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THEORETICAL STUDY OF PRIORITY TECHNICAL AND TECHNOLOGICAL INDICATORS OF DRILLING RIGS IN THE CONTEXT OF THE MINING INDUSTRY OF THE REPUBLIC OF UZBEKISTAN

The purpose of this study is to analyze the technical efficiency and other technological characteristics of SBSH drilling rigs, which are widely used in the open-pit mining industry of the Republic of Uzbekistan, and to compare them with the modern Epiroc Pit Viper 231E drilling rig. The useful work coefficient of drilling machines in the mining industry is determined by the depth of the wells they drill (drill wells) and is called work efficiency. Drilling ability and other technical parameters are carried out through theoretical calculations.The study also aims to identify the necessary factors for the extensive utilization and validation of these rigs. The core of the work focuses on assessing the technical performance and drilling efficiency of SBSH-250 drilling rigs, followed by a technical analysis and comparison with the Epiroc Pit Viper 231E drilling rig, which meets similar technical requirements. Additionally, the superior capabilities of modern rigs, particularly the Epiroc Pit Viper 231E, are highlighted, emphasizing their advantages over traditional rigs such as the SBSH series. Considering all factors, the introduction of advanced technologies like the Epiroc Pit Viper 231E is expected to significantly enhance the production capacity of open-pit mining enterprises in the Republic of Uzbekistan. The extensive use and practical implementation of the Epiroc Pit Viper 231E drilling rigs, in particular, result in significantly higher efficiency. This technology allows for precise control over both productivity and worker safety. Furthermore, the remote-control system of the Epiroc Pit Viper 231E offers a strong incentive for reducing key operational costs.

Keywords: drilling rigs, technical productivity, axial force, rotary torque, common automation panel (CAP), Rig Control System (RCS), rock drilling index.

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ТЕОРЕТИЧНЕ ДОСЛІДЖЕННЯ ПРІОРИТЕТНИХ ТЕХНІКО-ТЕХНОЛОГІЧНИХ ПОКАЗНИКІВ БУРОВИХ УСТАНОВОК У КОНТЕКСТІ ГІРНИЧОДОБУВНОЇ ПРОМИСЛОВОСТІ РЕСПУБЛІКИ УЗБЕКИСТАН

Метою даного дослідження є аналіз технічної ефективності та інших технологічних характеристик бурових верстатів СБШ, що широко використовуються в гірничодобувній промисловості Республіки Узбекистан, порівняння їх із сучасною буровою установкою Epiroc Pit Viper 231E та виявлення необхідних факторів для їх широкого використання та валідації. Основна частина роботи зосереджена на оцінці технічних характеристик та параметрів бурових верстатів СБШ-250 з точки зору ефективності буріння з подальшим технічним аналізом та порівнянням з буровою установкою Epiroc Pit Viper 231E, яка відповідає технічним вимогам в аналогічному порядку. Крім того, чудові можливості цих сучасних бурових верстатів, особливо Epiroc Pit Viper 231E, підкреслюються з точки зору їх додаткових можливостей, порівняно з традиційними буровими верстатами, такими як серія СБШ. Враховуючи всі фактори, очікується, що виробничі потужності з оснащення підприємств з видобутку корисних копалин відкритим способом в Республіці Узбекистан такими технологіями, як нові бурові установки Epiroc Pit Viper 231E, значно зростуть.

Ключові слова: Бурові верстати, Epiroc Pit Viper 231E, технічна ефективність роботи, осьове зусилля, момент, що обертає, Єдина панель автоматизації (CAP), Система управління буровою установкою (RCS), індекс буріння гірських порід.

Introduction

The Republic of Uzbekistan is one of the leading countries in terms of geological and mineralogical resources, with large enterprises forming a significant part of its industrial sector. Particularly notable are the major ore mining facilities specializing in the extraction of precious metals, located in the Navoiy region (Muruntau, Zarmitan, Marjonbuloq) and the Tashkent region (Kalmakir, Sarichoki).

