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Mechanical retention bunkers for run-of-mine material: design review and operational effectiveness assessment

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Abstract:

The article presents a review of structural solutions for mechanical retention bunkers used for run-of-mine (ROM) material in underground hard coal mining, together with an evaluation of their operational effectiveness. The study addresses the problem of unstable ROM feed in continuous haulage systems, resulting from the cyclic operation of mining equipment, which leads to fluctuations in transport capacity utilization. The implementation of horizontal retention bunkers is analyzed as a method for stabilizing material flow and improving the efficiency of transport systems. The operational effectiveness of mechanical bunkers is defined based on their ability to perform three key functions: retention of ROM, stabilization of the material stream, and separation of the feed with the possibility of bypassing the bunker. A classification of bunker types is proposed, taking into account structural and functional criteria, including loading systems, bottom design, and discharge methods. The analysis includes both historical and modern design solutions, ranging from simple fixed bunkers to advanced movable systems equipped with automated control and monitoring. The results indicate that modern bunker systems significantly improve the continuity of transport processes, reduce downtime, and enable better control of material flow. However, certain limitations are identified, such as high construction and maintenance costs, wear of components, and spatial constraints in underground workings. The study demonstrates that the proper selection and design of mechanical retention bunkers, combined with automation, can substantially enhance the operational effectiveness of underground haulage systems.

Keywords: underground mining, bulk material transport, mechanical retention bunker, run-of-mine (ROM), haulage systems, operational effectiveness

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1. Introduction

Ensuring the continuity and stability of the run-of-mine (ROM) transport process in underground hard coal mines is one of the key conditions for efficient mining operations. Underground continuous transport systems operate under conditions of irregular ROM feed, resulting from the cyclic nature of the operation of mining equipment in roadway headings and longwall faces. This leads to fluctuations in the load of transport equipment, periodic overloading and overburdening, or underutilization of the available transport capacity, and consequently to a reduction in the overall efficiency of the haulage process. Therefore, it is justified to consider the implementation of horizontal retention bunkers within transport systems, whose function is to provide controlled feeding of ROM into the transport system. These bunkers are most often located in the areas of panel loading stations, shaft top and bottom stations of production shafts, where they act as equalizing elements in the haulage system.

The operational effectiveness of horizontal mechanical retention bunkers in underground hard coal mines can be defined as the measurable ability to perform specific functions within the mine transport system. The key factors influencing the operational effectiveness of mechanical bunkers are three fundamental functions:

- Retention, that is, the ability to accumulate run-of-mine (ROM), expressed in units of mass or volume, is defined as the capability of the bunker to cyclically store a specified amount of coal over defined time intervals.
- Stabilization of the ROM stream is defined as the ability of the equalizing bunker to ensure a uniform flow of material within the transport system. The bunker effectively responds to fluctuations in the incoming ROM stream, minimizing the risk of downtime in the haulage system.
- Separation, that is, the ability to divide the feed stream into a portion stored in the bunker and a portion bypassing it, the bypass function. Control of the material flow is carried out depending on the type or physical properties of the conveyed material, e.g., the separation of waste rock.

2. Materials and Methods

The review of structural solutions for horizontal mechanical retention bunkers and the analysis of their applicability in underground mining, together with the assessment of their operational effectiveness, required an extensive review of both literature and patent sources, often of historical and archival nature. The study was based on classical monographs and textbooks on mining machinery and underground transport systems, which provide the theoretical foundations for the design and operation of bunker systems [1, 2]. These were supplemented with industry publications addressing operational performance, typical damage mechanisms, and methods for assessing the technical condition of underground coal bunkers [3]. To capture the historical development of retention systems, archival sources describing early implementations and their role in mining infrastructure [4, 5], as well as selected technical reports on contemporary applications and feasibility studies [6]. Due to the limited number of recent scientific publications devoted specifically to mechanical retention bunkers, the analysis was extended to include patent documentation that presents detailed constructional solutions and innovative concepts [6, 7, 8, 9]. This diversified body of sources made it possible to comprehensively evaluate both historical and modern approaches to the design and operation of retention systems in underground mining.

In practice, there are many types of mechanical bunkers that differ both in their structural design and in the functions, they perform within the transport system. In the industry and scientific literature, relatively little attention has been devoted to mining retention bunkers, possibly because their design has undergone only minor changes over the past several decades. Modifications have mainly concerned fill-level monitoring systems and discharge devices.

