

KRZYSZTOF KRAUZE*[#], ŁUKASZ BOŁOZ*[#], TOMASZ WYDRO***MECHANIZED SHAFT SINKING SYSTEM****MECHANIZOWANY FREZUJĄCY KOMPLEKS SZYBOWY**

Development of mineral deposits located at significant depth may be carried out by means of vertical shafts. Shaft sinking technology usually requires a number of works to be carried out, including the selection of appropriate excavating techniques adapted to geological and hydrological conditions, including natural hazards. The production technology and the machines used determine the level of sinking costs and execution period. The article discusses the excavating technologies currently used across the world. Then the assumptions, concept and construction of a new generation of shaft sinking system were presented. The proposed new solution of the system and the excavating technology allow for parallel execution of key processes related to winning, loading, transport and shaft wall-side lining, which significantly increases the progress of sinking. The shaft sinking system was created by scientists from AGH in cooperation with KOPEX – Przedsiębiorstwo Budowy Szybów S. A. and Instytut Techniki Górniczej KOMAG.

Keywords: shaft sinking, mechanical cutting, cutting machine, shaft sinking system

Znaczący wpływ na wybór systemu wykonywania szybu, jak i metody drążenia ma przyjęta technika urabiania. Można wyróżnić dwie techniki drążenia szybów: tradycyjną metodę górniczą czyli wiertniczo-strzelniczą oraz technikę mechanicznego urabiania dna szybu. Głównym czynnikiem determinującym wybór metody urabiania są własności fizykomechaniczne urabianych skał. Jednak istotne są również możliwości techniczno-ekonomiczne i organizacyjne. Stosowane obecnie i w przeszłości technologie głębienia szybów, niezależnie od stopnia zmechanizowania poszczególnych procesów charakteryzują się szeregiem wad, głównie w aspekcie urabiania w górotworze trudnourabialnym. Uzyskiwane rezultaty nie spełniają oczekiwań przyszłego użytkownika tak w zakresie stopnia mechanizacji procesów jak i postępów drążenia.

Na podstawie przeprowadzonej analizy, uwzględniając jednocześnie oczekiwania przyszłego użytkownika stwierdzono, że konieczne jest poszukiwanie nowego rozwiązania, w postaci unikatowego kompleksu szybowego urabiająco-odstawczego. Mając na uwadze powyższe jak również zapotrzebowanie rynku na w pełni zmechanizowany system, zaproponowano koncepcję nowej generacji kompleksu szybowego. Kompleks ten będzie realizował równoległe procesy urabiania, ładowania i transportu urobku oraz mon-

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tażu obudowy szybowej. Spełnienie tego założenia wymagało zaprojektowania zupełnie nowego systemu maszyn. Przedmiotowy kompleks przedstawiono schematycznie na rysunkach 1 i 2.

Dla przyjętych założeń konstrukcyjnych maszyny takich jak:

- zabiór organu urabiającego (szerokość urabianej warstwy) wynosząca $Z = 0,8$ m,
- głębokość urabiania warstwy skalnej wynosząca $H_u = 0,3$ m.

oraz ustalonych parametrów geometrycznych szybu i prędkości urabiania, przeprowadzono między innymi analizę możliwego do uzyskania postępu drążenia. Wyniki tej analizy wskazują, że zastosowanie proponowanego kompleksu szybowego pozwoli na osiągnięcie postępu drążenia dochodzącego do 3,3 m/dobę.

Drążenie wyrobisk szybowych jest procesem trudnym i skomplikowanym. Uwzględniając dodatkowo określone przez użytkownika wymiary szybu, czyli średnica około 9 m i głębokość około 850 m, należy liczyć się z trudnościami związanymi z wprowadzeniem zupełnie nowej maszyny urabiającej, zespołu ładowania i odstawy urobku oraz zespołu montażu obudowy przy jednoczesnym zapewnieniu bezpieczeństwa załogi. Przedstawiony w artykule projekt rozwiązania kompleksu szybowego spełnia postawione wymagania w zakresie założonych warunków pracy maszyn i urządzeń jak i możliwości realizacji procesów pomocniczych (zabezpieczanie wyrobisk, odwodnienie, mrożenie) nie związanych bezpośrednio z podstawowymi funkcjami kompleksu (urabianie, ładowanie, transport, zabezpieczenie ociosów). Szeroko przeprowadzona analiza efektywności przedmiotowego rozwiązania wykazała możliwość osiągnięcia dużego postępu, który spełnia postawione założenia.

