ANALYSIS OF THE INNOVATIVE SOLUTIONS IN THE DEVELOPMENT OF THE RESERVES IN THE *DZHURKOVO* MINE, LUCKY INVEST JSC

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ABSTRACT. This article examines and analyses the experience of implementing innovative solutions related to the uncovering, development and extraction of reserves in the "Dzhurkovo" mine, part of "Lucky-Invest" JSC, in the period 2010-2019 inclusive.
The first stage of the innovations consists in designing and driving an inclined shaft from the surface horizon 800 to horizon 322 for group uncovering of the reserves in three ore zones of the mine, emplacement of mobile equipment - middle class range, and implementation of a new mining model.
The second stage focuses on innovative solutions in determining the parameters of the system with sublevel stoping, in accordance with the geomechanical parameters of the ore massif, embedding rocks and the requirements for development, undercutting and mining drifts, keeping low levels of losses and contamination.
The third stage involves the elimination of manual technologies in the development and extraction of ore.
The introduction of the new mining model with mobile equipment leads to an increase in the labor productivity of general mining, underground and main underground workers 2 times.
The extracted ore mass has been increased by 32%, and the cost of extracted ore has been reduced 2 times.

Key words: innovative solutions, uncovering, development, extraction, *Dzhurkovo* mine

АНАЛИЗ НА ИНОВАТИВНИТЕ РЕШЕНИЯ ПРИ РАЗРАБОТВАНЕ НА ЗАПАСИТЕ В РУДНИК „ДЖУРКОВО“ ЛЪКИ ИНВЕСТ АД

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РЕЗЮМЕ. В настоящата статия се разглежда и анализира опитът от внедряване на иновативни решения, отнасящи се за разкриването, подготовката и добива на запасите в рудник "Джурково", част от „Лъки-Инвест"АД, в периода 2010-2019 г. включително.
Първият етап от иновациите се състои в проектиране и прокарване на наклонена шахта от повърхността хоризонт 800 до хоризонт 322 за групово разкриване на запасите в три рудни зони на рудника, внедряване на мобилна механизация - среден клас и въвеждане на нов минен модел.
Във втория етап се акцентира на иновативни решения при определяне параметрите на системата с подетажни изработки, съобразени с геомеханичните показатели на рудния масив, вместващите скали и изискванията към подготвителните, нарезните и добивните изработки, запазвайки ниски нива на загубите и обедняването.
Третият етап включва премахването на ръчните технологии при подготовката и добива на руда.
Внедряването на новия минен модел с мобилна механизация води до увеличаване производителността на труда на общоруднични, подземни и основни подземни работници 2 пъти.
Добитата рудна маса е увеличена с 32%, като себестойността на добиваната руда е намалена 2 пъти.

Ключови думи: иновативни решения, разкриване, подготовка, добив, рудник „Джурково“

Introduction

The *Dzhurkovo* mine is part of the *Lucky Invest* joint stock company and exploits lead and zinc and silver ore. The ore storages are concentrated into four ore bodies "Osnovna zona", "Goranska padina – zona 1", "Goranska padina - zona 2" and "Iztochen apofiz".

The mine entry is done via two vertical shafts, "Capital" and "Ancillary". Several cross entries are constructed through them leading to the main ore bodies. The mineral reserves are exploited in three types of layouts – the ore veins are extracted through the shrinkage method, the ledges are extracted through the continuous open-stope method and the pillar method. Up until 2009, the applied technology was mainly manual, consisting of light portable machinery and cyclic production, haulage and hoisting of the ore. The production was carried by hand rock drills, mucking of the ore was done with a scraper wench, and the in-mine haulage was made with railway wagons types VNR 1 and VNR 1,7 whereas the hoisting of the mine material was done via the "Capital" shaft.

In 2010, a design was assigned (Anastasov, a, b, 2010) of an inclined shaft starting from horizon 800 to horizon 322 with the option of reaching horizon 222 as well as implying new mining layouts.

Practically starting with the sinking of the inclined shaft and the introduction of new systems of mining methods, the main goal was a change of the existing mining model and the incorporation of innovative solutions which predetermined a new stage in working the ore reserves.

Essence of the innovative solutions in sinking of the inclined shaft

The main goal in the design and excavation of the inclined shaft was to take into consideration the specific mining, geological, and technical conditions in the mine and group opening-up of the ore storages in the four ore zones and ledges.

