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Shaft reaming machine for maintenance of mine shafts in the salt rock mass

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Paweł KAMIŃSKI [1*], Darian BOŽIČ [2]

Author's affiliations and addresses:

[1] KOMAG Institute of Mining Technology, Pszczyńska 37, 44-101 Gliwice, Poland

[2] Coal Mine Velenje, d.o.o., Partizanska cesta 78, 3320 Velenje, Slovenia

*** Correspondence:**

e-mail: pkaminski@komag.eu

Abstract:

Due to rheological properties of salt rock mass, maintenance of mine excavations, including shafts may be very challenging, especially in the long term. Many different ideas and approaches to a subject of sinking and maintaining a shaft in salt rock mass have emerged over the years, of which the main directions include two opposite ideas, such as an application of high-strength lining and an approach based on flexible lining. The article presents a shaft reaming machine designed for maintenance of mine shafts located in salt rock mass designed with a flexible shaft lining approach.

Keywords: mine shaft, shaft maintenance, salt rock mass, salt mining, mine safety, shaft reaming machine

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1. Introduction

In standard strength tests, rock salt shows rheological characteristics, reflected in creeping and stress relaxation. Creep process can be divided into three stages (as shown in Fig. 1):

- primary,
- secondary,
- tertiary.

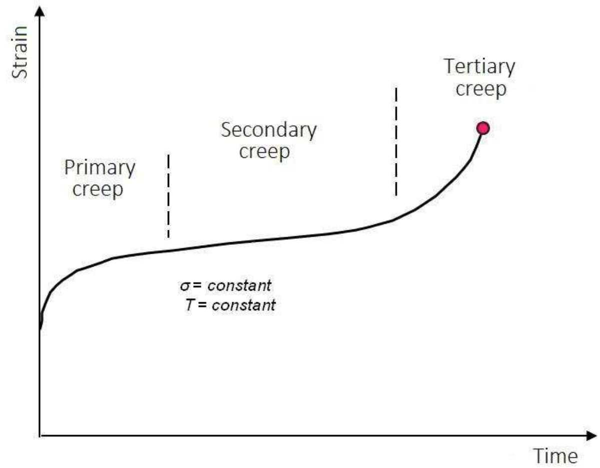

Fig. 1. Creep curve

Primary creep stage starts with a rapid rate – significant deformations occur within a short term. In the creep strain vs time graph it is projected as a steep curve. The material is subject to constant pressure, strain increase, but their rates decrease. This process lasts until the secondary stage begins, in which the creep rate is relatively uniform. Experiments show that the strain is dependent mainly on the stress conditions in the primary creep stage.

The creep process and thus the creep curve in the primary and secondary stages is dependent on two mechanisms: strengthening and regeneration. If those processes are in imbalance, the primary creep stage occurs, while in the case of their balance the equilibrium takes place. Creep rates decrease as the strengthening predominates over regeneration.

In the tertiary creep, the creep rate accelerates rapidly. The strain increases until the moment of material break or rupture. Volume of the rock sample increases in this stage due to an occurrence of microfractures, which are the main reason of the sample destruction [2-10].

Convergence is one of the key factors of stability and safety of mine shafts located in salt layers, as the sidewalls convergence is a source of major stress acting on the shaft lining. Thus the converge rate is a determinant of actions which should be undertaken to counteract its destructive impact on the shaft lining.

Experiments and practical experience show that sidewalls deformations caused by convergence may occur in a relatively short term. Thus, different approaches to shaft lining design have been used to solve the problem of its stability under the influence of convergence in salt rock mass. The first idea was to apply a high-strength steel lining, capable of bearing extremely high loads [10]. In contrast, an application of highly reactive, flexible lining was proposed and implemented in practice, e.g. in the SW-4 shaft at Polkowice-Sieroszowice mine, a part of the KGHM SA [11]. According to some experts [12] an implementation of a flexible shaft lining, providing hydraulic support with use of a column of fully saturated brine between typical watertight shaft lining (e.g. tubing lining) and shaft sidewalls, is more efficient.

High flexible shaft lining, implemented in the SW-4 shaft of Polkowice-Sieroszowice mine utilizes the coating made of composite mesh and layers of sprayed-applied polyurethane as well as mineral protective layer and auxiliary support, comprising bolted yielding arches. The task of the mineral coating is a protection of the shaft sidewalls against the impact of flowing humid air, while the auxiliary support is used to prevent the shaft against potential rock mass fracturing consequences. The design of the lining allows for a deformation of both shaft sidewalls and of the lining itself. To ensure a proper air flow in the SW-4 shaft (as the shaft is an upcast ventilation shaft) a reconstruction of the shaft lining is required within a designed time interval up to 12 years. Shaft lining reconstruction consists of several stages, including a disassembly of the worn out shaft lining, reaming of the shaft sidewalls to the designed diameter and a installation of the new shaft lining.