Przedmiotowy kompleks szybowy charakteryzuje budowa modułowa z szerokimi możliwościami modyfikacji co przekłada się na wiele wariantów dostosowanych nie tylko do różnych średnic, ale także różnych warunków pracy, potrzeb i wymagań przyszłych użytkowników. Kompleks ten znacznie różni się od dostępnych na rynku i znanych z literatury zestawów maszyn do drążenia szybów.

Słowa kluczowe: drążenie szybów, urabianie mechaniczne, maszyna urabiająca, kompleks szybowy

1. Introduction

The adopted shaft construction technology significantly influences the choice of shaft sinking system and excavating methods. Two techniques of excavating can be distinguished: based on drilling and blasting as a classic, traditional mining method and mechanical cutting with different types of boring machines.

Traditional mining method is based on blast holes drilled in the shaft bottom (face) loading them with explosive material and firing. However, this technique requires the withdrawal of the crew during the firing and ventilating of the shaft face, which at higher depths of the shaft significantly affects the progress of sinking. Moreover, such a system enforces the execution of all processes: sinking, firing, loading and reinforcement the walls, which also has a negative impact on the progress.

In the selection of the mechanical method of excavating, the main factor determining this selection are the physical and mechanical properties of the rocks and economic and organisational capabilities. Mechanical techniques cover all methods of shaft sinking, which use mechanical excavating with hammers, full diameter boring or cutting of various types of cutter heads. The above methods can be carried out manually (using hammers) or using a suitable machine (cutting, boring). On the other hand, the loading and transport of rocks can be carried out in series by means of shaft loaders or in parallel by means of a continuous mechanical conveyors or pneumatic/hydraulic transportation system.

Currently, there are many techniques used for shaft sinking. The new "Raise Boring" method used by Sandvik company should be mentioned here. In this method the drilling rig makes a pilot hole, and then in the upward direction a large diameter hole is made with the use of a special cutting head. This method, in comparison to the classic Raise Boring method, significantly limits

the maximum diameter of the hole and its length. In case of such solution, the maximum diameter of the shaft is 6.0 m and its depth can reach up to 2,000 m.

Also in the field of mechanical shaft excavating many years ago, attempts were made to create a shaft complex which simultaneously wins the bottom of the shaft, loads and strips the excavated material and makes the shaft lining. Such a system was this one designed in the former USSR on the basis of a PD-2 shaft sinking machine. PD-2 shaft sinking machine is suspended in a shaft on reel ropes installed on the surface. Excavating takes place through a specially shaped unit in the form of disks, and knives or chewing rings are attached to the discs. The extraction of excavated material from the shaft bottom was performed pneumatically using special containers.

Another of the mechanical excavating method is a shaft sinking with the machine designed by Wirth and marked with the symbol of GSB-V-450/510. The GSB-V-450/510 combines a full cross-sectional shaft sinking machine with hydraulic loading and spoilage. However, the hydraulic transport system limited the maximum sinking speed to 1.8 m/h (3cm/min). In addition, two levels of transport, pre- and primary transport were used. Therefore, a new design for the VSB VI-580/750-Eloch Deilmann-Haniel shaft sinking machine has been developed. The new shaft sinking machine of VSB VI-580/750-Eloch has improved the drainage system for excavated material from the shaft bottom. Two alternative solutions, namely pumps with channel rotors or a jet water pump operating on the ejector principle, have been designed for transporting sink cuttings from the bottom of the shaft up to the upper machine platform.

The PVS 3500 made by TURMAG company is another construction worth mentioning due to the complex kinematics of the excavating method. This is an example that illustrates the search for a compromise because of the requirements of two different criteria, namely cost and versatility in terms of application field. The well-known cutting technology and standard tools reduce costs.

Another technology for sinking shafts is the technology with submerged shaft lining. Currently, in the world mining industry two systems of shaft sinking with submerged shaft lining are used.

The first one is a system based on the use of VSM (Vertical Shaft Sinking Machine) and the second one with the use of turbine sinking technology.

The VSM system can be used in soft and stable rocks with the strength of up to 80 MPa. In this technology, the whole shaft is filled with heavy liquid during the sinking process, along with which the excavated material is hoisted up to the surface. In this case there is no need to lower the groundwater level or use a time-consuming and costly process of freezing the rock mass.

