Combined geotechnology potentials in the process of coal deposits integrated development

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Abstract. Significant coal resources situated in open-pit recovered sides and bottom being non-demanded are considered to be irretrievably lost and written off as losses. Integrated (open and underground) technologies for final extraction of contour reserves applying a highwall miner complex and mobile mechanical equipment which improve coal recovery ratio are introduced in the article.

1. Introduction
Integrated opening of a coal deposit means clean mining (a complete extraction of coal deposits) [1]. Surface mining operations (open-cut method) take a leading position in the industry. In Russia 440 mln. tons of coal were produced in 2018 and 75 percent was extracted by means of surface mining operations. The analysis of total open-pit losses (a coal profitable cut-off part situated in open-pit contours) in open-pit coal mines revealed that significant reserves in recovered sides and bottom of a coal pit are left to be non-demanded, irretrievably lost and as a fact are written off as losses. For example, in Kuzbass these losses exceed 450 mln. tons, in Tchernogorskey open-pit (Khakassia) it is 70 mln. tons [2, 3].

At the final stage of open-pit mining of a coal deposit or at open-pit-to-underground mining transition a combined (open and underground) worldly known mining technology with final extraction of contour coal reserves called technology of “Highwall mining system” (modification: Auger mining; Metec miner system; Continuous Highwall Mining (CHM); Longwall punch mining; Room/Board-and-pillar punch mining) is applied [4, 5]. “Metec Miner System” is well known in Russia under the name “Highwall Miners complex” (HMC) [6]. The equipment was delivered by CAT and SHM.

The Auger mining (Augering) technology is applied during thin seams mining extractions by means of drilling out the boreholes (wells) with adequate pillars between them using an auger situated at the highwall. The application of this method makes 4 percent of the total coal production in the USA [7]. Numerous closely situated thin seams in central coal deposits of Appalachians and Western Virginia make this method more advantageous and sometimes even the only one possible for final extraction of contour coal reserves after finalizing open-pit mining.

In Russia in a coal strip mine “Yunyaginsky” (JSC Vorkutaugol) the extraction of coal out of the seams with the thickness 0.6 – 1 meters with a slope angel reaching 18 degrees and drilling wells with 260 meter depth was done [8]. The technology conditions high mining losses (to 70 per cent) and limited application field as it doesn’t allow developing medium and high thickness seams.
Continuous Highwall Mining System (CHM) is applied for highwall excavation (robbing) of seams with the thickness to 4.5 meters by way of straight working extraction (extraction chambers) and leaving adequate pillars between them. There are two well-known modifications of this method: Addcar system (complex equipment that includes: extraction chamber of continuous operation, mobile belt-type conveyor sections, launch installation, conveyor of temporary coal storage, loading machines) and Archveyor system. Archveyor system differs from the first one by applying chain-and-flight conveyor that transports coal and provides pushing the extracting machine into the face. Total automated control of CHM System is supported by sophisticated navigation technologies which include passive gamma detector along the seam roof and floor, surveying tool, ring laser gyroscope and programmable logic controller [9]. This technology was not applied in Russia and didn’t get widespread use abroad due to the low reliability of conveyor sections.

Longwall punch mining System was initially applied in Australia in 1990 for developing flat seams in longwall faces. Windways and belt entries were made from the highwall. In the depth of the highwall a mechanized longwall set of equipment is installed meant for underground extraction with retreating. The coal along the belt entry is delivered into the belt conveyor installed at the highwall and is transported further into the coal storage. The production reached 6 mln. tons per year [10].

Apart from this system the technology of Room/Board-and-pillar punch mining is applied in short stopes for extracting limited reserves (for example, protective pillars) by means of mobile mechanical equipment (MME technology) [10, 11].

The advantages of these two systems are in high productivity of a stope, that the do not require permanent stripping workings, complex transportation and ventilation systems. However, it requires adequate planning and designing of an enterprise that provides saving and supporting the surface infrastructure of the open-pit during all the underground mining works. These systems can not be applied if the highwall rocks are hazardous (unstable).

Metec miner system technology being based on Superior Highwall Miners complex equipment which has started to be produced under Bucyrus Highwall Miners Brand (in the USA there are 65 operating complexes) since 2010 is widely used abroad [12]. Four SHM complexes No. 28, 29, 34, 56 were delivered in Russia and 3 out of them are used in operation under Highwall Miners complex brand [6].