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Due to the limited number of publications describing mechanical retention bunkers, the authors developed their own classification. Figure 1 presents the authors' classification of mechanical retention bunkers based on structural characteristics, developed using both the literature and patent data.

When developing the classification of mechanical retention bunkers, the following criteria were considered: the type of loading box, the type of bottom, the method of loading and discharge, and the type of conveyor forming the bunker bottom.

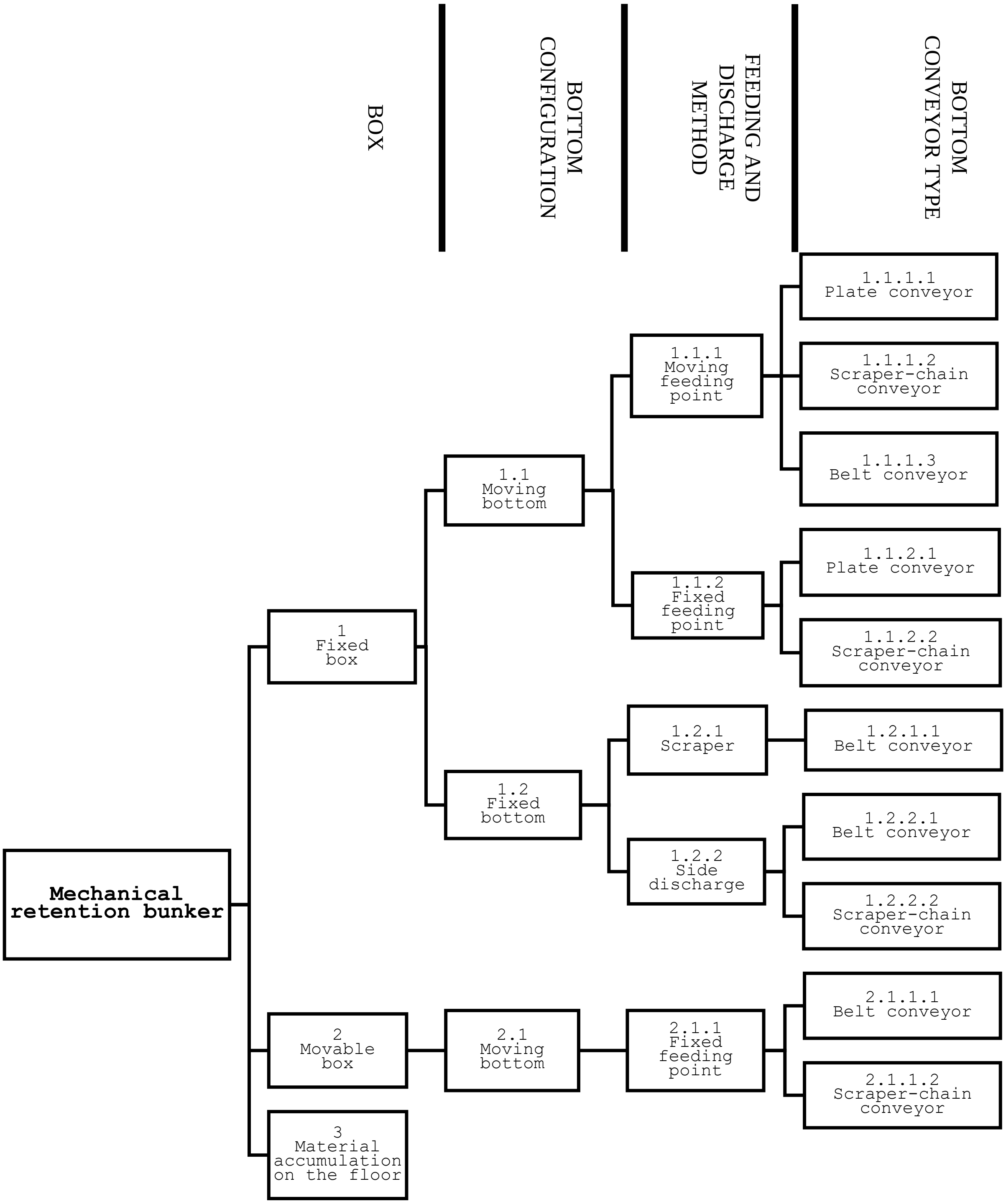

Fig. 1. Classification of mechanical retention bunkers

The next section discusses individual types of bunkers together with their applications.