The second system, like the VSM technique, uses a heavy liquid to maintain the walls of the deepened shaft. The difference is the type of the cutting tool used. This is because this method uses a special cutting head that works on a principle similar to turbo-drills.

Also the Polish shaft sinking technique deals with mechanical excavating. In addition to the traditional mining technology (sinking and D&B), PeBeKa company also performs shaft construction with the use of shaft sinking machine. The idea of the KDS-2 shaft sinking machine, constructed on the basis of the components of the KWB-6 shaft sinking machine, is dedicated for mechanical sinking of vertical mining shafts with a diameter of 7,5 m (tubing, concrete) to 9,7 m (circuit-wheeled steel shaft lining).

It is also worth to mention the offer, presented by German company of Herrenknecht. Herrenknecht has two solutions for shaft systems: SBR (Shaft Boring Roadheader) and SBM (Shaft Boring Machine). The SBR type machine excavates the rock mass by cutting. The broken rocks from the bottom of the deepened shaft are sucked in and transported pneumatically to the

intermediate containers, from where it is hoisted up to the surface by cyclic transport using typical tubes. The SBR machine enables sinking of the shaft in a rock, compact to a depth of about 1,000 m with a diameter of up to 12 m, without the need to drill a pilot hole.

Another solution is the SBM, which has been designed to perform shaft excavations with a diameter of up to 12 m and a depth of up to 2,000 m in compact rock formations. Disc tools are used for machining by static pressure.

The presented technologies of shafts sinking, not depending on the degree of automation of individual processes carried out during the sinking process, have their weaknesses, mainly in terms of excavating in the rock mass, as the progress achieved is unsatisfactory compared to the assumed performance in the world mining industry. The main obstacle to achieve proper progress is a number of activities resulting from the technology of the shaft lining construction.

Due to the fact that currently there is no mechanised shaft sinking system that meets the customer's expectations, it is necessary to find a solution for a new, unique shaft complex. The construction and technologies presented in this article have been developed as a part of the design of the shaft system (Krauze, 2009; 2010; 2015b; 2016a; 2016b).

It should be emphasized that also in case of longwall systems, drift complexes and drilling rigs for exploitation of deposits with explosive material as well as mining of difficult rock formations, significant progress and interest of scientific-research and development centres can be observed (Bołoz, 2013; Krauze, 2015a; 2015c; 2016a; Wydro 2015; Mendyka 2016).

2. Concept and assumptions for the new generation shaft sinking system with a surface hoisting installation

Taking into account the future user of Przedsiębiorstwo Budowy Szybów (PBSz), as well as the market demand for a fully mechanized system of sinking, concepts of a new generation of the shaft sinking system have been proposed and it will implement the following processes in parallel:

- Winning – carried out as a continuous process by the cutting-head attached to the working platform in such a way that the entire bottom of the shaft can be excavated,
- Loading and unloading – is carried out on a continuous basis by a storage unit (mixer loader) and a set of belt and bucket conveyors,
- Temporary protection of walls – executed by steel panels (shields) which simultaneously perform the function of opening with integrated hydraulic cylinders.

Therefore, the following parameters of the shaft complex have been adopted:

- nominal diameter of the shaft at breakage: ϕ 8.5 m ÷ ϕ 9.5 m,
- maximum load-bearing capacity of the rocks for single-axis compression: 150 MPa,
- maximum capacity due to transport restrictions: 40 m³/h,
- bucket capacity: 6 m³,
- daily working time of the shaft sinking machine for excavating, loading and transport: max. 20 h,
- maximum mass of the shaft sinking machine (working platform with unit and conveyors): up to 80 Mg,
- load on the working platform: up to 10 Mg (apart from the own weight of the shaft sinking machine),
- each level of the shaft (next platforms, platforms) will be independently extended.

The proposed assumptions of the shaft sinking system are based on AGH owned technical solutions, as well as on the structures proposed by the KOMAG (the spreading system and frame of the cutting unit) and the requirements specified by PBSz.

The system is shown in Figures 1 and 2. It consists of: Working platform 1, swivel ring 2, spreader system 3, stationary working platform 4, linear guide 5, shaft sinking machine arm 6, cutting unit 7, swivel actuator 8, sliding system 9, short belt conveyor 10, linear conveyor 11, chute 12, short bucket conveyor 13, tray 14, long bucket conveyor 15, permanent platform 16, lowering actuator 17, the lute line 18, operator's cab 19, short conveyor lifting system 20, rotation drive of the working platform 21.