The complex equipment consists of the launching set equipment, extracting machine of continuous operation, double-drum shearer conveyor, temporary coal storage conveyor and front-end loader. Highwall mining complex is installed on the open space formed as a result of extracting stripping soils along the highwall contour which is meant to be developed applying this system. Highwall mining complex allows excavating coal seams with 1.1 – 4.8 meter thickness (the depth of the seam development downwards – 300 meters) without presence of people in the stope areas [6].

In Kuzbass coal seams in the areas of surface operations of ZAO “Raspadskaya”, ZAO Razrez Kuprinsky”, JSC “Razrez Yuzhny” were excavated by this Highwall mining complex system.

As Russian and foreign practices show the main problem of Highwall mining complex technology is in large amounts of coal losses in pillars (to 60 percent) and during excavation of the seams with the thickness of more than 4.8 meters coal mining losses are even higher. The reason of its limited use in Russia is high hazardous level of stopes due to pillar disintegration and roof caving [13].

The authors of this work hold the task to develop technical solutions that improve the effective development of coal deposits applying Highwall mining technology by increasing the recovery ratio of coal reserves by means of extracting coal pillars due to improving roof stability of the workings by roof bolting and adapting MME technology to the existing mobile mechanical equipment.

2. Final extraction of contour coal reserves using Highwall Miners complex technology

Developing flat coal seams of medium thickness by Highwall Miners complex technology conditions high losses of coal left in ground due to the necessity of leaving adequate pillars between neighboring workings and high probability of accidents in stopes due to the absence of roof support in the workings. Coal Institute of the Federal Research Center of Coal and Coal Chemistry, SB RAS has
worked out a technological scheme of excavating contour coal reserves from highwall which includes roof bolting (anchorage) of the workings developed by Highwall Miners complex technology (figure 1) [14].

For preliminary preparation of a stoping ground, on the bench of a highwall along a seam ground level bearing an operation platform is installed. Starting from the edge of the opened-up part, a coal seam is figuratively divided into mining blocks parted from each other by safety pillars. The portals of the extracting workings between which the pillars are planned to be left are marked in the first mining block. The width of these pillars is planned considering the width of the excavating machine complex executive body. Then, on the operating platform in front of the extracting working portal with ranking I Highwall Miners complex is assembled.

Coal extraction is carried out in rectangular-sectioned form by the extracting machine which is pushed into the face by a double-drum shearer conveyor unit. As far as the extracting machine deepens into the massif the boreholes are drilled into the roof and the roof-bolting (anchorage) is installed (the extracting machine is provided with the boring rigs installed normally to the seam roof). To install roof-bolting a mechanically connected with an extracting machine roof-bolter can be used. For supplying (feeding) a set of roof bolts a mobile container which moves in the working along the unit or on the ground of the working along the unit can be used. All the works in a stope are carried out without the presence of people. The staff carries out direct control over the equipment remotely out of the operation control center (for example, applying technologies of brain-machine interface and augmented-reality) [15].

After carrying out the extraction with ranking I the Highwall Miners complex equipment together with the unit is drawn out of the working and dismantled. Further, it is moved to another portal with ranking II and a similar operation (described above), i.e. using roof-bolting is carried out.

![Figure 1](image_url)  
**Figure 1.** Flat medium thickness coal seam extraction scheme using Highwall Miners complex: a) side-view; b) front view.
At the next stage the extraction of the pillar (III) which is situated between the workings with ranking I and II is carried out but without bolting the roof. After that the working ranking IV is extracted using roof-bolting technology and then the extraction of the pillar (V) situated between the workings ranking III and IV follows. And it continues in the same order till the final pillar (IX) is extracted in mining block I.

After developing the workings and pillar extraction in the first mining block the stoping in the same order starts in mining block II etc.

3. Final extraction of contour reserves applying MMC technology
The range of flat coal seams covers the seams dip at $\alpha < 18$ degrees towards horizon, however, mobile mining mechanical equipment (coal drawing, coal loading, transportation facilities, roof bolting etc.) which may move up at the angle of about 18 degrees to the horizon has not been created yet (figure 2). For example, heading-and-winning machines of JOY brand (mining combined machines of forward action with the horizontally oriented cylinder of the cutting body) can work successfully with longitudinal slope $\beta$ to 7 degrees; domestic tunneling machines of GPKS type (with selective executive body) can do it with longitudinal slope of 10-12 degree.

For final extraction of thick, flat coal seam reserves dip at about 7 degrees MMC technology requires carrying out the works from the bench of the highwall by way of extraction chambers and coal extraction in diagonal stub headings [11]. To achieve this it is important that a coal seam enter on the slope but not on its platform while carrying out mine stripping and forming the bench itself.