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3. Results of literature and patent analysis

Figure 2 presents a schematic of a mechanical retention bunker with a fixed box filled by a moving plough scraper. A plate conveyor (1.1.1.1), a scraper-chain conveyor (1.1.1.2), or a belt conveyor (1.1.1.3) can be installed in the bunker bottom. When incorporated into the transport system, the bunker performs three functions, enabling retention, stabilization of the run-of-mine (ROM) stream, and storage of separated waste rock. The bunker capacity is equal to the maximum capacity of the feeding conveyor. The discharge capacity is limited by the capacity of the receiving conveyor and constitutes the sum of the output of the feeding conveyor and the mechanical bunker. It is also possible to transport ROM while bypassing the bunker (bypass function). The estimated capacity of bunkers with fixed boxes is approximately 200 tonnes and their maximum length can reach up to 200 m.

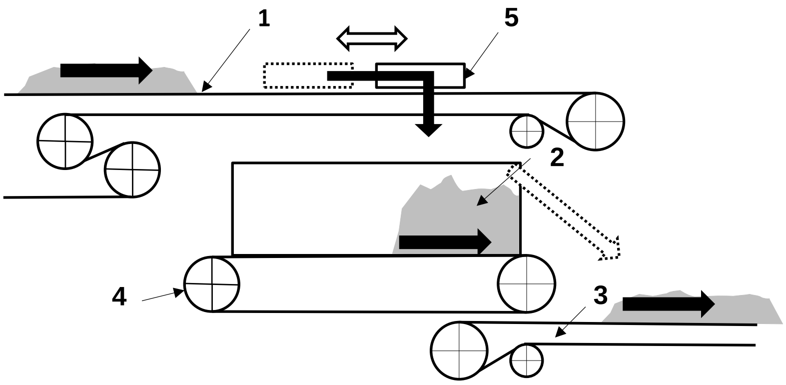

Fig. 2. Schematic of a mechanical retention bunker with a fixed box and a bottom moving in one direction (1.1.1)

1- feeding conveyor, 2- mechanical retention bunker, 3- receiving conveyor, 4- bottom conveyor, 5- plough scraper

Figure 3 presents a horizontal coal bunker (horizontal type coal bunker), which is the subject of a patent application filed with the Chinese Patent Office under the number CN2756833Y. The device is constructed on a conveyor belt feeding the bunker and a plate conveyor that allows its discharge. The conveyor belt located in the upper part of the bunker is equipped with a discharge trolley and two scrapers. The element enabling the movement of material within the bunker is a plate conveyor installed in its lower part. The horizontal bunker cooperates with the mine haulage system and is installed in such a way that it does not restrict the movement of personnel in the roadway [10].

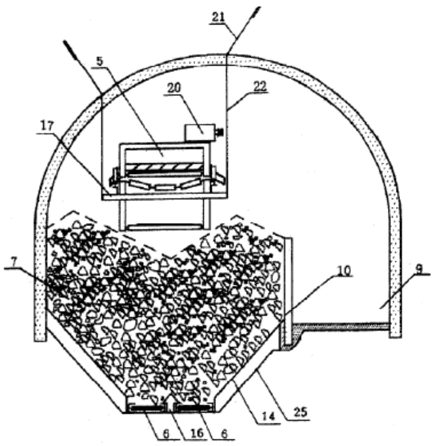

Fig. 3. Horizontal type coal bunker (1.1.1.2) [10]

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Figure 4 presents a schematic of a mechanical retention bunker equipped with a fixed box and a bottom formed by a scraper-chain conveyor, enabling the movement of the stored material in two directions. The use of a bunker with a scraper-chain conveyor at the bottom is associated with operational challenges, particularly when transporting rock material with high abrasive properties. The bunker structure itself does not present significant sealing issues. However, in mechanical retention bunkers, scraper-chain conveyor systems may cause difficulties in maintaining continuous operation, especially in the event of chain failure, as its replacement or reconnection is complex and time-consuming. The capacity of bunkers with movable boxes is approximately 260 tonnes. According to available sources, their maximum dimensions may reach 2.4 m in width, 3.75 m in height, and up to 200 m in length.

