Developing a methodology for estimation of excavation techniques for given operating conditions

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Abstract. This article discusses the basic principles of developing a methodology for comparing the performance of mining excavators for given operating conditions. The indicators determining the effectiveness of mining excavators are given. The main aspects of the developed methodology are considered. A comparison algorithm is proposed.

1. Introduction

Currently, the main type of technological equipment used for mining operations in open pit mining in the Russian Federation are single-bucket mining excavators—mechanical and hydraulic shovels, which, having high specific digging force, reliable construction and large ranges of variation of operating parameters, are ultimately adapted to harsh excavation conditions. Different mining conditions and production capacities of mining enterprises require different sizes and models of mining excavators [1-3].

Indeed, already in 2006, 1452 excavators were in operation at open coal mining in the Russian Federation, of which 1,406 were single-bucket excavators and 46 units were multi-bucket machines. The main technological processes involved 931 single-bucket excavators, including 239 production units (25%), 621 stripping units (67%) and 71 dump units (8%); the remaining 475 units (33%) of excavators were used for auxiliary works, were on conservation and reserved [4-7].

Russian market proposes machines locally manufactured by IZ-KARTEX named after P.G. Korobkov and Uralmash Machine-Building Corporation, and imported excavators produced by Bucyrus International Inc. and P&H Mining Equipment. The operating parameters of these machines are comparable; however, the cost of imported equipment is approximately two times higher than that of domestic machines.

The specific metal consumption of the excavators is 14-25 t/m³ for imported front-shovel hydraulic excavators (for domestic the figure is 23-28 t/m³), for imported mechanical shovels, it is 30-35 t/m³ (for domestic ones, it is 38-52 t/m³).

The power ratio of different mining excavators (front-shovel machines) varies in a very wide range: from 35 kW/m³ to 100 kW/m³. The specific metal consumption and power ratio of the backhoe machines is slightly higher. These parameters for modern excavators are presented in Figure 1.
Figure 1. Specific metal consumption ($m_{ud}$) and power ratio ($e$) of modern mining excavators

In the mining industry of Russia and the CIS countries, a steady trend has recently been observed in the purchase of imported equipment by mining enterprises, primarily this applies to hydraulic excavators. Indeed, at the enterprises of diamond mining, iron ore extraction and chemical industries, the share of imported excavators reached 10% by 2007 [10, 11].

The primary task of the technical re-equipment of Mining and Processing Plants using opencast mining operations is to complete the complex mechanization structure with equipment of increased and mutually appropriate production capacity (drilling rig – excavator – dump truck – bulldozer).

For example, at the Kuzbass opencasts, the task of acquiring mechanical excavators of large unit capacity, EKG-18R and EKG-32R, has been set and is being carried out, which allows for efficient loading of rock mass into dump trucks with a carrying capacity of over 120 tons, and increases the efficiency of mining operations. At the same time, choosing an excavator model is a crucial step in completing the structure of complex mechanization.

Unfortunately, at the moment there is no generally accepted engineering methodology that enables an objective comparison of the effectiveness of mining excavators in relation to specific mining conditions. The justified choice of such a machine for given conditions is an extremely difficult task, since its solution requires simultaneous accounting and analysis of a large number of technical and economic factors: excavator's operating parameters, its reliability, face parameters, the properties of the developed rock mass, the presence and technology of drilling and blasting, rock bearing capacity, transport equipment parameters, safety requirements, ergonomics, reliability, capital costs, excavation costs, etc. [12–14].

Existing methods either do not take into account all of the factors above, or are too bulky and inapplicable for engineering use, or use obscure complex indicators with an unclear physical meaning as comparison criteria.

The authors proposed a methodology for comparing front-shovel mechanical mining excavators as applied to given operating conditions, based on an analysis of the necessary minimum of simple and understandable technical and economic indicators. The result of the work is a fully debugged software product.

The need to develop the proposed methodology was confirmed on seminars and scientific conferences in presentations of specialists from IZ-KARTEX named after P.G. Korobkov and BelAZ Company [15].

2. Main aspects of methodology

At larger scale, the process of selecting an excavator for given conditions can be divided into three stages.

2.1 Choice of bucket drive: dragline or rack.

The choice is determined by the category of rock mass according to the difficulty of excavation by a single bucket (according to Yu.I. Belyakov). According to this classification, all rocks are divided
into six categories depending on the digging resistance coefficient $k_F$, which is equivalent to the average pressure developed in the face under the influence of a force applied through the cutting edge of the bucket to the conditional cross section of the separated rock formation.

2.2 Choice of excavators for the maximum digging radius, digging height, unloading height, unloading radius, bucket capacity, specific ground pressure.

At this stage, the excavator's compliance with the mining technology adopted by the enterprise is determined: cutting depth, bench width, the transport scheme and the compatibility of the excavator with the dump truck in terms of unloading height and weight module.

As a result of the first two stages of comparison, the number of mining excavators for further analysis is limited - only those are accepted for consideration that, in their technical parameters, meet the specified conditions and requirements of the “Unified safety rules for the development of opencast mineral deposits”.

2.3 Construction and solution of comparison matrices, which include the following indicators:

a) operational performance,
b) specific energy consumption for excavation,
c) specific digging force,
d) power ratio,
e) reliability,
f) safety,
g) ergonomics,
h) economic criteria: capital costs, operating costs, payback period, cost of excavation.

The indicators for items “a”, “b”, “c”, “d”, “h” are determined by calculation; item “e” is determined according to manufacturers or on the basis of statistical information; items “f” and “g” are assessed by experts. Each of the indicators considered at this stage is assigned a significance level, taking into account its specific weight in the total amount of indicators that form the quality. The maximum level of significance should certainly be assigned to safety indicators and economic criteria. The significance level for other indicators may vary depending on the conditions of a particular mining enterprise.

As a result of this stage, an excavator is determined, the use of which under given conditions will be most effective both from a technical and economic point of view.

The solution to the first stages considered is implemented as an algorithm that is a part of a computer program for comparing the performance of mining excavators. The algorithm is shown in Figure 2.

3. Conclusions

1. The developed method enables an objective comparison of the effectiveness of mining excavators in relation to the given mining and technical conditions.

2. The methodology has been brought to an engineering solution, is simple to use, and can be used by enterprises operating and producing mining excavators as well as design organizations.
Figure 2. Block diagram of “selection of models satisfying design parameters” block with additional “attractiveness” block.
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