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PROPOSALS FOR THE USE OF CONVEYOR TRANSPORT IN URANIUM ORE MINING IN UKRAINE

Abstract. In Ukraine, uranium deposits are mined only by the underground mining method using a large volume of drilling and blasting operations. The main technological scheme of underground transport of load flows at uranium mines is locomotive transport in combination with cage hoist by a vertical shaft. The main negative factors affecting the process of transporting uranium ore are: a significant amount of oversize in the recovered ore mass with high strength; physical and mechanical properties of uranium ore; a certain disproportion when using railway transport for ore transport, which occurs in systems with massive rejection, between the volume of stockpiles that fall down simultaneously and the rate of their extraction; the hazard of inert radon gas released during uranium ore mining. The paper considers the possibility of using belt conveyors for transporting uranium ore in a chamber mining system along the strike of the ore body. This possibility appears when using new methods of blasting, developed at the IGTM of the National Academy of Sciences of Ukraine, in which the maximum piece size is 400 mm. A technological scheme of conveyor delivery of ore in a uranium mine is proposed. The ore is vibrationally released from the chamber through special reloading devices to the assembly belt conveyor. It delivers the ore to the dumping drift, where ore is transferred to a dumping line consisting of two dumping conveyors. The multi-point loading of the assembly conveyor is carried out from three vibratory feeders in turn. Prior to unloading, a radiometric control station is installed on the roll-off conveyor to ensure large-portion sorting of uranium ore before it is lifted up. The sorted ore and rock are unloaded into a specially designed hopper with an adjustable gate that redirects the ore mass flow to one of the two hoppers. At the bottom of each hopper there is a feeder that portionally loads the ore mass into the double skip hoist. The parameters of the conveyors of the proposed technological line are determined based on the expected productivity of 200 t/h. The use of this scheme will eliminate the negative factors affecting the process of transporting uranium ore and significantly increase the environmental friendliness and efficiency of its extraction.

Keywords: uranium ore mining, underground transport of uranium mines, belt conveyors, vibratory feeder, skip hoist.

1. Introduction

Today, the number one issue is to strengthen the energy security and independence of our country. The Cabinet of Ministers of Ukraine has approved the Energy Strategy of Ukraine until 2050, which envisages the development of modern and safe nuclear generation and renewable energy sources [1]. Electricity generation by nuclear power plants is possible, in particular, due to the extraction and enrichment of uranium ore. Ukraine's current demand is about 2,500 tonnes of uranium per year. Ukraine currently ranks ninth in the world in terms of uranium ore reserves. The state balance sheet of uranium reserves includes 22 deposits, of which 4 are under development and 10 are thoroughly explored. All of them are concentrated in Dnipro, Mykolaiv and Kirovohrad regions. The explored reserves alone can cover more than 100 years of natural uranium demand for Ukrainian nuclear power plants. The largest deposits of uranium ore are located in Kirovohrad region. In the first nine months of

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2023, enterprises in the Kirovohrad region produced 266 tonnes of uranium oxide concentrate. At the same time, the technological capacity of the uranium mining enterprise is 1200 tonnes of concentrate per year [2].

Uranium ore is currently mined at three deposits: Michurinske, Central (Separate Subdivision Inhulska Mine, Kropyvnytskyi city) and Novokostiantynivske deposits. The Novokostiantynivske deposit has uranium reserves of 93626 tonnes (uranium content of 0.139%) and is one of the ten largest deposits in the world. It is planned to be developed to a depth of 700 m using vertical shafts, but the main ore horizons are at absolute minus 120–440 m. The Novokostiantynivska mine was built on this deposit.

The only operating enterprise in Ukraine that carries out a full cycle of uranium ore mining and processing is the State Enterprise “Eastern Mining and Processing Plant” (SE “VostGOK”). The company includes a uranium processing complex and three mines – Inhulska, Smolinska and Novokostiantynivska – where uranium is mined underground and is technically not much different from iron ore mining in the Kryvyi Rih basin.