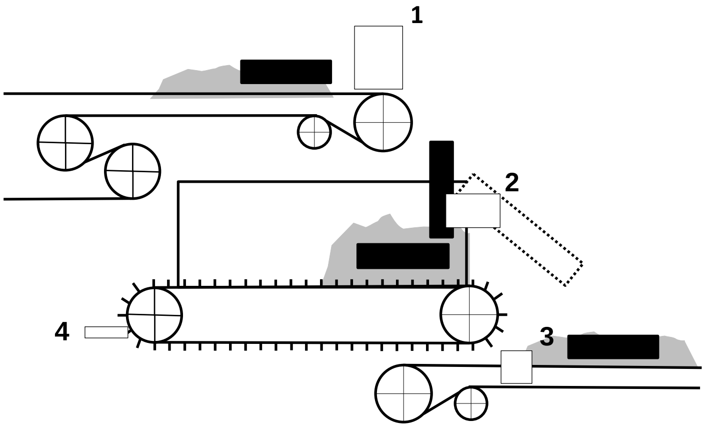

Fig. 4. Schematic of a mechanical retention bunker with a fixed box and a bottom moving in two directions (scraper-chain conveyor) (1.1.2.2)

1- feeding conveyor, 2 - mechanical retention bunker with a scraper-chain conveyor in the bottom, 3 - receiving conveyor, 4 - scraper-chain conveyor

In the publication [5], the author describes fixed and mechanical equalizing bunkers. A bunker capacity of 100 t ensures a uniform supply of run-of-mine (ROM) to the loading station. The first bunker in Poland was commissioned in 1968 at the experimental "Jan" mine. Its volume was 235 m³, which provided a capacity of 200 t and allowed a feed rate of 450 t/h. The drive system was implemented using two hydraulic motors transmitting power to two scraper chains located at the bottom of the bunker [1, 5]. The device was fully automated, allowing stabilization of shaft operation and acting as a backup in the event of the failure of transport equipment [4].

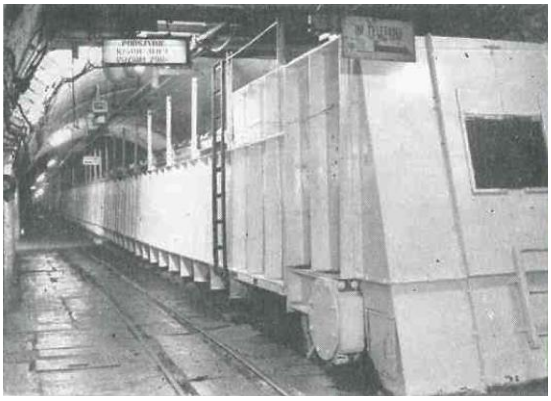

Fig. 5. Application of a reversible bunker in the Jan mine (1.1.2.2) [4, 5]

Figure 6 presents a retention bunker with a fixed box and bottom, equipped with a side discharge. The outflow of material is controlled by a hydraulically operated gate valve (5), enabling lateral emptying of the bunker. This retention bunker differs in terms of its discharge mechanism. In this solution, a material scraper (5) is used, ensuring uniform and controlled movement of the stored material toward the receiving conveyor.

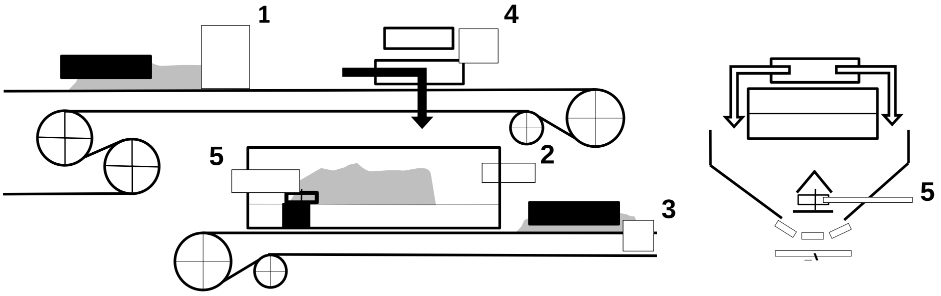

Fig. 6. Schematic of a mechanical retention bunker with a fixed box and bottom equipped with a material scraper (1.2.1.1)

