; Q_e^{tech} is technical capacity of an excavator, K_e is an excavation coefficient; K_{irr}^{e} is a coefficient of irregularity of excavators' operation; K_{irr}^{om} is a coefficient of irregularity of a dump truck's operation; K_{uf} is an excavator utilization factor.

The values of coefficients are determined using the formula

$$K_{irr}^{e}=\frac{\sqrt{N_e}}{\sqrt{N_e}+\frac{1}{K_r^e}-1},$$

where K_r^e is an excavator availability factor,

$$K_{irr}^{dt}=\frac{\sqrt{N_{dt}}}{\sqrt{N_{dt}}+\frac{1}{K_{af}^{dt}}-1}.$$

Here, N_{dt} is the number of dump trucks required for the operation of excavators, pc., K_{af}^{dt} is a dump truck technical availability factor

$$N_{dt}=\frac{Q_e^{tech}\cdot N_e}{P_{dt}}, \quad (1)$$

where P_{dt} is a dump truck productivity, t/hour.

$$P_{dt}=\frac{q_{dt}}{t_{lt}+t_{tt}}.$$

Here, q_{dt} is a carrying capacity of a single dump truck, t; t_{lt} is a truck loading time, hour

$$t_{lt}=\frac{q_{dt}}{Q_e^{tech}},$$

where t_{lt} is truck trip time in freight-hauling and empty directions, hour.

$$t_{tt}=\frac{L_{td}}{v_{av}},$$

where v_{av} is an average technical speed of dump trucks in freight-hauling and empty directions, km/hour; L_{td} is an average weighted transportation distance, km.

After transformations, expression (1) will take the following form

$$N_{dt}=N_e\left(1+\frac{Q_e^{tech}\cdot L_{td}}{v_{av}\cdot q_{dt}}\right).$$

The analysis of dependence of the quarry annual productivity on the number of excavators with due account for irregularity of operation of load-haul-dump machines reveals that as the volume of excavator buckets increases from 4.6 m^3 (Komatsu D475A-5) to 16 m^3 (EX2600-6), under otherwise equal conditions, the quarry annual productivity increases by 2.5 times. As the number of working excavators and dump trucks increases, the coefficient of irregularity grows nearing the values equaling one [12, 13].

Depending on the productivity and irregularity of the load-haul-dump machines, the parameter of the mass service system (reloading station) can be represented as follows

$$\alpha=\frac{N_e^2 Q_e^{tech}K_e K_{uf} t_{serv}\sqrt{1+\frac{Q_e^{tech}\cdot L_{td}}{v_{av}\cdot q_{dt}}}}{q_{dt}K_{afts}\left(\sqrt{N_e}+\frac{1}{K_{af}^{e}}-1\right)}\times$$

$$\times\frac{1}{\left(\sqrt{N_e\left(1+\frac{Q_e^{tech}\cdot L_{td}}{v_{av}\cdot q_{dt}}\right)}+\frac{1}{K_{af}^{dt}}-1\right)},$$

where t_{serv} is the time of processing of a dump truck at the reloading station, hour; K_{afts} is a transport system (with trucks) availability factor.

The time of servicing a truck at the bunker equipped with automatic folding doors consists of the time of driving dump truck to the unloading point (t_{dr}), the time for opening the folding doors (t_{ofd}), the time for closing the folding doors (t_{cfd}) and the time of the strictly unloading (t_{ul}), i.e.

$$t'_{serv}=t'_{dr}+t_{ofd}+t_{cfd}+t_{ul}.$$

Also, the processing time at the bunker reloading point is characterized by the intensity of operation of transport at the exit from the bunker, i.e.

$$t''_{serv}=\frac{nq_{dt}}{kQ_b},$$

where n is the number of unloading points at the bunker; k is the number of batchers under the bunker; Q_b is the capacity of one batcher, t/hour.

The highest of the calculated values t'_{serv} and t''_{serv} is accepted as the processing time t_{serv}.

The batcher capacity (t/h) must be

$$Q_b\ge\frac{nq_{dt}}{kt'_{serv}}.$$

The condition of continuous unloading of dump trucks at the reloading station is

$$t_{serv}\le\frac{nq_{dt}}{kQ_b}.$$

The average queue length of dump trucks depending on the number of unloading points and parameter α will be written as

$$M=\frac{\alpha^{n+1}}{n\left(1-\frac{\alpha}{n}\right)^2\left[\alpha^n+(n-1)!(n-\alpha)\sum_{i=0}^{n-1}\frac{\alpha^i}{i!}\right]},\ \text{at}\ \frac{\infty}{n}<1.$$

Results. Based on the graph (Fig. 4) plotted at constant values α it is possible to determine the rational number of unloading points n at the reloading station. The shaded part of the graph represents a zone of the most favorable conditions for continuous unloading of dump trucks at the reloading station, i.e. the zone of such values n at which the dump trucks will not stay in a queue ($M \le 1$).

