Mining shovel energy efficiency and its relationship with the explosive fracture of rocks

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Abstract. Production cycles are correlated with the processes of drilling and blasting in rocks. It is shown that energy efficiencies of explosive fracture and shovel operation are interconnected with the face advance velocity. Modeling results on operation per one run of rope power shovels with different bucket capacities are presented. The found approximate relation for the determination of energy efficiency of excavation is based on the interconnection of explosive fracture of rocks, geometry of face and dynamics shoveling.

1. Introduction
Operation of open-cast mining shovels is extensively described in the scientific and technical literature. At the same time, it is yet difficult to determine mining shovel capacity for specific conditions of different open-cast mines based on the practical polices available [1, 2].

The production sequence of an open-cast mine features a range of interrelated and interdependent work processes (process stages). Efficiency of every process stage is governed, first and foremost, by the cost/quality ratio of an output product and, for the second thing, by the compliance of the product with the requirements of the optimum technology of the product treatment at the next process stage. The most appropriate index and criterion of the entire production sequence efficiency is assumed an integral energy consumption per unit marketable product [3, 4]. In this fashion, the inaccurate definitions of productivity, energy efficiency or any other criterion introduces errors in the process control systems based on definite laws and interrelations. Practical experience shows that determination of criteria and adjustment of interrelations in the course of open-cast mine operation never lose topicality.

2. Numerical modeling and results
Regarding drill and blast operation, energy interconnections are quite certain [3, 5–7]. The relation between the specific energy characteristics of drilling and explosive fracture of rocks is refined in [7]. It is suggested to characterize energy of rotary drilling process using the index of specific energy per 1 cubic meter of drilling in rocks and energy of explosive fracture by the overall specific work of explosion or specific explosive energy $a$:

$$E = \frac{N t}{q_{\text{rock}}}, \quad \text{J/m}^3,$$

(1)

where $q_{\text{rock}}$—rock yield per 1 m of blasthole, m$^3$; $t$—average time of 1 m of drilling, h; $N$—motor power consumption, kW.
The specific explosive energy is a universal index as it both defines blastability of rocks, conforms with the theoretical description of blasting [8–13] and communicates with the energy inputs in the related processes such as drilling as the latter also spends energy for rock breakage. Setting such relations makes it possible to determine powder factors by energy consumptions in drilling.

Specific energies of drilling and explosive fracture of rocks have the same dimensionality:

\[ A = \frac{q_{pr} Q_{sp}}{V}, \quad J/m^3, \quad (2) \]

where \( q_{pr} \) — project powder factor; \( Q_{sp} \) — specific heat of explosion per 1 kg of explosive, MJ/kg; \( m_{ex} \) — explosive weight, kg; \( V \) — volume of blasted rocks, m³.

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Specific energies of drilling and explosive fracture of rocks have the same dimensionality:

\[ A = \left[ \frac{J}{m^3} \right] \leftrightarrow E = \left[ \frac{J}{m^3} \right]. \quad (3) \]

This means that the specific energies of drilling and explosive fracture per 1 m³ of rocks are directly proportional. The ratio of such energies for understanding the amount of work (in Joules) in blasting as against the amount of work in drilling per 1 m³ in a specific type rock is determined experimentally. This ratio is different in rocks of different hardness and jointing. The input energy is an indication of the rock hardness and jointing all together. For a certain rock, this expression is given by [7]:

\[ \frac{A_i}{E_i} = \Pi_i, \quad (4) \]

where \( A_i \) — energy consumption of explosive fracture in \( i \)-th type rock; \( E_i \) — specific energy of drilling in \( i \)-th type rock; \( \Pi_i \) — proportionality factor.

Found in [7], the interrelation represented by expressions (3) and (4) has the specific physical sense as the dimensionality \( (J/m^3) \) is a unit of measurement of pressure (Pa). Accordingly, the interrelation between the specified energy characteristics of processes is consistent with the theoretical provisions on physics of rock disintegration. An attempt to set a similar relation with the efficiency of mining shovel reveals some mechanisms described below. In [14] it is show that the overall energy efficiency of mining shovel operation and explosive fracture of rocks lowers as the velocity of face advance is increasing; furthermore, it is supposed that the latter may be an interconnection criterion, including the other related processes. The comparison of the overall energy inputs in excavation on blasting in a model rock block yields similar results for different mining shovel machines (Figure 1).

**Figure 1.** Total energy efficiency of excavation versus total energy of blasting in rock block for mining shovel EKG-10.

The further efforts undertaken to compare energy efficiencies (per 1 m³) had no success and revealed no clear relation. Probably, this was connected with the geometrical parameters chosen for the modeling. In the meanwhile, it is still of importance that blast energy is spent for rock breakage (mostly uncontrollable) and mining shovel energy is taken by pressing, hoisting and turning the bucket. For this reason, physically, this mechanism is difficult to present on the flat. Nonetheless, the parameter of the face advance velocity is worthy of considering [15]:
\[ v = \frac{Q}{S}, \]  

where \( Q \) — mining shovel capacity; \( S \) — face area.

The length of an excavation block was assumed the same in the model experiments and, thus, withdrawn from the overall energy consumption. As a result, specific energies multiplied by face area were interrelated. The face area has the strongest geometrical sense and has influence on the process energy efficiency as it is related with the face advance velocity [14]. Figure 2 depicts the described relationship for mining shovel EKG-10.

All in all, operation of four models of shoveling machines was modeled: EKG-8I, EKG-10, EKG-12.5 and EKG-20s. The motor capacities were calculated in terms of forces of a shovel per one run according to [16]. After interpretation of the modeling results, the relation determined for mining shovels with bucket capacity of 8–20 m³ provided that the face width is smaller or equal to the shoveling width is given by:

\[ E_{sp}^{ex} = \frac{0.74Q}{\nu S}, \]

where \( E_{sp}^{ex} \) — specific energy of excavation, J/m³; \( A \) — specific energy of explosion, J/m³; \( Q \) — mining shovel capacity, m³/shift; \( S \) — face area, m²; \( \nu \) — project velocity of face advance, m/shift.

![Figure 2. Relationship between the mining shovel energy multiplied by face area and the explosive energy multiplied by face area for mining shovel EKG-10.](image)

3. Conclusions
Knowing specific explosive energy in a rock block and capacity of a mining shovel, with the found face area after blasting and by setting the wanted velocity of the face advance, it is possible to determine energy efficiency of shovel machine operation.

During the research, the approximate relation has been set between the energy efficiency of rope power shovels with bucket capacity of 8–20 m³ and energy efficiency of blasting with regard to the shoveling machine capacity, face area and the required velocity of face advance.

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