From the bench, down-dip, an in-seam working is carried out, firstly, starting from the ground to its roof and continued further at the seam roof to the open-pit contour with adequate support setting. The height of the working is considered with technical specification of the applied mechanical equipment. At the open-pit contour this working is gradually rounded up at 90 degrees and then it is continued along the seam level bearing in the form of the drive at the length equal to 4 multiple length of the combined machine (figure 3).

For ventilation of a dead cut while carrying out the extraction a booster fan and ventilation tubing are used. Broken-down coal is transported by a self-propelled wagon to the operating platform organized on a bench where in a cross-section with the working a temporary coal-storage is formed. Alongside of the portal working, at the distance equals to its 5-6 multiple width, by means of the same mechanical equipment an extraction chamber is developed till the joining with the drive and the roof of this chamber is supported by roof bolting. The ventilation of the extraction chamber after its joining with the drive is done by inflating the air into ventilation tubing, laid out along the in-seam working and further. Owing to this pressure difference between the one in the drive and the one in the bench the ventilation process takes place. When the combined machine goes out of the extraction chamber into the drive the latter is lengthened at the distance equals to its 3-4 multiple widths.
Figure 3. The scheme of final extraction of thick seam reserves dip at about 7 degrees (view the plan): 1 – in-seam working; 2 – combined machine; 3 – self-propelled wagon; 4 – drive; 5 – booster fan; 6 – ventilation tubbing; 7 – temporary storage; 8 – extraction chamber; 9 – diagonal stub heading.

After finalizing the works on prolonging the drive the combined-machine and a wagon are returned into the extraction chamber space and starting from the chamber and the drive joining the coal is extracted in diagonal stub headings, cut along both sides of the extraction chamber. The stub headings are oriented anglewise 120-135 degrees toward the axes of the chamber and situating them in checkerwise order leaving safety pillars between the slips from one side; the length of the stub heading is taken equal to the length of the combined-machine not longer.

After the coal extraction in all possible stub headings of the extraction chamber in a layer at the roof seam the extraction chamber is deepened to the ground starting from the portal of the working to the drive. Further the coal is extracted by diagonal stub headings situated right under the worked-out stub headings at the roof seam correspondently.

Having finished the coal extraction in stub headings of the deepened extraction chamber the combined machine and the wagon are driven out on the operating platform and alongside the portal of the worked out chamber at the distance that equals to 3-4 multiple length of the chamber the following extraction chamber is developed in the same manner. Further on, the coal extraction works are repeated, as it is described above, and the worked out space of the chamber get isolated.

In case of final extraction of thick seam reserves dip up to 7-8 degrees the technology differs in the way that an in-seam working and an extraction chamber are extracted diagonally (figure 4) towards the bench face at the angle more than 7 degrees towards the horizon [11]. At this the diagonal stub headings started from a seam pitch are cut at the angle of 120-135 degree towards the extraction chamber axes measured from its portal and the stub headings started from the seam gradient are cut at the same angle measured from the joining of the extraction chamber with the drive.

Due to this differences transportation of coal broken down in stub headings from the seam gradient is fulfilled along the extraction chamber in reverse direction that is in the direction of a drive and further it moves along the in-seam working till the temporary storage.
Figure 4. The scheme of final extraction of thick seam reserves dip at about 7-18 degrees (view the plan): 1 – in-seam working; 2 – combined machine; 3 – self-propelled wagon; 4 – drive; 5 – booster fan; 6 – ventilation tubing; 7 – temporary storage; 8 – extraction chamber; 9 – diagonal stub heading.

4. Conclusion

There are a lot of proven technologies for final extraction of contour coal reserves. Providing that stable enclosing rocks allow lengthy and significant in terms of area roof exposure (to 1000 square meters) the most effective system is Highwall Miners system which allows developing coal seams with the thickness from 1.1 to 4.8 meters without presence of people in mining zone. Roof bolting helps to increase the operational period. To do this it is important to upgrade Highwall Miners system installing a remotely controlled roof-bolter into the extracting machine. It provides safe coal mining and complete coal extraction out of medium thickness seams with single layer development.

Using mobile mechanical equipment for basic operations of MMC technological cycle allows organizing coal extraction from highwall in stub headings cut both in the layer at a seam roof and in the layer at the ground without significant financial expenses.

The introduced technical solutions allow involving into intensive development coal reserves in a gotten side of an open-pit, that in its turn decreases total mining losses; minimizing period of preliminary works and they require minimum of operating staff comparing to traditional resources of large-scale mechanization, i.e. increase labour productivity.

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