All uranium deposits of SE “VostGOK”, which are usually steeply dipping deposits, are opened by vertical shafts. The main shafts were drilled in the recumbent direction in the central part of the deposit, while the ventilation shafts were drilled on the flanks. In addition, auxiliary shafts for various purposes were driven, as well as shafts that were driven during the additional exploration of the deposits. At new mines, as well as at the lower horizons of existing mines, the proven ore reserves are first opened to a depth of 300–500 m, gradually deepening by 1–3 floors using blind shafts to deepen the main shafts.

The aim of the study is to analyse the existing technological schemes of uranium ore mining and transportation and to propose new transport schemes to improve the efficiency of uranium ore mining in Ukrainian mines.

2. Methods

Currently, in the technological schemes of uranium mines, the main underground transport of load flows is locomotive transport in combination with cage hoisting by vertical shafts.

Mine production capacity (horizon) and transportation distance are the main factors influencing the choice of locomotive weight, as well as the type and capacity of dumping vessels. The production capacities of the main mining divisions (mines) of SE “VostGOK” are considered in [3, 4].

Inhulska mine exploits the Michurinske and Central uranium deposits at depths ranging from 60 to 420 metres. Production capacity is 470 thousand tonnes of ore per year.

The Smolynska mine exploits the Vatutynske uranium deposit at depths ranging from 70 to 640 metres. Its production capacity is 450 thousand tonnes of ore per year, but the mine is currently in the process of closure.

Novokostiantynivska mine mines ore deposits underground at a depth of 180 to 300 metres. The mine's design capacity is 1.500 thousand tonnes of ore per year, with a further increase to 2.500 thousand tonnes. The mine is under construction and produces 235 thousand tonnes of ore per year (350 t of uranium).

At ferrous metallurgy mines that mine hard ores and have a production capacity of more than 400 thousand tonnes per year, trolleys with a capacity of 2 m^3 or more are used, which are rolled by electric locomotives weighing 10 and 14 tonnes [5]. At uranium mines with a production capacity of 450–470 thousand tonnes of ore per year, VG-4M trolleys with a blind body, 4 m^3 capacity, and 13 tonnes of carrying capacity are used.

The most commonly used ore loading machines at ferrous metallurgy mines are gates and vibratory conveying machines – vibratory feeders used for direct release of rock mass from the treatment space (blocks) and its loading into trolleys [4, 5].

The main mining-geological and mining-technical factors that determine the choice of technological schemes for underground transport of mines and ore mines are: angle of dip of the seams, depth of development, thickness and natural gas content of the seams, ventilation schemes, physical and mechanical properties of ore and its host rocks, etc. [6].

For uranium mines, the most important factor affecting the process of ore transportation is its physical and mechanical properties and particle size distribution. The transportation process is adversely affected by a significant amount of oversize in the recovered ore mass (up to 1200 mm) with high strength, which creates the risk of high dynamic loads on the elements of transport machines and congestion in the places of overloading [7].

The inert gas radon, which is released during uranium ore mining, is also dangerous. Its half-life is less than 4 days, and over the entire period of time, daughter products of decay are formed – radionuclides that bind to particles of ore dust that hang in the mine air. Large volumes of radon are released by operations to separate ore fragments from the ore body: blasting, drilling, etc. When ore is loaded and transported to the surface, it continues to release radon into the mine air.

Under the existing technological schemes of uranium mining, the disadvantage is that when using railway transport to transport ore, there is a certain disproportion, which occurs in systems with massive rejection, between the volume of stockpiles that fall down simultaneously and the rate of their extraction. This fact causes certain productivity limitations due to the limited cyclicality and low productivity of cage hoisting compared to skip hoisting.

When selecting development systems for VostGOK mines, the experience of previously developed deposits at Pershotravneva mine (Kryvyi Rih, Terny) and Vilkhivska and Nova mines (Zhovti Vody city) was used. To mine uranium ores from the Michurinsky and Central deposits (Inhulska mine) and the Vatutinsky deposit (Smolinska mine), chamber mining systems were designed and are being implemented using subfloor orthos and drifts with alternate extraction of blocks and filling the excavated space with hardening mixture. The Novokostiantynivske field also adopted a chamber development system (sub-floor orthos, drifts). Thus, the chamber system of mining with sub-storey drifts (orts) with alternate mining of blocks and filling the voids with hardening mixtures has become traditional over the more than 30 years of VostGOK's operation [3, 8].