1- feeding conveyor, 2 - retention bunker, 3 - belt conveyor, 4 - plough scraper, 5 - scraper

A horizontal type bunker for coal mines (Fig. 7), developed by L. Zhiwang, consists of a bunker box, a discharge system installed in the lower part, and a supporting frame. The bunker cooperates with an upward-inclined receiving belt conveyor. The solution is characterized by a simple design, compact dimensions, and low weight. The lower part of the bunker has a protective structure in the form of an inverted V, which allows continuous operation of the discharge system regardless of coal the amount of accumulated coal and reduces the risk of failure. This eliminates the problem of immobilization of the discharge device, increasing the effective bunker capacity and reducing construction costs [11].

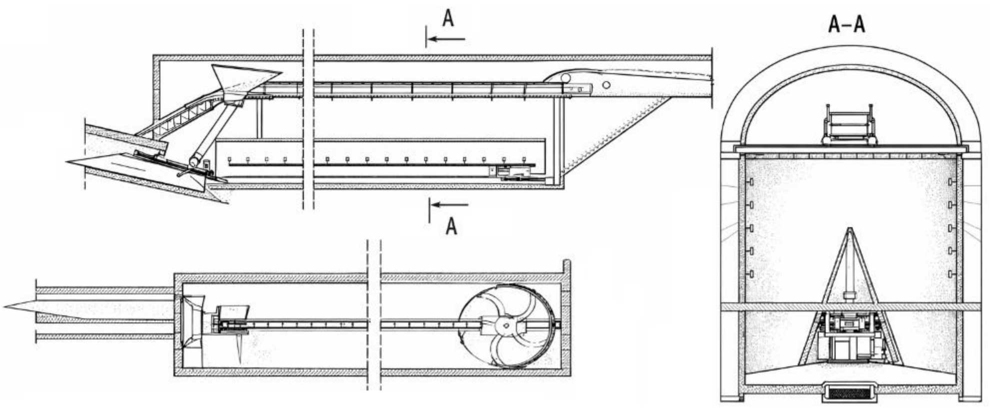

Fig. 7. Horizontal type bunker for coal mines (1.1.2.1) [11]

Figure 8 shows a mechanical bunker with a belt conveyor in the bottom and a moving box. The device enables controlled storage and transport of run-of-mine (ROM) material in two directions. Plate and belt conveyors, operating in cooperation with the movable loading box, ensure effective movement of the stored material. This also reduces friction between the accumulated ROM and the bunker bottom as well as the sidewalls, thereby decreasing wear of structural components. The device is characterized by low energy consumption, which contributes to its cost-effective operation. However, it should be noted that the movement of the box requires additional space in the excavation, which must be taken into account when planning the installation of the bunker. Solutions equipped with plate conveyors are used in the mining, metallurgical, and cement industries, ensuring continuity of bulk material transport.

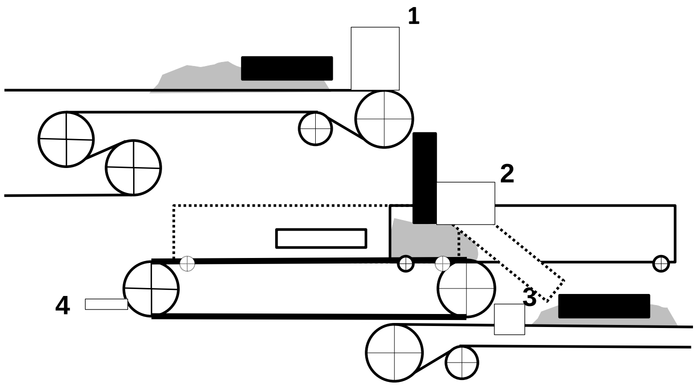

Fig. 8. Schematic of a mechanical retention bunker with a movable box and bottom, equipped with a belt conveyor in the bottom (2.1.1.1)

1 - feeding conveyor, 2 - mechanical retention bunker, 3 - receiving conveyor, 4 - belt conveyor

A movable type buffering coal bin (CN113895899A) was filed with the Chinese Patent Office in 2021 (Fig. 9). The system consists of two belt conveyors - an upper and a lower one - between which interconnected bins move. The bins are equipped with running wheels and the first (leading) box is connected to a drive unit. A boom enables the transport of run-of-mine (ROM) material into the bins or bypassing them. The system is equipped with devices for monitoring the filling level and weight of the bins, as well as an automatic control system and a vision-based monitoring system. The solution was developed to stabilize the feed between the panel haulage and the main haulage system. Under stable feed conditions from the panel conveyor, the material can be directed directly to the main haulage conveyor. In the event of a stoppage of the receiving conveyor, temporary storage of ROM in the bins is possible [12].