The innovative solutions at this stage included:

- Justification for buying one set of mining mobile mechanisation, consisting of a drill rig, an underground loader and a mid-range underground mining truck.
- Justification of the cross profile of the inclined shaft (straight sectors, bends, extensions of crossing points, extensions of the existing cross galleries) taking into account the dimensions of the machinery and the statutory requirements regarding mine ventilation in the processes of laying and production in a mine.
- The maximum allowable slope of the inclined shaft is 9 degrees or 15 %, in order to meet the requirements set by the manufacturing companies of the sets of mining machines Sandvik and Epiroc (www.sandvik.com, 2020; www.epiroc.com, 2020).
- Sizing of the support constructions of the shaft when passing through various geological structures and rock formations – shales, gneiss, marble etc.
- Developing a special passport for drilling and blasting operations in conformity with the dimensions of the drill rig (accomplished headway of 3.0-3.4 m in comparison to the former of 1.6 m)
- A new organisation of the production process has been created in sinking of the shaft, where the empty chambers (a result of the usage of shrinkage systems) are used as storage depots for the blasted rock mass, therefore reducing the size of the area of the outer rock embankment.

At the beginning, the sinking of the inclined shaft started in one heading from the surface with an average monthly speed of 120-150 m/month. Subsequently, another set of mining machinery was dismantled, moved down, and assembled on horizon 472, therefore opening a second heading. The whole length of the constructed inclined shaft is 4 400 m.

Innovative solutions in mining layouts in the mine

The subject matter of examination is the three alternatives of the open-stope method with sublevel stopes regarding the four ore zones.

Version I (Fig. 1) includes a technology with hand rock drills in drilling and blasting works and the blasted ore is mucked in a scraper winch. The dimensions of the operational block are 100 m length, deck height 100 m, average operational width 2.2 m.

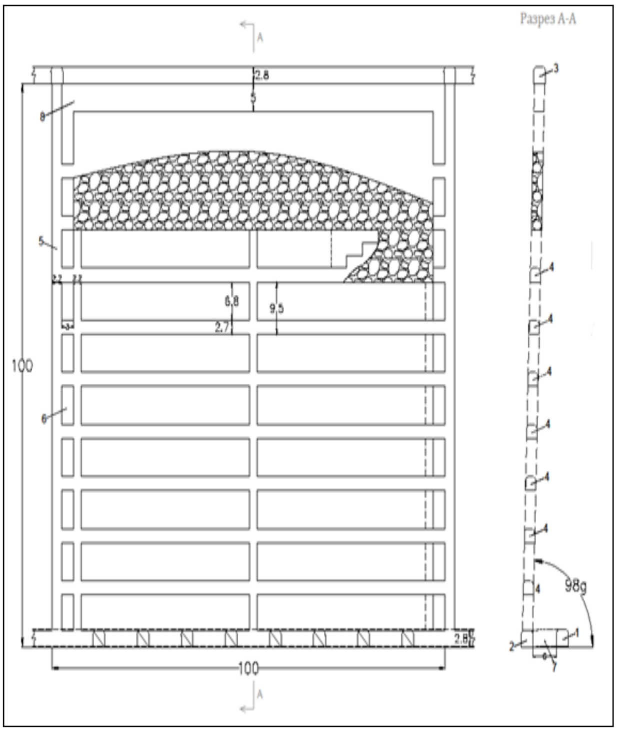

Fig. 1. 1. Version I. Legend: 1 – haulage level drift; 2 – trench gallery; 3 – ventilation level drift; 4 – sublevel roadways; 5 – block raise; 6 – stopes; 7 – loading pocket; 8 – sublevel stopes

Version II (Figure. 2) includes the usage of mobile mining equipment. The dimensions of the operational block are 100 m length, deck height 100 m, average operational width 2.2 m and sublevel height of 19 m.