Depending on the thickness of the ore body, the chamber mining system is used along strike or across strike of the ore body. The chamber system of development along the strike of the ore body by underground drifts with hardening mixtures is used at SE “VostGOK” enterprises when developing ore bodies with a thickness of 3 to 20 m, with an angle of incidence of 50–55° or more, and with a strength coefficient of ore and host rocks of more than 14–18 according to the Prof. M.M. Protodiyakonov scale. The ore and rocks are stable and allow exposure of individual elements of the chamber.

In the case of a small overburden yield (up to 3 %), the bottoms are formed by sinking separate holes from the dumping horizon and equipped with vibratory feeders operating under the rock mass blockage (direct release). In the case of an increased yield of oversize material (up to 5–7 %), additional sightings are made in such bottoms. Typically, bottoms with a secondary crushing horizon are used when the oversize yield exceeds 10 % [8]. The bounced ore is discharged from the chamber through horns and vibrating hoppers into the ore loading drift into the trolleys. The trolleys then move through the orthogonal trains to the field dumping track, where the ore is sorted at the radiometric control station and transported up the cage hoist in trolleys.

The classical uranium ore mining technology at VostGOK's mines with a chamber mining system using sub-floor orts involves the delivery of ore from the mining chamber to the hoist by trains with VG-4M trolleys, which has certain performance limitations due to limited cycling, low cage hoisting performance compared to skip hoisting, and certain delays associated with radiometric ore sorting.

The existing practice of using conveyors for transporting minerals in mines confirms their advantages, efficiency in difficult mining conditions and the fundamental possibility of their effective use both in the main haulage workings and in delivery. The conveying of the delivery process with controlled intensive vibration release of ore makes it possible to eliminate the disproportion arising in systems with massive rejections between the volume of stockpiles that fall down simultaneously and the rate of their extraction. The integrated use of vibration release and conveyor delivery in ore mines has shown sufficient efficiency in their application [9].

The use of special types of belt conveyors for ore transportation in ore mines makes it possible to use the controllability of the release process and a significant intensification of the mining process. The operation of such conveyors in underground conditions imposes requirements on their design, primarily related to the need to transport large pieces of material coming from vibration discharge devices within the limited dimensions of the conveyor itself. When conveyor lines are connected at right angles, an important task is to develop and apply devices that allow the ore flow to be received, deployed along the belt and loaded onto it.

The length of the delivery (assembly) conveyor is determined by the development system. An assessment of existing technological solutions shows that the length of delivery within the block does not exceed 100 m, and the length of the delivery (assembly) conveyor is determined on this basis. Moreover, the design of the conveyor should allow loading material both at the tail station and at any point in the framework during discharge from the vibrating hoppers. The emergence of conveyor belts with high strength and wear resistance makes it possible to use belt conveyors of a special design in multi-point loading conditions.

Let us consider the possibility of using belt conveyors in the case of using a chamber mining system across the ore body. In this case, the use of belt conveyors was limited by a significant amount of oversize in the recovered ore mass (up to 1200 mm) with high strength, which creates a risk of high dynamic loads on the conveyor support elements, porosity and rapid wear of the conveyor belt. In the case of using new methods of blasting, developed at the IGTM of the National Academy of Sciences of Ukraine, where the maximum piece size is 400 mm, there is a real possibility of using belt conveyors in the case of delivering ore mass from the place of vibration release to the hoist shaft [10, 11].