In recent years, an idea of the shaft lining utilizing a characteristic feature of rock salt, which is water solubility appeared. This feature is generally considered a drawback in terms of mine workings' maintenance, however it may be used to control the load acting on the shaft lining. The key elements of the shaft lining design include preliminary shaft sidewalls bolting, tubing lining of modified construction, porous material filling of the annulus between the shaft sidewalls and the tubing shaft lining and a system of pipelines, pumps and tanks for the leaching medium circulation [13-14].

The idea of the described shaft lining is based on periodic leaching of the shaft sidewalls in the controlled process carried out in the annulus between the tubing lining and the shaft sidewalls. Such design allows for simultaneous shaft lining "reconstruction" (leaching of the shaft sidewalls) and typical shaft operation, including airflow, men-riding, transport of materials and media to and from the mine workings. Experiments were carried out to verify assumptions and validate a possibility of implementing such a construction in a mine shaft. They allowed also for a determination of parameters of the designed shaft lining and leaching medium. The effects of the tests are optimistic, however real-life tests in mine shafts are indispensable to verify the results in practice [13-16].

2. Materials and Methods

Shaft reaming machine

The designed and patented shaft reaming machine may be applied for shaft liquidation and reconstruction operations. Its base is a working platform suspended on steel ropes. It consists of three sections:

– top section,
– reaming section,
– loading section.

The reaming section is separated from the other sections with two platforms – the top platform dividing it from the top section and the bottom platform separating it from the loading section. The device is equipped with a tubular guide for a conveyance (typically shaft bucket) which is located in the shaft axis and allows for men-riding and transporting material to and from the top and loading sections. The top and loading sections are also equipped with stabilizers which are used to support and stabilize the reaming machine at the level on which it is used. The reaming section is equipped with a frame, which is an angular truss construction to which a boom of a cutting head is attached. The truss construction and the tubular guide are connected with bearings.

The main goal of the presented machine designers was a design and a construction of a lightweight reaming machine, which allows for controlling the cutting head web depth, an easy stabilization of the device on the cutting level, suitable for intervention activities and facilitating loading and hauling processes [17-18]. A view of the shaft reaming machine is presented in Fig. 2.

Fig. 2. A view of the shaft reaming machine

The key structure of the reaming section is the frame to which both the cutting head boom and operator's cabin are assembled. A gear a rack allows for a vertical movement of the cutting head, while the bearing connecting the truss construction with the top platform and the tubular guide is responsible for a rotational movement of the whole construction and thus of the cutting head [17].

The diameter of the bottom platform is smaller than the loading deck diameter, which allows for a gravitational transport of the excavated material to the loading deck, from where it is loaded into buckets and hauled to the surface. The stabilizers, attached to the bottom platform, allow for horizontal and vertical positioning of the machine, which in turn enables a greater adjustability of the cutting head web depth. The design of the cutting head boom and its attachment to the frame allows for controlling a vertical position of the cutting head position and of the cutting head web depth [17].

The design of the shaft reaming machine is presented in Fig. 3 and 4.

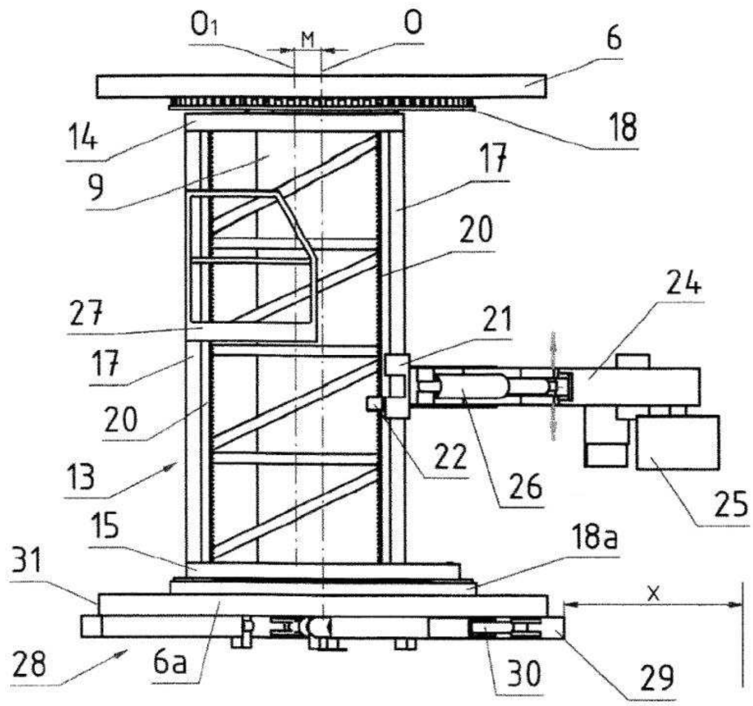

Fig 3. Vertical presentation of the shaft reaming machine [16]