Open-pit mining of valuable ore deposits involves several technological processes and stages, with the primary operations being excavation and blasting, which are considered the key processes. Nearly one-third of the total expenditures are attributed to drilling and blasting operations, largely influenced by the physical and mechanical properties of the rock mass. These properties can vary significantly, with fluctuations ranging from 0 to 28% (as indicated by Prof. V.S. Khokhryakov) [1].

Problem formulation

Currently, approximately 82% of the open-pit mining machinery used in Uzbekistan's mining industry belongs to the SBSH series (250, 270, 320). For instance, in 2016, there were 27 units of SBSH-250 drilling rigs operating at the Muruntau quarry, 6 units at Sarichoki, and 18 units at Kalmakir quarry [2]. These figures indicate that the majority of open-pit mining operations in Uzbekistan, since the Soviet era, have relied on SBSH series drilling rigs. From these numbers, it is known that the majority of drilling rigs used in the open-pit mining industry of the republic (since the Soviet era) are SBSH type drilling machines.

Table 1

The dynamics of the supply of all types of drilling rigs by the main manufacturers in 2013-2023 [3]

Manufacturer	Number of drilling machines by year, units.											In 10 years
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	
EPIROC (Atlas Copco)	29	35	19	17	58	59	24	14	1	17	25	298
Rudgormash	35	28	9	21	36	35	20	19	15	12	17	247
Sandvik	3	7	4	0	11	3	2	0	0	1	1	32

It should be noted that, while plant is recognized as a supplier of drilling rigs like the SBSH types and has the highest demand for SBSH drilling rigs, however the greatest demand between 2007 and 2017 was actually for drilling rigs manufactured by the Swedish company Epiroc.

As you can see from the table above, the manufacturer of drilling machines such as the Epiroc Pit Viper. Therefore, it is necessary to use modern drilling machines in the quarries in the territory of the Republic of Uzbekistan in order to increase work productivity and moderate costs.

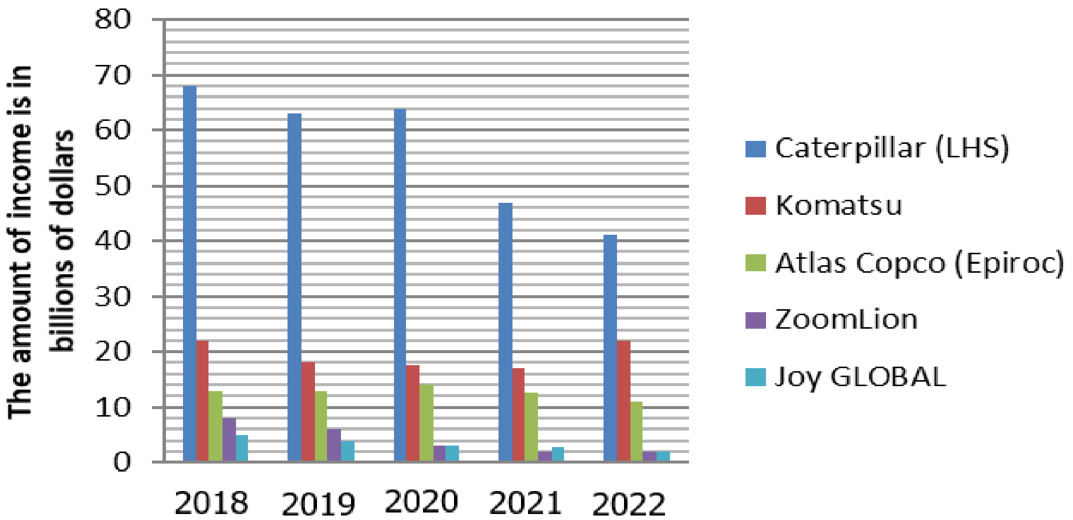

Fig. 1: Income dynamics of the world's largest mining equipment manufacturers, source: Bloomberg, BMI

As you can see from the table above, among the largest well-known mining equipment manufacturers, Atlas Copco is famous for its drilling equipment. It is known that the main share of this enterprise corresponds to drilling equipment and their use is popular. In addition, although economic decline among enterprises has been sharp in recent years, it is not so serious in Atlas Copco. For example, Catirpilar lost $20 billion from 2018 to 2022. This is approximately $1.5 billion in Atlas Copco.