The proposed technological scheme of conveyor delivery of ore in a uranium mine to the surface is shown in Figure 1. Based on the above, we propose to vibrate ore 1 from chamber 2 by horns 3 with vibrating feeders 4 through special reloading devices onto an assembly belt conveyor 5, which is mounted in an ortho-race 6 and has a length of 100 m. It delivers the ore to the dumping drift, where it is transferred to the dumping line consisting of two dumping conveyors (No. 1 and No. 2) 7, 8. Multi-point loading onto the assembly conveyor is carried out from three vibratory feeders in turn. In the process of excavation of the ore mass during the development of the next chamber, the orth with the assembly conveyor moves along the seam to the width of the chamber (about 50 metres), and the place of loading the ore mass onto the No. 2 dump conveyor is moved accordingly. When the excavation reaches the No. 2 dump conveyor, the No. 1 dump conveyor is dismantled. The production time for one block is 6–8 weeks.

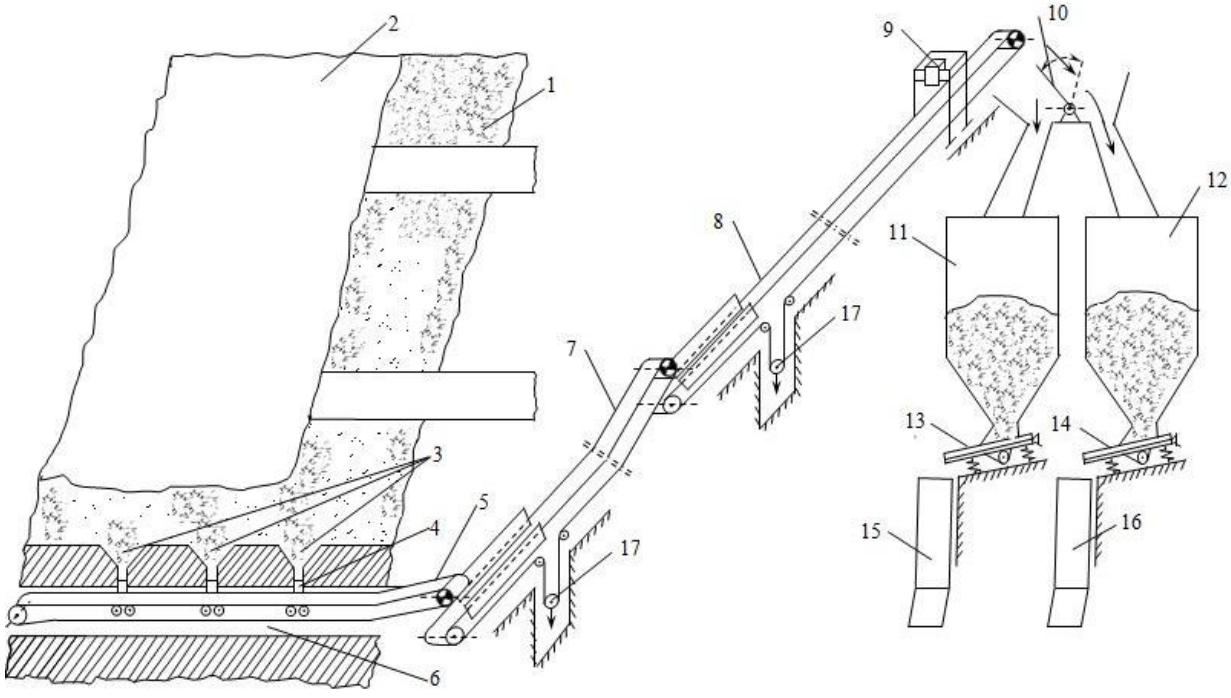

Figure 1 – Flow chart of ore conveyor delivery in a uranium mine

It should be noted that ore is currently lifted in trolleys by cage hoists, but for the efficient of the technological chain, it is necessary to lift the ore mass by skips using a skip shaft. One of the mines at the Michurinske deposit has a skip shaft that is not currently in use. Therefore, the conveyor delivery system can operate with its use.