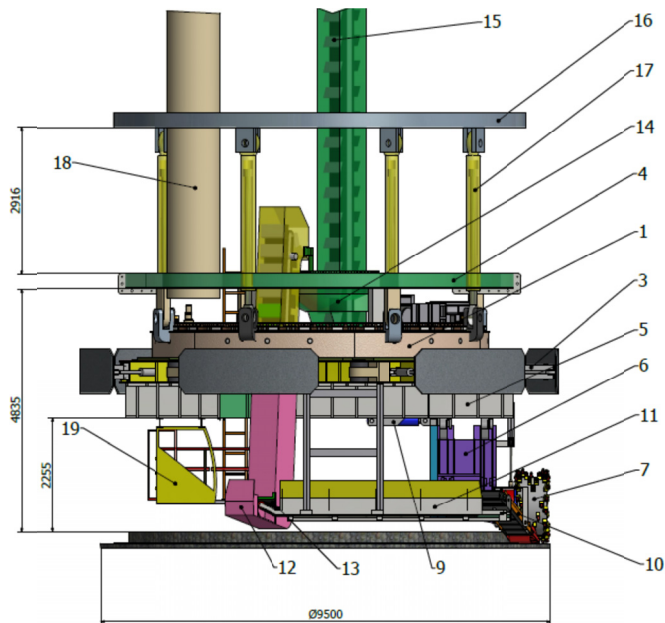


Fig 1. New generation mechanized shaft sinking complex

3. Construction and principle of operation of the shaft complex

Taking into account the presented concept of the shaft complex, an appropriate technological cycle has been proposed. This technological process begins the course of slotting and then excavating after stabilisation and disintegration of the working platform 1. The work platform (Figs 1,2) is stabilized by extending the spreader system 3, consisting of six pairs of cylinders located every 60° at the perimeter of the working platform and an additional guide between the actuators. The actuators with a single 500 kN actuator opening force have been proposed for spreading purposes. The actuators span three pairs each.

The wall protection covers are mounted on the spreader system (Fig. 3). The spreading cylinders are equipped with a piston displacement transducer and pressure transmitters. This

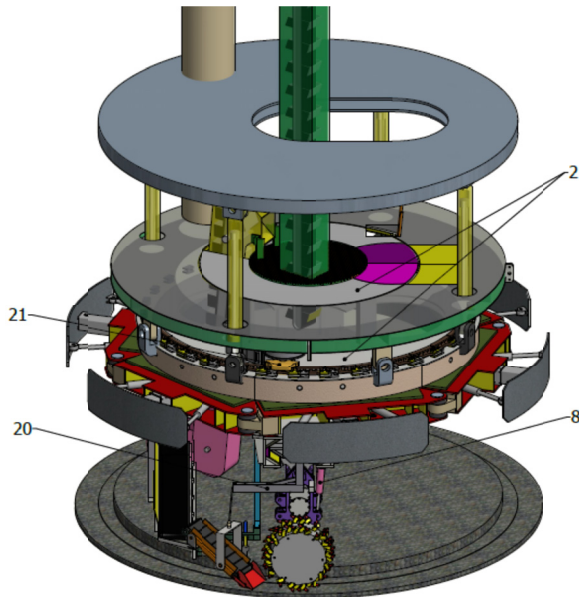


Fig. 2. 3D visualisation of mechanized shaft sinking complex

equipment will allow for precise centring of the platform during stabilization and to check (inspect) to what extent the individual actuators have already been opened and thus to correct their outflow. The operation of the actuators will be controlled by a control unit with an electrically operated (open-safe) distributor and hydraulic locks. The spreader speed settings are set via the flow controller.