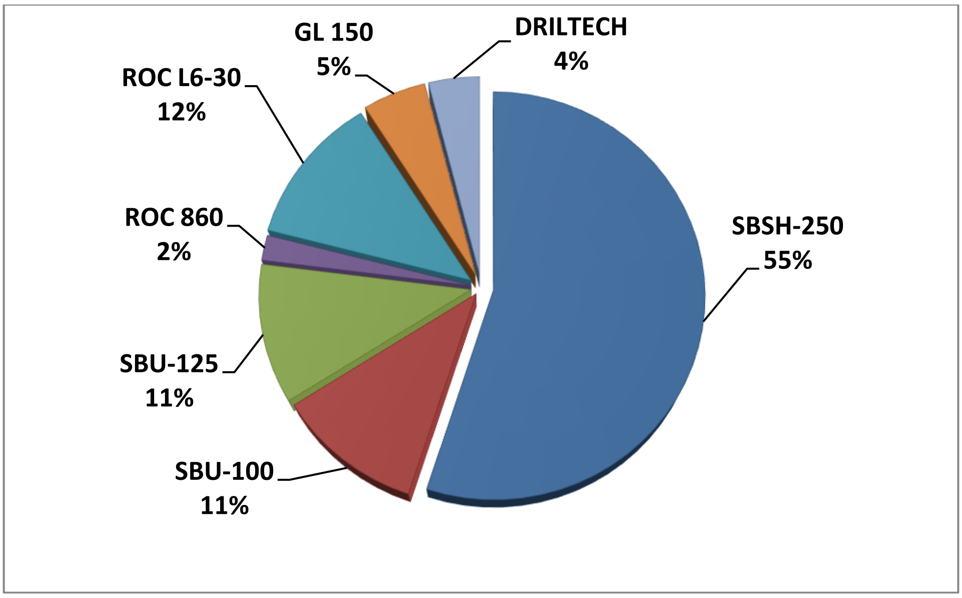

Fig. 2: The composition of the fleet of Navoi drilling machines NMMC (Uzbekistan)

Main material

Currently, one of the most widely used drilling machines is the SBSH-250 MNA 32. The extensive use of this model is due to the similar geological classifications and other technological factors across the republic's quarries, resulting in relatively consistent drilling parameters. For instance, the Kalmakir, Qorabuloq, and (northern and western) Balqiti mines belong to the same Angren-Almalyk ore deposit, and their geological and mineralogical analyses have yielded almost identical results [3, 4].

Brief information about the drilling machine SBSH-250MNA 32.

The SBSH-250MN-32 drilling rig is designed to drill boreholes with a diameter of 250 mm and a depth of 32 meters in rock formations with an average strength range of f = 8 to 14, applying an axial force of 300 kN. Drilling machines of this type belong to the middle class and are capable of drilling almost all types of rocks in large quarries (annual productivity of more than 2 million m^3). Technical information about all types of drilling machines under study (SBSH-250 MNA32, Epiroc Pit Viper 231E) was compiled using the technical passport of the manufacturing plants, and accounting work is also carried out based on this information [5].

Table 2

Technical work efficiency of the drilling machine SBSH-250MNA 32 [6,7]

Name of indicators	SBSH-250 MNA32
the ability to drill according to the Protodyakonov scale; f	~ 6-18
drilling depth; m	32; 47; 55
borehole diameter; mm	244,5-269,9 (270)
single pass depth (of the bit barbell)	8-8,2
speed of movement; m/s	0,2-0,4
rotary torque; kNm	4,2
angle drilling (option); °	30
axial force; kN	300
carriage speed (maximum); m/s	0,017-0,12
rotational speed of the drilling head; rp sec.	0,2-2,5
Electric power consumption	
total consumption	460-500 kWt; 50-60 Hz; ~380-390 V
Width (operational / idle state); m	5,7 ; 5,7
Height (operational / idle state); m	16,2 ; 6,6
Length (operational / idle state); m	10,5 ; 15,6
Weight; t	max 80

Fig. 3: Appearance of the SBSH-250MNA 32 drilling machine

Brief information about the Epiroc Pit Viper 231E drilling machine.