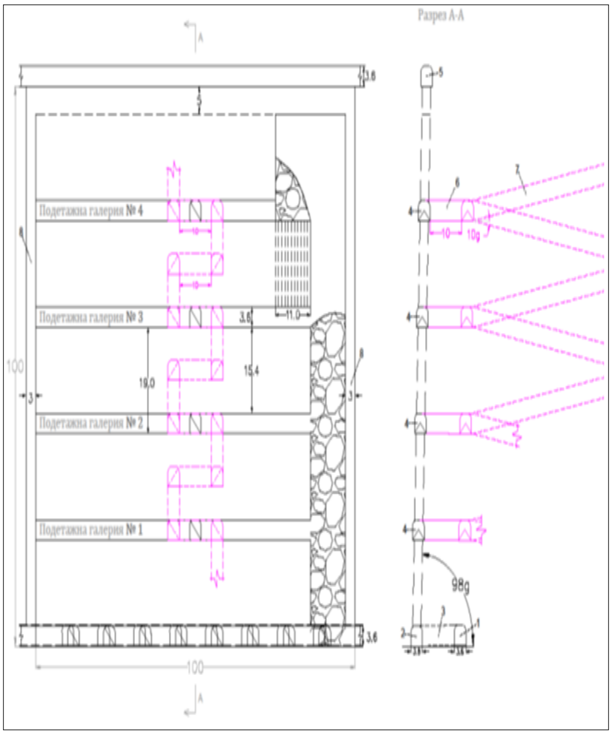

Fig. 2. Version II. Legend: 1 – haulage level drift; 2 – trench gallery; 3 – loading pocket; 4 – sublevel roadways; 5 – ventilation level drift; 6 – cross cuts to main passages; 7 – main entry; 8 – barrier stope

Version III (Fig. 3) includes mobile mining equipment. The constructive elements of the operational block are: length 200 m, deck height 60 m, average operational width 2.2 m and sublevel height 15 m. In this case, it is necessary for a discreet analysis of the geomechanical properties and assessment of the stability of the open chambers to be applied. (Sainsbury et al., 2015).

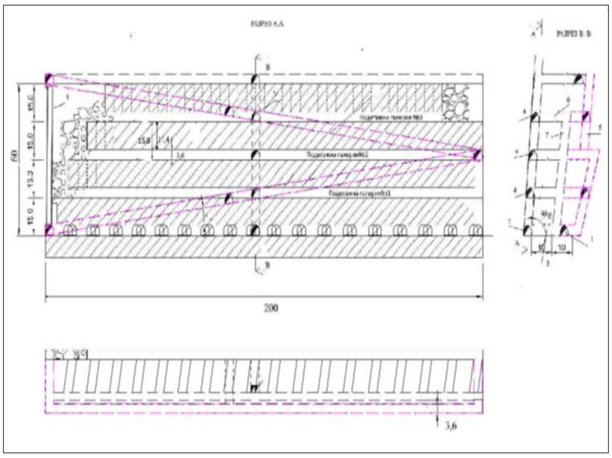

Fig. 3. Version III. Legend: 1 – haulage level drift t; 2 – trench gallery; 3 – loading pocket; 4 – sublevel; 5 – main roadway; 6 – crosscuts to main roadways; 7 – block ore pass; 8 – barrier stope.

The first two versions of the mining layouts are applied to the previous schemes of preparation of the operational blocks. Under these conditions, considering the aforementioned average width of the ore body, a significant chunk of the blasted ore is detained in the so called “ridges”, or is held up high, thus leading to losses in exploitation when withdrawing the ore.

In order to prevent such hold-ups of the ore, the third alternative of the mining method is applied. It differs from the other two in terms of lower sublevel height and twice as long block length, thus leading to better conditions in withdrawal, mucking, and haulage of the ore.

With these new dimensions of the operational block, the head area is twice as wide, conforming to the dimensions of the mining machinery. A significant increase in productivity in ore extraction and mucking is observed, while the losses of the detained ore have significantly lowered.

The main cost–effectiveness indices, linear and volumetric ratios of opening–up and blocking-out are shown in Table 1 below:

Analysis of the innovations in mine methods

The data analysis indicates that the alternatives which include application of mobile mining equipment have less constructive losses at the expense of larger dilution due to bigger dimensions of the cross profiles of the sublevel roadways.

A comparison between the volumetric coefficients of opening-up and blocking-out led to the following conclusion:

There is no firm advantage in favor of any of the alternatives in terms of opening-up ratios; also, the values of the blocking-out ratios are very close in all three alternatives.

