Improvement of Access Methods for Ore Reserves Beyond Ultimate Limits of Open Pits

Introduction

Reduction in potential of open pit mining technology calls for transition to underground method [1]. This factor predetermines rapid advancement of hybrid method of mineral mining [2]. Operating experience of Russian and foreign mines shows that hybrid mining allows capital cost saving by 15–30% in case of harmonization of opencast/underground technology parameter or, vice versa, raise expenses by 35–50% in the event of piecemeal action [3]. When estimating workability of opencast void in terms of accessing and extracting underground ore reserves, it is necessary to take into account the distance and location of an open cast relative to underground ore body [4], as well as the sequence and technology of mining. Considerable contribution to technical approaches to the comparison and selection of access schemes for thick ore bodies with regard to geological and geotechnical conditions is made by such Russian scientists as M. I. Agoshkov, A. S. Voronyuk, L. D. Shevyakov, V. A. Shchelkanov, V. Yu. Demidov, V. L. Yakovlev and many others. The researchers emphasize that construction cost of a mine, depending on the access and development schemes, makes not less than 50–60% of total capital investment [5]. With rapidly increasing mining depth and productivity, the cost of access and haulage escalates even higher while mine safety grows worse [6, 7].

Improvement in mining safety and efficiency is possible through stimulation of production and application of energy-saving and high-productive transport systems to ensure prompt stage-by-stage access to ore reserves at minimized human part in the process. Such systems are primarily modern continuous-handling systems (vertical, high-angle and inclined conveyors with curved paths). This type of transportation maintains required conveyance capacity irrespective of increasing depth. Furthermore, there are some cycling systems (trolley cars, light weight and bottom dumping rail cars, etc.), especially if they are remotely operated. The remote control over self-propelling machines has allowed the foreign mines to raise productivity by 23–121%, extend life of machines to 20%, decrease the quantity of machines by 30% and deman operations by 60–80% [8, 9].

It is proposed to evaluate and select parameters of effective access schemes for ore reserves in open pit walls and bottoms using the methodical approach based (alongside with the conventional analysis of current and future conditions of mining operations) on integration of 3D and optimization economic-and-mathematical modeling of the access and development scenarios with computer-aided and independent transportation systems (underlined in Fig. 1).

This approach has been implemented in the Kola Peninsula deposits such as Kovdor (baddelyte–apatite–magnetite), Olney Ruchey and Partomchor (apatite–nepheline). All deposits are (or to be) subjected to open/underground mining (partly synchronized) mostly using systems with caving (at the underground stage). On the one hand, it is possible to apply common approaches to the access scheme and arrangement of access openings relative to the ground surface and and geometry of ore bodies. On the other hand, positional relationships and distances between open pits and underground reserves differ considerably per the listed deposits.
Kovdor deposits

Ore reserves are represented by a large pipelike ore body (Glavnaya site holding 97% of all reserves) and a few small ore bodies. Subsurface reserves are extracted by open pit down to elevation of ~660 m (depth of 900 m) with underground mining of pitwall and bottom reserves down to a depth of 2000 m. The open pit mining stages uses the cyclic—continuous transportation technology (CCT) with motor vehicles and crushing-and-conveying system (CCS). The deposit dips sub-vertically (at 80—85°), which conditions the same vertical operation plane of open and underground mining when the open pit locates in the caving zone of the future underground mine. Partial overlap of operations to balance depleting reserves of the open pit mine is only possible during extraction of ore reserves from pit walls and bottom. A favorable factor is possibility of ore haulage using access openings of the future underground mine. Pre-studies show that advanced construction of the underground mine subject to growing project capacity of the open pit mine (from 16 to 22.5 Mt/yr) and accelerated increase in the pit mining depth enables reduction in haulage distance by dump trucks from 6—10 km to a few hundred meters, which thereby decreases the number of dump trucks by 80—90% (on the lower levels) as well as, accordingly, weakens intensity and enhances safety of haulage, improves ventilation, etc.

In view of high productivity and depth of the underground mine, 4 access scenarios were subjected to aggregate assessment with 3D modeling and determination of capital cost and period of construction in MineFrame mining and geological information system (Table 1) [10]. The detailed evaluation embraced scenarios with access through the incline conveyor shafts owing to their technical-and-economic indexes (including the level of the technology application efficiency in the mine).