After vibration release from the chamber 2, the ore mass is fed through one of the three vibrating feeders 4 to the 100 m long stacking belt conveyor 5 located in the ortho. The stacking conveyor delivers the ore to the dumping drift, where it is fed through a special reloading device to the 500 m long dumping conveyor No. 1 (Fig. 7). Further down the dumping drift, the ore is transferred through a reloading device to the No. 2 dumping conveyor (pos. 8), which is also 500 m long. Prior to unloading, a radiometric control station (RCS) (item 9) is installed 20 m before it on the rolling conveyor No. 2 for large-portion sorting of uranium ore before it is lifted up. The sorted ore and rock are unloaded into a specially designed hopper with an adjustable gate 10, which redirects the flow depending on the readings of the RCS.

The hopper device is a “trouser” with a gate 10 that redirects the flow of ore mass into one of the two hoppers (pos. 11, 12), which act as intermediate storage tanks before unloading into the skips. At the bottom of each hopper there is a feeder (pos. 13, 14), which portionally loads the ore mass into the skips (pos. 15, 16) of the two-skip hoist. The RCS uses radiometry to detect areas of ore or waste rock and, depending on this, controls the gate drive, which opens one or the other hopper. The ore or waste rock is loaded into the skips from the hoppers through the feeders. The sequence and cyclicality of loading is determined by the level of ore mass in the hoppers, which should not exceed two portions of skip loading.

3. Results and discussion

Let us determine the possible parameters of the above technological scheme. When calculating the capacity of the conveyor line, we can proceed from the expected productivity of a mine, for example, Novokostiantynivska mine, which is 1 million tonnes of ore per year. This translates into a daily output of approximately 3.500 tonnes per day. Such a flow with a margin can be achieved by a line with a capacity of 200 t/h. Based on this, we will determine the parameters of the conveyors and their components.

To determine the parameters of the process line conveyors, we use the experience of conveyor design available at the M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine, as well as the Methodology for the calculation of belt conveyors [12, 13].

Properties of the transported load:

– bulk density of the transported load, 2.5 t/m^3;

– angle of natural slope of bulk load when it moves with the belt along the conveyor roller-coasters, 42°;

– average linear size of the largest pieces of load, 0.4 m.

For the assembly conveyor, we get the following parameters and types of main components:

– mass capacity of the conveyor, 200 tonnes per hour;

– length of the framework, 100 m.

Parameters of roller bearings:

three-roller bearings:

– distance between roller bearings of the loaded branch of the straight section of the conveyor framework, 1 m;

– distance between roller bearings of the unloaded branch of the straight section of the conveyor framework, 3 m;

– weight of rotating parts of the rollers of the loaded branch of the conveyor, 8 kg;

– weight of rotating parts of the rollers of the unloaded branch of the conveyor, 19.5 kg;

– length of the upper rollers, 0.315 m;

– length of the lower rollers, 0.950 m;

– bearing, 305 series;

– angle of inclination of the side upper rollers, 45°.

Conveyor belt:

– for our conditions, we choose a four-ply belt type EP – 800/4 = 630–5+2 from Continental or Pirelli.

Drive:

– we choose a 55 kW NORD gear motor.

For the rolling conveyors No. 1 and No. 2, the parameters and types of the main components are as follows:

– mass capacity of the conveyor, 200 t/h;

– length of the framework, 500 m.

Roller bearings parameters:

three-roller bearings:

– distance between the roller bearings of the loaded branch of the conveyor framework, 1 m;

– distance between the roller bearings of the unloaded branch of the conveyor framework, 3 m.

Rollers parameters:

– weight of the rotating parts of the rollers of the loaded conveyor branch, 8 kg;

– weight of the rotating parts of the rollers of the unloaded conveyor branch, 19.5 kg;

– length of the upper rollers, 0.315 m;

– length of the lower rollers, 0.950 m;

– bearing – 305 series;

– angle of inclination of the side upper rollers, 45°.

Conveyor belt:

– five-ply belt type EP – 800/5 = 800–5+3 from Continental or Pirelli.

Drive:

– choose a 370 kW NORD gear motor.

The above is the calculation of the parameters of a conveyor line for ore delivery in a uranium mine.

For the first time, the possibility of using belt conveyors to transport uranium ore in a chamber mining system across the ore body, which appears when using new methods of blasting, developed at the IGTM of the National Academy of Sciences of Ukraine, in which the maximum piece size is 400 mm, is substantiated. A technological scheme for conveyor delivery of ore in a uranium mine is proposed, in which the ore is vibrated out of the chamber from the vibration feeders through special reloading devices onto the conveyor line.