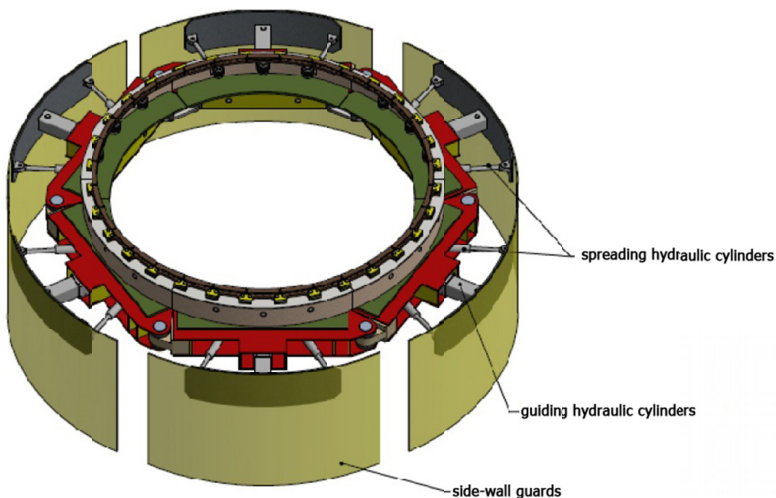


Fig. 3. Spreading system model

The swivel ring is installed inside the work platform 2. The swivel ring, as in the previous versions, is positioned on the rollers which move along the raceway of the work platform. The rotation of the respective ring is carried out by means of a drive which consists of two hydraulic motors and traction wheels (teeth) interlocked with a ladder placed on the inside of the working platform, as shown in Fig. 2. To the lower part of the swivel ring, the linear guide has been attached in a separable manner (Fig. 4). A sliding arrangement of the shaft sinking machine arm is mounted inside the linear guide. The whole system allows the shaft sinking machine arm to pass with the cutting unit in the direction of the shaft axis, i.e. to the set of the proper unit round. The linear guide has bars inside which allows the beam guide of the shaft sinking machine arm to move with a linear feed cylinder and locking trolley. At the moment of setting appropriate round, the trolley is locked by means of a double-acting cylinder in the bar, fixed in the linear guide (Fig. 1), and the arm guide is stabilized by two double-acting cylinders (Fig. 4).

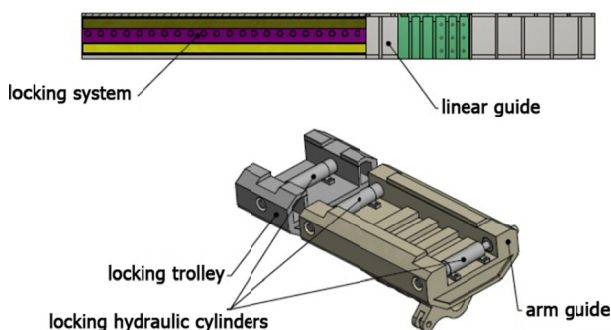


Fig. 4. Model of the moveable system with the locking trolley and linear guide

Another unit of the shaft sinking machine is the mining unit. The mining unit includes a shaft sinking machine arm, two arm lifting cylinders, a short conveyor lifting system with a unit arm and a cutting unit (Fig. 5).

The shaft sinking machine arm is the adopted arm of a longwall shearer. It is equipped with an electric motor of 250 kW power and mechanical gearboxes. The slotting is carried out by means of two cylinders (Figs 6,7) placed on one side of the arm.

The platform's rotating ring rotates at the working speed when performing slotting. During the movement of platform's swivel ring, the cutting unit makes rectangular cuttings with a width equal to the Z unit round and a height equal to the working depth g_u . Once a single cut has been performed, the unit is lifted and then the rotating ring of the platform is moved back to its initial position. It is necessary to carry out the slotting of the unit in a new cut, i.e. in a new position, in the direction towards the shaft axis by the value of unit round. When carrying out slotting to successive cuts, the unit moves along the linear guide in the direction of the shaft axis at the same time as the ring rotates, resulting in a spiral movement of the organ until the new cut position is reached. The subsequent cuttings are produced in the same way until a complete layer is made (Fig. 8). During the phase of slotting and normal excavating phase, the short belt conveyor runs behind the unit and transfers the muck to the horizontal (linear) belt conveyor.

The conveyors assembly is the last "link" of a closed mine shaft sinking machine operation. The excavated material from underneath the cutting unit, through a scraper and a short belt