Epiroc Pit Viper 231E is a drilling machine powered by elector energy, which provides an opportunity to increase the drilling ability in medium and soft rocks by up to 25%7. The ability to use a wide range of drill head sizes (152-250 mm) is fundamentally different from the SBSH-250 MNA32 drilling machine [6].

The pit Viper 231 E has a hydraulic and comfortable, multiplying cabin, protected from external noise and discomfort. The spacious and comfortable cab is equipped with the Rig Control System (RCS), which features controls that provide on-board automation capabilities as part of the standard drill rigs for added safety and productivity. This system, with all the conveniences, improves the level of profitability of the work and helps to achieve high accuracy on a large scale [7].

Fig. 4: Appearance of the Epiroc Pit Viper 231E drilling machine

Table 3

Technical work efficiency of the drilling machine Epiroc Pit Viper 231E [12]

Name of indicators	EPIROC PV 231E
the ability to drill according to the Protodyakonov scale; f	~ 6-18
drilling depth; m	37,5
borehole diameter; mm	152-250
single pass depth (of the bit barbell)	16,1
speed of movement; m/s	0,5-0,86
rotary torque; kNm	11,1
angle drilling (option); º	30
axial force; kN	267
carriage speed (maximum); m/s	up-0,69 down-0,79
rotational speed of the drilling head; rp sec.	3,1

Electric power consumption:	
total consumption	597 kWt; 50-60 Hz; ~380-400 V
Width (operational / idle state); m	5,44 ; 5,44
Height (operational / idle state); m	23,3 ; 6,41
Length (operational / idle state); m	5,7 ; 23,6
Weight; t	max 65,8

Common Automation Panel (CAP) is a device equipped with the latest modification system, designed for remote and autonomous control machines. Based on multiple RCS systems, it allows remote control of drilling rigs. A single operator can remotely operate multiple Pit Vipers and SmartROC machines from a single CAP station [5].

The main advantages of the CAP system [5, 6]:

- Saving time spent on changing shifts
- Ensuring a high level of security
- Savings in labor and funds
- High quality accuracy using advanced technologies

Fig. 5: Appearance of the CAP operative system

Basic computational work.

The useful work coefficient of drilling machines in the mining industry is determined by the depth of the wells they drill (drill wells) and is called work efficiency. Drilling ability and other technical parameters are carried out through theoretical calculations.

To determine the shift productivity of drilling machines, we need to have the following values:

$$A_D^{sh} = \frac{T_{shift}-(T_{sf}+T_t)}{\vartheta_d^{-1}+T_a}, \quad (1)$$

where T_{shift} - shift duration, hours; T_{sf} - time taken to start and finish work during the shift, hours; T_t - time spent during the shift for some technical reasons, hours; T_a - time taken for auxiliary processes during the shift, hours; ϑ_d - technical speed of drilling, m/h.

The technical speed of drilling (ϑ_d, m/s) is:

$$\vartheta_d = \frac{3,5\cdot P_o\cdot n_f}{I_d\cdot d_b^2} \quad , \quad (2)$$

where P_o - the optimal tension applied to the axle (axial force), kN; n_f - the optimal rotation frequency of the drilling rod, min $^{-1}$, I_d - rock drilling index; d_b - bit (crown) diameter, cm.

Firstly, we can obtain some of the given values in a constant state for all two (SBSH-250 MNA32; Epiroc PV231E) drilling machines:

They are constant:

- bit diameter d = 243 mm.

– rock drilling index, I_d = 15.
– shift duration, hours. T_{shift} = 8 hours.
– the distance between the boreholes, l = 2.5 m.
– T_{sf}+T_t 0,5 hours.

Secondly, we determine the necessary values for the calculations of the SBSH-250 MNA32 drilling machine based on the above data (Table 2):

- P_o = 300 kN;
- n_f =2,5 sec^{-1} = 150 min^{-1} (the maximum value is taken from: Table 2);
- I_d =15 (const);
- d_b = 243 mm (24,3 cm) (const);
- ϑ_d= 0,4 (max speed of movement)

I.Technical speed of drilling, m/h.

$$\vartheta_б = \frac{3{,}5 \cdot P_o \cdot n_f}{I_d \cdot {d_b}^2} = \frac{3{,}5 \cdot 300 \cdot 150}{15 \cdot 24,3^2} = 17{,}78 \quad m/sec$$

The technical speed of drilling on the SBSH-259 MNA32 machine is 17.78 meters/sec.