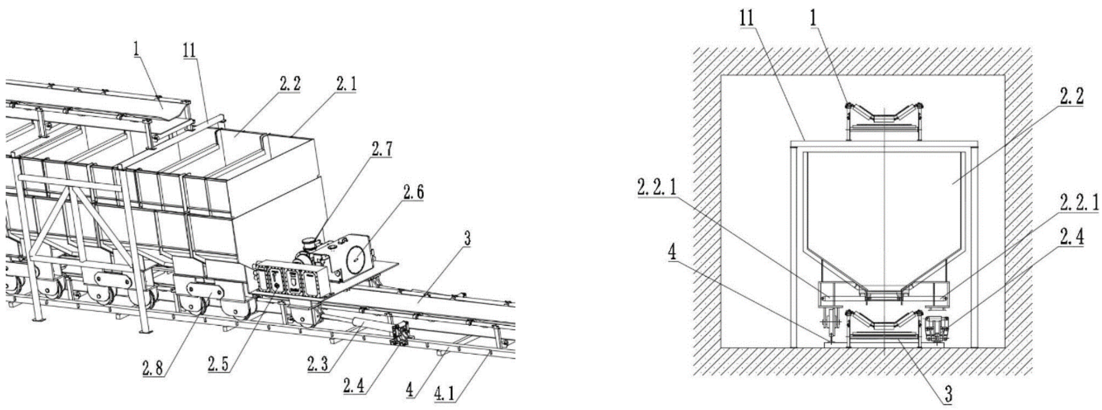

Fig. 9. Movable type buffering coal bin (2.1.1.1) [12]

A mechanical bunker with a plate conveyor in the bottom and a movable box is shown in Fig. 10. The device operates on the same principle as the previously described system; however, instead of a belt conveyor, a plate conveyor is used as the bunker bottom.

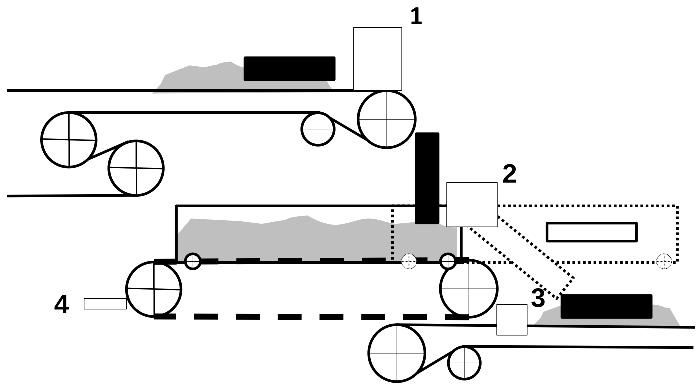

Fig. 10. Schematic of a mechanical retention bunker with a movable box and bottom, equipped with a plate conveyor in the bottom (2.1.1.2)

1- feeding conveyor, 2 - mechanical retention bunker, 3 - receiving conveyor, 4 - plate conveyor

A run-of-mine (ROM) bunker (Fig. 11), filed with the Polish Patent Office in 1996, is intended to decouple face operations from discontinuities in ROM reception. The material is delivered to the bunker by a belt conveyor. The bunker is constructed from segments equipped with inwardly inclined sidewalls and an open bottom. The system moves on rails installed on the floor. Motion is provided by a drive unit installed on the floor of the roadway. It is equipped with a gear wheel on the output shaft, which moves along rack bars mounted on the sides of the bunker. The loading of the bunker occurs when the receiving scraper-chain conveyor is stopped and the opposite bunker segments move in the direction to that of the feeding conveyor. Discharge can occur when the conveyor is stopped or is in operation, by moving the bunker segments in the direction of belt motion [13].