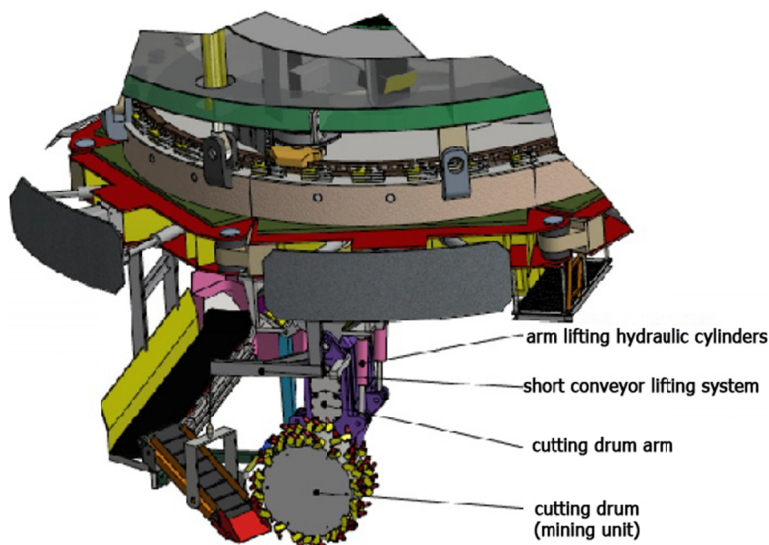


Fig. 5. Cutting unit model

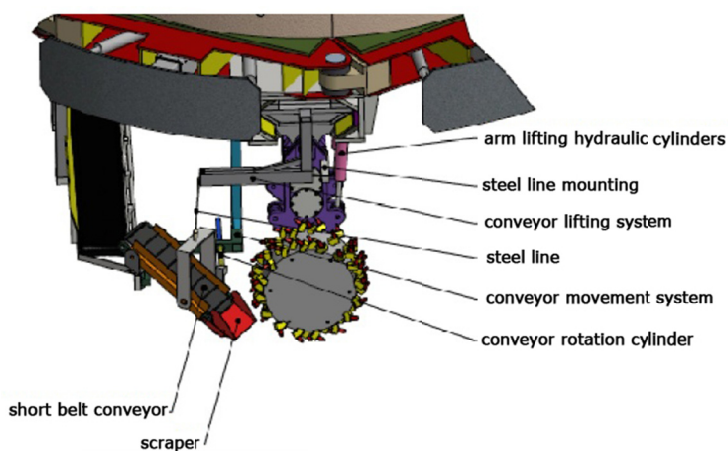


Fig. 6. Model of the elevation and movement of the belt conveyor (side view)

conveyor loads the excavated material onto a horizontal conveyor belt, and then the excavated material is fed into the conveyor belt. The muck is picked up from the chute by a short bucket conveyor, which transports it to the hopper. Then the bucket transports the excavated material from the hopper to a height to be determined by the user.

The short conveyor is lifted by means of a steel cable connected by a lifting system between the shaft sinking machine arm and short conveyor belt. An actuator was also introduced to allow for straightening of the short belt conveyor in relation to the horizontal conveyor during the transfer of the arm to the centre of the shaft (Figs 6 i 7).

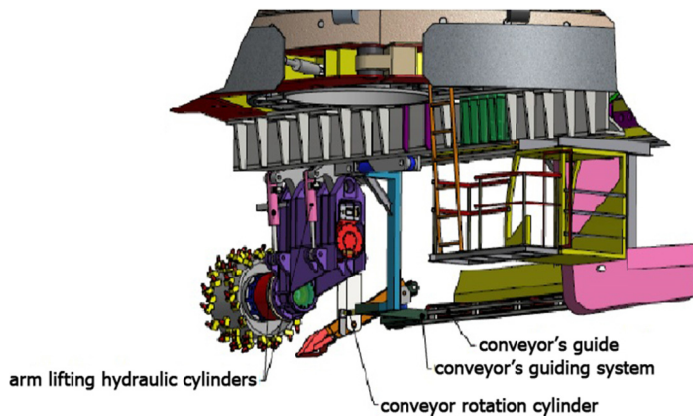


Fig. 7. Model of the elevation and movement of the belt conveyor (rear view)