4. Conclusions

1. A review of existing uranium ore mining and processing schemes revealed that uranium deposits in Ukraine are mined only by underground mining using a large volume of drilling and blasting operations during the excavation of stope mine workings and preparatory workings. They use floor-by-floor stripping and working of floors from top to bottom using a chamber system of development by underground drifts (orts) with alternate working of blocks and filling of voids with hardening mixtures.

2. The analysis showed that the main technological scheme of underground transport of load flows in uranium mines is locomotive transport in combination with cage hoisting by a vertical shaft.

3. It has been found that the main negative factors affecting the process of transporting uranium ores are: a significant amount of oversize in the recovered ore mass with high strength; physical and mechanical properties of uranium ore; a certain disproportion when using railway transport for ore transportation, which occurs in systems with massive rejection, between the volume of simultaneously falling stockpiles and the rate of their extraction; the hazard of inert radon gas released during uranium ore mining.

4. To increase the efficiency of uranium mining, a technological scheme of conveyor delivery of ore in a uranium mine is proposed in the case of using a chamber mining system consisting of a stacking and two rolling conveyors, reloading points, sorting and unloading points. The parameters of the conveyors are calculated. The use of this scheme will eliminate the negative factors affecting the process of transporting uranium ore and significantly increase the environmental friendliness and efficiency of its extraction.

Based on the results of the research, 2 patents of Ukraine for a utility model were obtained [14, 15].

Conflict of interest

Authors state no conflict of interest.

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ПРОПОЗИЦІЇ ЩОДО ЗАСТОСУВАННЯ КОНВЕЄРНОГО ТРАНСПОРТУ ПРИ ВИДОБУТКУ УРАНОВОЇ РУДИ В УКРАЇНІ

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Анотація. В Україні родовища урану розробляються тільки підземним способом видобутку з використанням великого обсягу буропідривних робіт. Основна технологічна схема підземного транспорту вантажопотоків на уранових шахтах – локомотивний транспорт у поєднанні з клітьовим підйомом вертикальним стволом. Виявлені основні негативні фактори, що впливають на процес транспортування уранових руд: значна кількість негабариту у відбитій рудній масі з великою міцністю; фізико-механічні властивості уранової руди; певна диспропорція при використанні для транспортування руди залізничного транспорту, що виникає в системах із масовим відбоєм між обсягами запасів, що одночасно обрушуються, і швидкістю їх вилучення; небезпечність інертного газу радону, який виділяється під час видобування уранової руди. Розглянуто можливість застосування стрічкових конвеєрів для транспортування уранової руди при камерній системі розробки впоперек простягання рудного тіла, що з'являється при застосуванні нових способів відбою вибухом. Вібровипуск руди з камери здійснюється через спеціальні перевантажувальні пристрої на складальний стрічковий конвеєр. Він доставляє руду до відкотного штрека, де вона перевантажується на відкотну лінію, що складається з двох відкотних конвеєрів. Багатопунктове навантаження на складальний конвеєр відбувається з трьох віброживильників по черзі. Перед розвантаженням на відкотному конвеєрі встановлено радіометричну контрольну станцію для великопорційного сортування уранової руди перед підйомом нагору. Розвантаження сортованої руди і породи відбувається в бункерний пристрій спеціальної конструкції з регульованим шибером, який перенаправляє потік рудної маси в один із двох бункерів. Внизу кожного бункера розташований живильник, який порційно завантажує рудну масу в скипи двоскіпового підйому. Визначено параметри конвеєрів пропонованої технологічної лінії, виходячи з очікуваної продуктивності 200 т/год. Використання цієї схеми дозволить усунути негативні фактори, що впливають на процес транспортування уранової руди та значно підвищити екологічність та ефективність її видобутку.

Ключові слова: видобуток уранових руд, підземний транспорт уранових шахт, стрічкові конвеєри, віброживильник, скіповий підйом.