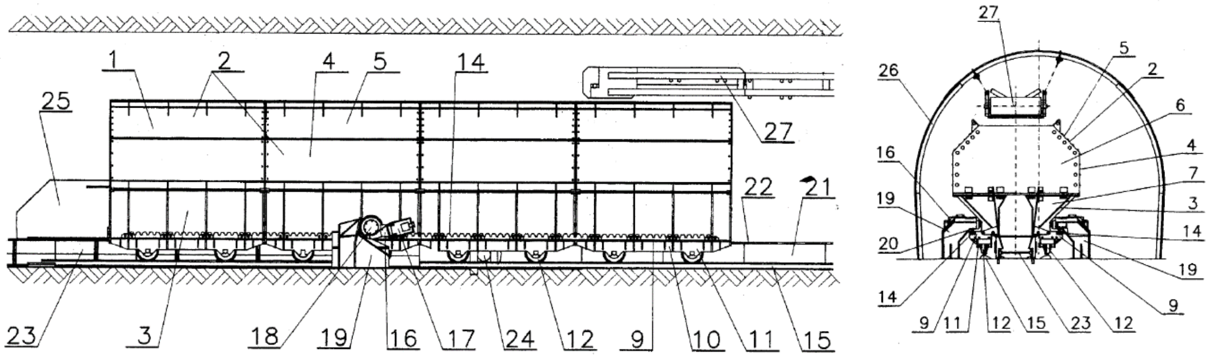

Fig. 11. Retention bunker (2.1.1.2) [13]

Figure 12 presents a mechanical bunker with a fixed box and bottom.

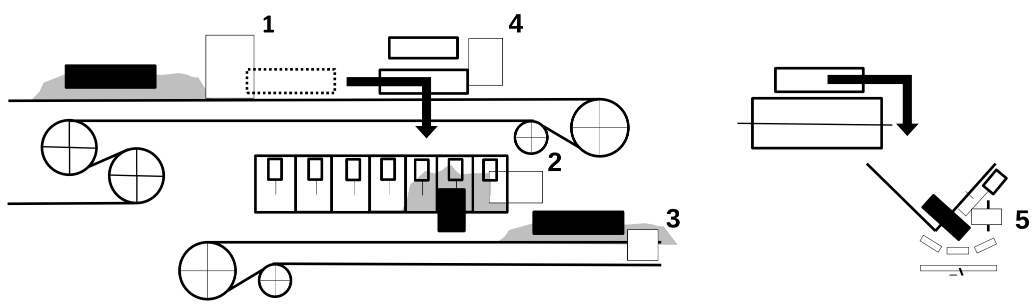

Fig. 12. Schematic of a mechanical retention bunker with a fixed box and bottom, with side discharge (1.2.2.1)

1- feeding conveyor, 2 - retention bunker, 3 - belt conveyor, 4- plough scraper, 5 - hydraulically operated gate valve

The loading process is carried out using a belt conveyor (1). A plough scraper (4) enables controlled loading of the bunker. It can be moved aside or removed to allow for separation of contamination in the run-of-mine (ROM) material by waste rock. The discharge process is carried out using a receiving belt conveyor (3).

The "run-of-mine (ROM) retention bunker" PL181956 [14], filed with the Polish Patent Office in 1996 (Fig. 13) and also described in [2], is intended for operation in underground mining plants during roadway drivage. The bunker is designed for the retention of material generated during roadway excavation and to decouple the operation of the belt conveyor haulage system from discontinuities in material reception. It is constructed on a system of two conveyors: a spreading conveyor and a receiving conveyor. The bunker is installed in a roadway, separated by steel partitions running along the axis of the excavation. The partitions have a modular structure and divide the bunker into a storage section and a transport section. The material is fed into the bunker by a belt conveyor, where it is either stored or discharged through openings onto a scraper-chain conveyor. Then it is transported toward the belt conveyors of the transport system.