4. Analysis of the excavation efficiency of the developed shaft complex

As part of the system concept, the initial working technology of the shaft sinking machine has been developed and achievable productivity has been calculated. At the same time, this shaft system is performing the process of excavating, loading and haulage the broken rocks from the shaft bottom. The presented analysis was carried out for the shaft sinking machine being lowered by means of actuators with a stroke of 1.8 m (Figs 1,2). The unit cutting round was adopted at 0.8 m. It should be noted that it is possible to use actuators with a stroke of 1.0 m. According to the assumptions, the cutting is carried out with a cutting unit with horizontal axis of rotation. Before cutting, the working platform with the shaft sinking machine is positioned at a distance from the bottom of the shaft so that it is possible to carry out the slotting of the unit to a depth of up to 0.3 m. Slotting is carried out by means of a swivelling arm of the body. When the working platform is lowered, the backfill on its surface is separated from the long bucket conveyor and must therefore be lowered to the correct position. Once the working platform has been determined and disassembled, the phase of slotting follows (Figs 8,9). The platform's rotating ring rotates at the working speed when carrying out slotting. During the rotation of the platform's swivel ring, the cutting unit makes the toroid-shaped cuttings with a rectangular cross-section equal to the width of the unit round (0.8 m or 1.0 m) and a working depth equal to 0.3 m (maximum 0.35 m) for a unit with a diameter of $\varnothing 1500$ mm depending on geological conditions. Once a single cut has been performed, the unit is lifted and then the rotating ring of the platform is moved back to its initial position. It is necessary to carry out slotting of the unit in a new cut, i.e. in a new position, in the direction towards the shaft axis by the value of unit round. Slotting to the subsequent cuts is realized after the unit is lowered to the bottom of the previously performed cut. When carrying out slotting to successive cuts, the unit moves along the linear guide in the direction of the shaft axis at the same time as the ring rotates, resulting in a spiral movement of the organ until the new cut position is reached. The subsequent cuttings are produced in the same way until a complete layer is made. During the slotting and normal excavating phase, the loader moves behind the unit and transfers the muck to the conveyors assembly. The long bucket conveyor

transports the excavated material outside the working platform to the required height resulting from the current equipment of the shaft system. After completing the full layer, the unit returns to its initial position and a further 0.3 m thick layer is made by lowering the platform with the shaft sinking machine. The shaft sinking machine makes a total of 7 layers with the actuators of the platform with a stroke of 1.8 m (0.3 m tilting arm and 6 changes of the actuator position after 0.3 m – Figs 8,9).

It should be noted that slotting of each layer is carried out by means of a protruding arm after leaving the platform. When the full stroke of the actuators is used, the actuators are released from the opening of the system and lowered by 2.1 m (for 1.8 m cylinders) with simultaneous or earlier return of the platform and the unit to its original position (vertical actuators slipped down, tilting arm and the unit on the external cut). When lifting the platform, a long bucket conveyor must be lifted or lifted at the same time, so that it follows with the bucket. The excavated material from a long bucket conveyor is transported to the chute and from there to a 6 m³ bucket. On the working platform, along with the excavating process, the development of the shaft lining may be processed. The shaft lining will be transported to the working platform and positioned by means of suitable hanging devices, e.g. to higher levels.

The following data were used to determine the productivity of the bottom layer excavating:

- unit round (unit width): $Z_1 = 0,80$ m,
- Layer thickness (depth of excavating): $H_{ur} = 0,3$ m,
- Unit rotary speed: $n_o = 60$ rev/min,
- Maximum platform rotary speed: $n_p = 2,0$ rev/min,
- working speed of the platform (during excavating): $n_{pc} = 0,2$ rev/min.

The shaft sinking machine makes further toroidal cuts, which make up the whole layer of the shaft bottom. At the given parameters, for the largest shaft diameter of ϕ 9.5 m and for unit round of 0.8 m, 6 cuts are obtained (Fig. 8).

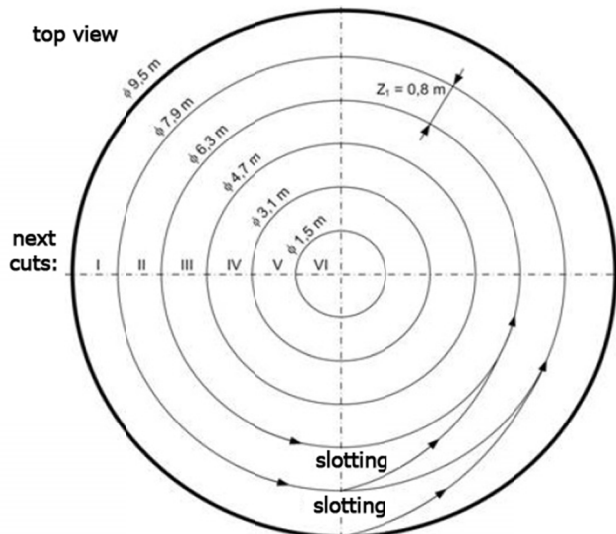


Fig. 8. Technology of performing next cuts of the shaft. Top view for $Z_1 = 0,8$