Then, economic-and-mathematical modeling of mining, haulage and processing costs was performed per ore blocks (the deposit was represented as a set of blocks, and the program determined the costs for each block depending on its location). Each scenario is given the trend and its reliability R² (Fig. 2a). The scatter of the points in the

Table 1. Underground ore body access alternatives

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<tr>
<th>Access scenario</th>
<th>Capital cost, BRub</th>
<th>Construction period, years</th>
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<tr>
<td>1. Vertical skip hoisting shafts and open-pit ore passes from the level of ~760 m</td>
<td>9.9</td>
<td>7.6</td>
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<tr>
<td>2. Incline conveyor shafts and open-pit ore passes from the level of ~760 m</td>
<td>5.6</td>
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<tr>
<td>3. Incline conveyor shafts and adits from the levels of 260 and ~470 m</td>
<td>3.2 (2.2—Stage 1, 1.0—Stage 2)</td>
<td>4.5 (2.1—Stage 1, 2.4—Stage 2)</td>
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<tr>
<td>4. Vertical conveyor shafts and adits from the levels of 260 and ~470 m</td>
<td>4.0 (2.9—Stage 1, 1.1—Stage 2)</td>
<td>3.4 (1.2—Stage 1, 2.2—Stage 2)</td>
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plot results from the difference in haulage distance for the blocks. From the modeling results, transition to ore haulage via underground opening is expedient at the pit bottom elevation between −300 and −350 m.

The closing detailed assessment of the conveyor-assisted access parameters refined potential surface sites for access openings, spatial arrangement of haulage routes, types and number of conveyors. As a result, it was selected to carry out access to underground ore reserves from the fine ore blending plot site by inclined conveyor shafts at the elevation point of +280 m/-800 k and a gate-way equipped with belt conveyors with an intermediate stage of accessing via an adit at the elevation point +260 m on the northern pit wall (Fig. 2b) [10, 11].

Oleniy Ruchey deposit

The top level of the tiered ore bodies are subjected to current open mining (upper body 200 m thick) and the lower level (50–330 m) is meant for underground mining. The bodies have a nonmetallic parting 200–300 m in thickness, which makes it possible to carry out excavation and to construct the underground mine. The open pit mining reserves are insignificant (around 4.5 % of total reserves) but sufficient to maintain production capacity until maturity of the underground mine. Failure is possible in the pit upon completion of surface mining operations. On the north-east, underground mining reserves adjoin the Norpkapkh deposit under developed by surface mining by another company. Until closedown of the Norpkapkh open pit project, the Oleniy Ruchey project keeps some underground reserves in a safety pillar. The dip angle of the deposit is 30–40° on the south-west and 60–70° on the north-east. Occurring at the depth of 450 m, the deposit runs under a mountain. This circumstance governs the initial solutions on accessing from a foothill valley at the elevation point of +240 m through three adits (haulage, conveyor and ventilation) and three shafts: main 1 (MS, blind), air feed 1 (blind) and auxiliary 1. An accumulation horizon is planned at the elevation point of −220 m: ore from the accumulation horizon is to be transported by rail cars to underground crushing chambers and, then, to skips to be hoisted the the conveyor adit and, later on, to the processing plant.

Construction of the underground mine revealed deficiencies of the accepted scheme (low reliability of multi-link transportation chain, great efforts and high cost of construction and operation of the kip hoist in the blind ore drawing shaft, impossibility of stage-by-stage introduction of the mine into service, adverse geomechanical behavior of rock mass in in the area of underground mining and skip unloading (this is a rockburst-hazardous deposit). Aimed to cut down original investment size in construction and shorten the period of the mine putting into operation, a pilot mining site (PMS) was chosen above the elevation point of +0 m and its annual capacity was estimated as 1 Mt. After the underground mine reached the project capacity of 6 Mt/yr, the access scheme of PMS would be integrated in the general mine scheme. For the adjustment of the access scheme and method with regard to all necessary conditions, scenarios of modern cyclic mode transport were analyzed.