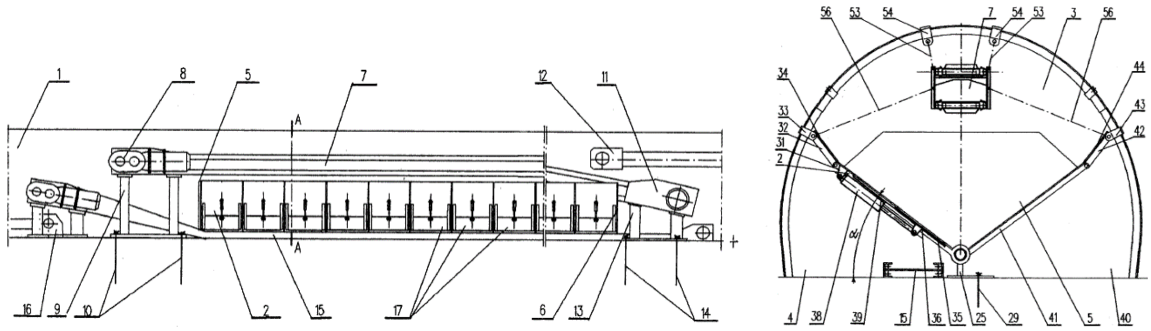

Fig. 13. Run-of-mine (ROM) retention bunker (1.2.2.2) [14]

4. Discussion

This article presents selected technical solutions identified during the state-of-the-art analysis and literature review. The described devices or systems enable the retention of coal run-of-mine (ROM); however, from a practical point of view, most of them also allow the storage of separated impurities and stabilization of the ROM stream. Analysis of the development of ROM retention systems indicates significant progress, from simple constructions to complex, automatically controlled systems. The solutions have evolved from basic arrangements that form part of the mining operation to advanced automated systems equipped with multiple subsystems that allow unattended operation. Devices are characterized by compact design and the possibility of increasing or decreasing the active storage capacity.

In the presented solutions, bunker filling is carried out using mobile discharge heads (stand-alone or moving together with a feeder), ploughs, or mechanisms enabling the movement of material into the bunker. In most cases, does not provide detailed technical information (both design and operational). Existing bunkers are generally characterized by limited possibilities for expansion to increase capacity, except for systems cooperating with sets of bins or mining haulage cars. Some of the described solutions exhibit excessive dimensions relative to their capacity. The complex design of bunkers results in high manufacturing, maintenance, and service costs (e.g., replacement of a chain in a bunker filled with material). In the case of chain conveyor bunkers, it was necessary to use larger drive units due to excessive friction between the device components and the material. The size of the drive unit in such cases was also limited by the strength of the chain. Additionally, the high wear of the components leads to increased maintenance costs and high energy consumption. In the cases of peripheral locations, bunkers were associated with high construction and maintenance costs. Stationary devices (constructed within mining workings) may also be exposed to the influence of the rock mass. For manually operated bunkers, the authors indicate the possibility of introducing automatic control. Horizontal mechanical bunkers have been implemented in underground mining operations as individual, largely custom-designed solutions.

5. Conclusions

Table 1 presents a comparison of various types of mechanical retention bunkers used in underground hard coal mines in terms of operational effectiveness. The comparison is based on both the available literature and the authors' conclusions. Some of the analyzed solutions have not been widely implemented in industrial practice. The comparison highlights the advantages and limitations of individual types of mechanical retention bunkers. The analysis takes into account key functional and structural aspects that should be considered when designing and implementing bunkers in underground mining to ensure their effective operation.

Table 1. Operational effectiveness of mechanical bunkers [3 + authors' own elaboration]

	1.1.1	**1.1.2**	**1.2.1**	**1.2.2**	**2.1**	**2**	**3**
Capacity V (t)	200	260	2000	265	700	700	1800
Length l (m)	200	200	200	200	200	200	200
Capacity/Length ratio		+	+		+	+	+
Ease of transport		+					
Ease of automation	+	+	+	+	+	+	+
Ease of maintenance				+	+	+	+
Operational effectiveness				+	+	+	
Susceptibility to geomechanical impact							+
Low component wear	+		+	+	+	+	
Low energy demand	+		+	+	+	+	
Bypass function	+	+		+	+	+	

The operational effectiveness of mechanical retention bunkers is defined by their ability to perform key functions within the transport system. The main criteria determining the level of operational effectiveness are the ability to retain run-of-mine (ROM) material, stabilize the ROM stream, and enable the separation of waste rock. Properly selected design solutions allow for the integration of bunkers with automation systems, ensuring unattended operation and reducing the risk of downtime. The appropriate selection of the bunker parameters, along with the possibility of automating the handling processes, ensures the continuity and reliability of the transport process. Technological development has significantly contributed to improving the operational effectiveness of mechanical retention bunkers.

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