The rational volume of the bunker (t) at the reloading station will be calculated using the formula

$$V = nq_{dt}.$$

Fig. 5 shows a dependency graph of the bunker rational volume on the quarry productivity for the following parameters

$$Q_q = 5 \div 20;\ q_{dt} = 60.$$

where Q_q – $mln \cdot \frac{t}{year}$; q_{dt} – t; t_{serv} = 90 sec for dump trucks with load capacity at the reloading station will be

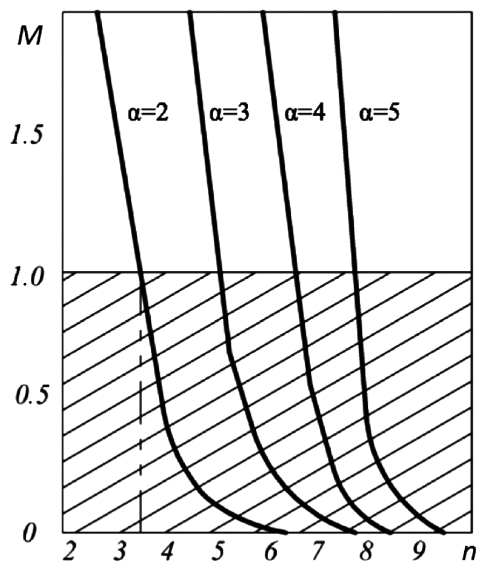

Fig. 4. Dependence of the average queue length of dump trucks M, pc. on the number of reloading points n at the bunker reloading unit

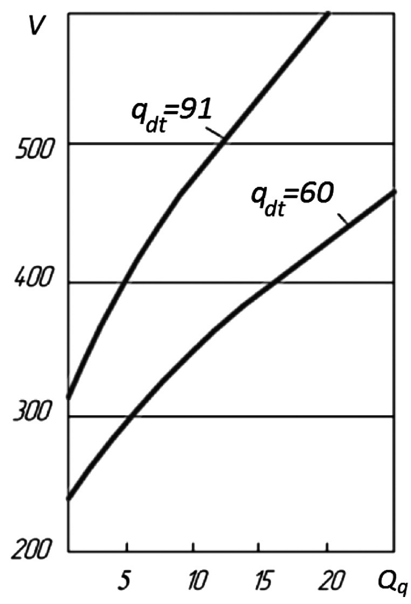

Fig. 5. Dependence of the bunker rational volume V(t) on the quarry productivity Q_q (mln. t/year)

calculated using the formula exit from the bunker, i.e. 60 t; t_{serv} = 120 for dump trucks with load capacity 91 t.

Conclusions and recommendations for further use. The conducted research shows that the double increase in the quarry productivity results in the 1.7 times increase in the bunker rational capacity at q_{dt} = 60 t and in 1.8 times increase at q_{dt} = 91 t. Under otherwise equal conditions, the increase in load capacity of trucks from 60 to 91 tons lead to the need to increase the bunker capacity by 1.3 times.

These results were obtained on the basis of the approach outlined by the authors at the conference [14]. The use of this approach in the design of mining machines will increase the productivity of open quarries.

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Мета. Визначення раціональних параметрів перевантажувальних пунктів при циклічно-потоковій технології під час відкритих гірничих робіт із застосуванням автосамоскидів.

Методика. В основу розробленої методики було покладено моделювання фізичної суті процесу транспортування автотранспортом, якій найбільш повно відповідає найпростіший потік у теорії масового обслуговування пуассонового типу, а перевантажувальний пункт, із точки зору бункеризації й складування, можна розглядати як розімкнену систему масового обслуговування, в якій тривалість очікування розвантаження апроксимується показовим розподілом.

Результати. У результаті проведених розрахунків на основі умови безперебійного розвантаження автосамоскидів на перевантажувальному пункті були визначені раціональна ємність бункера та раціональне число точок розвантаження.

Наукова новизна. Уперше виконана кількісна оцінка технологічних параметрів перевантажувальних пунктів з урахуванням тривалості рейсу автосамоскиду у вантажному й порожняковому напрямках, вантажопідйомності автосамоскиду, тривалості навантаження, загального числа автосамоскидів, необхідних для обслуговування екскаваторів, і ряду інших параметрів. Таким чином був виконаний комплексний аналіз роботи транспортної системи кар'єра.

Практична значимість. На основі запропонованої методики можна заздалегідь планувати можливість підвищення ефективності роботи транспортної системи при відкритих гірничих розробках, що в кінцевому підсумку сприятиме підвищенню загальної продуктивності роботи кар'єра.

Ключові слова: *автосамоскид, циклічно-потокова технологія, гірські породи, раціональна ємність, перевантажувальний пункт*

Цель. Определение рациональных параметров перегрузочных пунктов при циклично-поточной технологии при открытых горных работах с применением автосамосвалов.

Методика. В основу разработанной методики было положено моделирование физической сущности процесса транспортирования автотранспортом, которой наиболее полно отвечает простейший поток в теории массового обслуживания пуассоновского типа, а перегрузочный пункт, с точки зрения бункеризации и складирования, можно рассматривать как разомкнутую систему массового обслуживания, в которой продолжительность ожидания разгрузки аппроксимируется показательным распределением.

Результаты. В результате проведенных расчетов на основе условия бесперебойной разгрузки автосамосвалов на перегрузочном пункте были определены рациональная емкость бункера и рациональное число точек разгрузки.

Научная новизна. Впервые выполнена количественная оценка технологических параметров перегрузочных пунктов с учетом продолжительности рейса автосамосвала в грузовом и порожняковом направлениях, грузоподъемности автосамосвала, продолжительности погрузки, общего числа автосамосвалов, необходимых для обслуживания экскаваторов, и ряда других параметров. Таким образом был выполнен комплексный анализ работы транспортной системы карьера.

Практическая значимость. На основе предложенной методики можно заранее планировать возможность повышения эффективности работы транспортной системы при открытых горных разработках, что в конечном счете будет способствовать повышению общей производительности работы карьера.

Ключевые слова: *автосамосвал, циклично-поточная технология, горные породы, рациональная емкость, перегрузочный пункт*

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