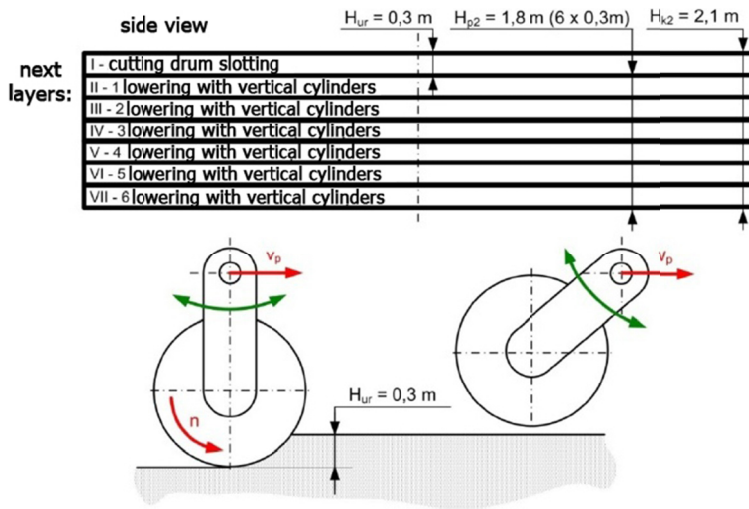


Fig. 9. Technology of performing next cuts of the shaft. side view for $H_{p2} = 1,8 \text{ m}$

On the basis of these geometrical and kinematic parameters, the excavation performance of a single layer was determined. Machining is carried out at a constant rotation speed of 0.2 rpm of the platform's rotary ring. In such a situation, the linear velocity of the organ (stretch to the shaft radius) changes in particular cuts. The duration of each cut is 5 minutes.

Determining the efficiency obtained from a single layer allows to estimate the maximum muck stream and the choice of a proper haulage means. In order to be able to determine the progress of shaft sinking or the nominal investment duration, it is necessary to take into account the time needed for lowering the platform by the next runaway and the time needed to move the entire system by the set value associated with the stroke of vertical cylinders. The analysis of the progress of the shaft excavation was carried out for the following data:

- The daily working time of the shaft sinking machine is $T = 20$ hours,
- Time for 24-hour inspection, inspection and maintenance $T_r = 4$ h,
- Shaft lining and transport processes are carried out in parallel,
- Organizing time $t_{ow} = 15$ minutes is added to the time of selecting each layer,
- One layer of $H_{ur} = 0.3 \text{ m}$ is taken $t_w = 1$ hour,
- System transfer time by $H_{k1} = 1.2 \text{ m}$ and $H_{k2} = 2.1 \text{ m}$ $t_k = 2$ h,
- Number of working days in the year 260 days (52 weeks, 5 days each),
- The analysis does not take into account the time needed for troubleshooting,
- The final result is given with a 40 percent utilisation of the system.

For the adopted assumptions and pre-established parameters, a number of values were calculated, including the progress of shaft sinking. An example of this can be the analysis of the shaft sinking efficiency for the round of $Z_1 = 0.8 \text{ m}$ and the vertical actuators stroke of $H_{p2} = 1.8 \text{ m}$. This analysis has allowed to determine that the shaft can be sunk with 3.3 m/day progress.

The performed analysis allows us to conclude that the results of the exploitation efficiency of this shaft complex are satisfactory and in accordance with the assumptions of the Ordering Party.

5. Summary

Shaft sinking technology is a difficult and complicated process. Taking into account the goal of such a task as a construction of the vertical excavation with a diameter of approximately 9 m and a depth of approximately 850 m, it is necessary to emphasize the difficulties associated with working conditions, operating technology and machinery, while at the same time ensuring the safety of the crew. The implementation of full mechanization of the sinking process with the assumption that some activities could be carried out in parallel (excavating, loading, shaft lining installation), it required the development of a new shaft sinking machinery and new work organization. The presented design of the shaft sinking system solution meets the requirements of the ordering party with regard to the assumed working conditions of the machine and the possibility of executing the auxiliary processes (protection of excavation, dewatering, freezing) not directly related to the basic functions of the shaft sinking machine (excavating, loading, haulage). The analysis of the effectiveness of this solution also meets the assumptions concerning monthly progress. The presented machine differs from the machines available on the market and known from the complexes' literature, which results in particular from the application of solutions covered by patent protection within the utility model of PL 68320 Y1.

This shaft sinking machine is characterized by a modular construction with extensive modification possibilities, which translates into many variants adapted to different operating conditions, user needs and requirements and machines and equipment, existing in the excavation.

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