First, the main alternative of access via inclined conveyor shafts was developed and a rough feasibility study was performed as compared with the project access scheme (Table 2). The comparison proved efficiency of the conveyor-assisted access as it reduced the mine commissioning period by 2.6 times, the capital cost of the mine commissioning by 75% and total cost of mining down to the elevation point of −220 m by 18% [12].

After that, as with the Kovdor deposit, the accessing parameters and mechanical means were specified and compared. One of the selection criteria was the maximum use of the earlier driven conveyor adit. The detailed access scenarios, depending on spatial arrangement, of transportation routes, provided six schemes with different combinations of series installed conveyors: horizontal and inclined (variants 1, 4 and 6); horizontal, inclined and high-angle (variants 2 and 3); horizontal and radial inclined (variant 5) as illustrated by Fig. 3.

Modeling of ore crushing and haulage costs at the mine project capacity $A_m$ yields some analytical dependences (Fig. 4) [12].

From the comparison of the construction and operation costs, the lowest expenses characterize variant 3 with ore haulage by horizontal and high-angle conveyors, as well as variant 5 with pore haulage by horizontal and radial inclined conveyor (See Fig. 4). The average capacity of the calculation period is 34.6 Mt/yr at the minimum cost of −61.9 Rub/t.

Partomchorr deposit

The deposit is composed of three ore bodies striking to 6 km with lens out at ground surface at the piedmont elevation point of +225...+250 m and dipping downhill to the point of −600 m at the angle of 30–35°. The thickness of the deposit is on average 50–70 m. The subsurface layers can be extracted by small open pits in the period of the underground mine construction. Large-scale open pit mining is inefficient due to considerable stripping in the hill area. This deposit ore is of low value, which predetermines the use of the cheapest but high-productive systems of mining with caving. The open pit voids will be unsuitable for the construction of permanent opening of the underground mines and can only be used to access reserves in the pit walls and bottoms.

Unlike the above discussed ore field, the Partomchorr is currently not under development owing to low profitability and ecological constraints, which imposes more stringent requirements on the project safety and effectiveness. The estimate capacity of underground mine is not finalized yet, and optimization of access schemes and methods

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<td>Accessed reserves, Mt</td>
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*Values of PMS access scheme down to the level of −220 m.
was implemented for different values of $A_m$. Applicability of both conventional and potential (included automatic and robotic) transport systems was discussed in order to determine efficient ranges of their alternating application [13]. The analyzed variants of accessing and developing ore reserves are compiled in Table 3.

The hoisting and haulage costs versus $A_m$ are obtained analytically and presented in Fig. 5.

These relationships help select the most efficient methods of transport and push theoretical limits of smart use ranges for advanced transportation systems, which is
applicable at other mineral deposits in the similar conditions. Regarding the Partomchorr and its feasible capacity up to 7 Mt/yr, it is efficient to combine transportation system. It is advisable to combine inclined hoisting conveyors and horizontal remote-control rail haulage [14] (Fig. 6), which will ensure high safety and maximum economic efficiency of operations.

Conclusion

The proposed methodical approach to evaluation and selection of parameter for efficient schemes of accessing underground reserves beyond the ultimate open pit limit is implemented in terms of deposits on the Kola Peninsula. The research results are summarized below:

- Kovdor deposit (Zheleznny Mine): it is expedient to access pore reserves in the pit walls and bottom using underground openings of the future mine at the elevation point of ~300 m from the fined-crushed ore blending plot using a set of conveyor shafts at the point of +280 m/–800 m and a drift equipped with belt conveyors, with an intermediate stage of access via an adit at the elevation point of +260 m on the northern pit wall;

- Oleniy Ruchey deposit: the proposed access scheme uses a combination of horizontal and inclined radial belt conveyors, with an intermediate stage of access at the elevation point of +240 m/0 m, which ensures planned development of mining up to the project capacity;

- Partomchorr deposit: the determined relationships between hoisting and haulage costs make it possible to select efficient access schemes as function of future A_m. At A_m > 7 Mt/yr it is expedient to combine inclined conveyor hoisting and remote-control horizontal rail transportation.

On the whole, the calculations prove efficiency of the conveyor transport system, while their design variety ensures their efficiency even at the relatively low capacity of a mine or when the haulage path is limited by horizontal dimension of an ore body.

References