6 – top platform, 6a – bottom platform, 9 –tubular guide, 13 – frame, 14 – top bearing, 15 – bottom bearing, 17 – truss, 18 – top ring, 18a – bottom ring, 20 – gear racks, 21 – horizontal adjustable beam, 22 – cutting head drive, 24 – cutting head boom, 25 – cutting head, 26 – hydraulic cylinder, 27 – operator's cabin, 28 – hydraulic stabilizer, 29 – stabilizer's beam, 30 – hydraulic cylinder, 31 – outline of the bottom platform;
M – eccentricity, O – horizontal axis of the shaft reamer, O_1 – axis of the frame

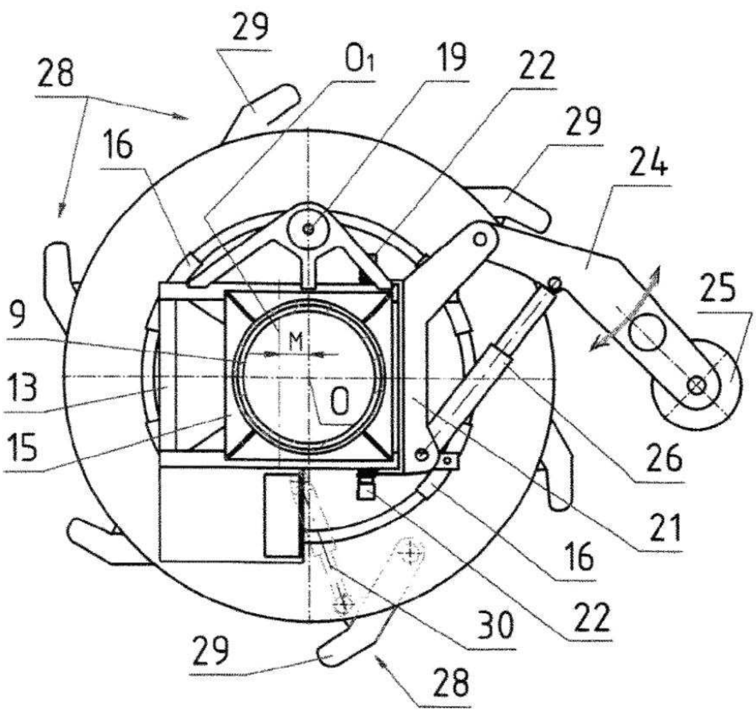

Fig. 4. Horizontal view of the shaft reaming machine [16]

9 – tubular guide, 13 – frame, 15 – bottom bearing, 16 – guidance, 19 – drive, 21 – horizontal adjustable beam, 22 – cutting head drive, 24 – cutting head boom, 25 – cutting head, 26 – hydraulic cylinder, 28 – hydraulic stabilizers, 29 – stabilizer's beam, 30 – hydraulic cylinder;
M – eccentricity, O – horizontal axis of the shaft reamer, O_1 – axis of the frame

A small number of salt mines in Poland and thus a small number of mine shafts sunk and maintained in salt rock mass do not make a development of such a machine a sort of priority. However, in numerous countries of the world, including Germany, not only new solutions for mine shaft lining are developed but also shaft reaming and shaft sinking machines. A machine of similar construction is currently in use in one of German salt mines, which shows that the approach of flexible shaft lining for salt mines gains popularity.

3. Conclusions

Salt mining, although still remains in the shadow of other branches of the mining industry, is a field of continuous development. Specific characteristics of rheological salt rock mass require an application of solutions not feasible in other places, which applies also to shaft sinking and design of shaft lining. Conventional solutions, successfully used in numerous mine shafts over the world are not always suitable for an application is salt rock mass. It fosters a development of alternative solutions, of which flexible shaft lining is currently gaining popularity. Modern solutions of shaft lining with use of periodic leaching of the shaft sidewalls are also considered promising.

However, the problem of shaft lining in the sections located in salt rock mass does not concern only salt mines. KGHM SA, the biggest producer of copper and silver in Poland, has broad experience in sinking and maintaining mine shafts in the sections located in salt rock mass, as some of the shafts of the Company's copper ore mines are partially located in the salt rock mass. This is where the most modern flexible shaft lining construction in Poland has been applied.

Different designs and constructions of flexible shaft lining, similar to the one applied in the SW-4 shaft of Polkowice-Sieroszowice mine, require a periodic reconstruction of the shaft lining, such as activity is connected with periodic shaft operation stoppages, which can have a negative impact on the whole mine efficiency.

The shaft reaming machine presented in the article, enables to facilitate the process of shaft reaming in a mine shaft section located in the salt rock mass and supported with flexible shaft lining, similar to the solution implemented in the SW-4 shaft. Despite the cost of development and construction of the machine, it can help reduce costs of shaft maintenance due to a reduction of the shaft downtime. An application of a similar device in the German mining industry allows to conclude that a development of the flexible shaft lining and of the shaft reaming machine is reasonable due to economic and technological reasons.

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