Table 1. *The main parameters*

№	Parameter	Unit of measurement	Value		
			Version		
			I	II	III
1.	Ore reserves	m^3	22005	22005	26405
		t	67555	67555	81063
2.	Losses				
2.1.	Constructive losses in stopes				
	Sub-gallery stopes	m^3	1100	1100	-
		t	3377	3377	-
		%	5.0	5.0	-
	Stopes block raises	m^3	898	-	-
		t	2756	-	-
		%	4.08	-	-
	Barrier stopes	m^3		603	372
		t		1851	1142
		%		2.7	4.32
	Total constructive losses	m^3	1998	1703	372
		t	6133	5228	1142
		%	9.08	7.7	4.32
2.2	Losses in exploitation	m^3	660	1100	1320
		t	2026	3377	4052
		%	3.0	5.0	5.0
3.	Commercial reserves	m^3	20007	20302	26033
		t	61421	62327	79921
		%	90.9	92.2	98.59
4.	Ore dilution	m^3	1100	1760	2112
		t	2860	4576	5491
		%	5.0	8.0	8v0
5.	Extracted ore from the block	m^3	20447	20962	26828
5.1	Weight	t	62159	62327	81289
5.2.	Volume weight	t/m^3	3.04	3.03	3.03
6.	Recoverable reserves	m^3	19347	19202	24712
		t	59395	58950	75868
		%	87.92	87.28	97.29
7.	Opening up/blocking out ratios				
7.1	Linear opening-up ratio	m/1000 t rec. reserves	9.12	4.07	7.76
7.2	Volumetric opening-up ratio	m^3/1000 t rec. reserves	52.83	43.96	78.36
7.3	Linear blocking-out ratio	m/1000 t rec. reserves	17.65	9.58	11.29
7.4	Volumetric blocking-out ratio	m^3/1000 t rec. reserves	107.66	95.79	113.02

A factor of the utmost importance in choosing an alternative is the capital expenses. In version II, the inclined main roadway is situated crosswise with a length of 850 m (turns included) and a volume of 9180 m^3, whereas in version III, these values are 480 m and 5184 m^3, respectively.

The relative volume of opening roadways related to 1000 t reserves in version I is 158.27 m^3/ 1000 t, while in version II, it is 65.73 m^3/1000 t.

In economic terms, the achieved expenses by the mine are 15.51 $/ t rock mass per capital roadways; in version II – 6.38 $/ t ; and in version III - 2,65$/ t, which is 2 times less .

The developed innovative passports for drilling and blasting for the opening-up, blocking-out, and extraction works have led to a sharp increase of the labour efficiency in ore production. In the process of excavation of the sublevel roadways, the labour efficiency is as follows: 1.89 m^3/ h for version I and 5.88 m^3/ h for versions II и III, or alternatively stated, a raise of about 3 times.

A significant increase is also observed in the labour efficiency regarding the operations of extraction from sublevel galleries from 2.85 m^3/ h for version I to 15.38 m^3/ h in versions II and III, or by more than 5 times .

As a result of the application of the innovative solutions in the opening, opening-up and mine layouts, a change in the mining model has been put into practice – from manual technologies to mobile mining mechanisation with an added value in three directional groups.

The first direction shows a shift in the main to supplemental workers ratio in the mine. In 2009, the total number of mine personnel was 239 people, whereas in 2019 it was 144 people. The number of main underground workers (head group) has dropped from 56 people in 2009 to 35 people in 2019.

The supplemental workers in 2009 were 124 people versus 66 people in 2019, or in other words, their number has declined twice.

The second tendency is directed towards the annual yield of extracted ore mass from 44,407 t in 2009 versus 58,568 t in 2019 which indicates a growth of 32%.

The third direction is related to an increase in labour efficiency - general labour efficiency rising from 0.71 m^3/ms in 2009 to 1.56 m^3/ms in 2019, or 2 times; the output per man shift of an underground worker has risen from 0.95 m^3 in 2009 to 2.23 m^3, i.e. more than twice; and the output per man shift of a main underground worker has increased from 3.05 m^3 in 2009 to 7.11 m^3 in 2019, or more than 2 times.

The economic efficiency (prime cost reduction per 1 t of ore) in incorporating the innovative solutions in opening, opening-up and extraction using mobile mining equipment is shown to have dropped from 48.23 $/t to 28.88 $/t, or 1.7 times less.

Conclusion

The implementation of mobile mining equipment puts an entirely different complexion on the labour of the underground miners, from manual technologies to operational work, leading to a steady increase in labour efficiency and safety.

Subsequent activities in the mine should be committed to 3D modelling of the ore bodies and mine roadways, annual, monthly, weekly and daily planning, and remote control of all mining works.

An increase in the efficiency of mining works in the exploitation of mineral deposits in an underground environment requires a complex approach in opening, opening-up, and extraction. It is necessary for the innovative solutions to be implemented in the design stage in order to gain a high added value when adapting the mining model, which is distinctive for the mining industry.

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