II. Calculation time taken for auxiliary processes during the shift:

$$T_a = t_{k/t} + t_h + t_m + n \quad (3)$$

where $t_{k/t}$ - the time taken for the rise and fall of the drill assembly, t_h - the time taken by the drilling machine to move from the 1st well to the 2nd well (between the wells), t_m - the speed of movement of the drilling tower (during the calculation, we take this value as 70% of the time taken for the rise and fall of the drill assembly), n - time spent on other additional work (for all two samples we take the value n... as 0 during the calculation).

1.The time taken for the rise and fall of the drill assembly is 0,12 m/sec (at max. according to table 1). 0,12 meters for 1 sec after the proportion $t_{k/t}$ = 8,33 second per meter.

2.Speed of movement for SBSH-250 MNA32 (table1) ϑ_h at maximum value: 0,4 m/sec. The distance between the boreholes: l= 2.5 m.

$$t_h = \frac{1}{\vartheta_h}; \; t_h = \frac{2{,}5}{0{,}4} = 6{,}25 \text{ sec.}$$

3.t_m is the speed of movement of the drilling tower (during the calculation, we take this value as 70% of the time taken for the rise and fall of the drill assembly).

$$t_m = t_{k/t} \cdot 70\%; \; t_m = 8{,}33 \cdot 70\% = 5{,}83 \text{ sec.}$$

– t_m for SBSH-250MNA32 at maximum value: 5,83 sec.
– $t_{k/t}$= 8,33 sec.
– t_h = 6,25 sec (for movement from well 1^{st} to well 2^{nd}).

The determined values were presented in the maximum value according to the technical instructions of the drilling machine.

$$T_a = t_{k/t} + t_h + t_m; \quad T_B = 8{,}33 + 6{,}25 + 5{,}83 = 20{,}41 \quad sec.$$

T_a - the time taken for auxiliary processes during the shift is 20,41 seconds between the 1^{st} and 2^{nd} wells.

III. The shift productivity of drilling machines:

– T_{shift} = 8 hours
– T_{sf}+T_t= 0,5 hour (same for all two samples)
– T_a = 20,41 sec = 0,0056 hour
– ϑ_d = 17,78 m/s.

$$A_d^{sh} = \frac{T_{shift} - (T_{sf} + T_t)}{{\vartheta_d}^{-1} + T_a} = \frac{8 - 0{,}5}{\frac{1}{17{,}78} + 0{,}0056} = 121,3 \quad metr \quad per \quad shift$$

The SBSH-250 MNA32 drilling machine has the ability to drill 121,3 meters of wells with maximum power during 1 shift (time for 8 hours).

We determine the necessary values for the calculations of the Epiroc Pit Viper 231E drilling machine based on the above data (Table 3):

– P_o = 267 kN;
– n_f =3,1 sec^{-1} = 186 min^{-1} (the maximum value is taken from: Table 3);
– I_d =15 (const);
– d_b = 243 mm (24,3 cm) (const);.
– ϑ_d= 0,4 (max speed of movement)

I. Technical speed of drilling, m/h.

$$\vartheta_d = \frac{3{,}5 \cdot P_o \cdot n_f}{I_d \cdot {d_b}^2} = \frac{3{,}5 \cdot 267 \cdot 186}{15 \cdot 24,3^2} = 19,6 \quad m/sec$$

The technical speed of drilling on the Epiroc PV 231E machine is 19,6 meters/sec.

II. Calculation time taken for auxiliary processes during the shift (3).

1. t_k - the time taken for the rise and fall of the drill assembly is 3,1 m/sec (at max. according to table 2). 3,1 meters for 1 sec after the proportion $t_{k/t}$ = 0,32 second per meter

2. t_h is the time taken by the drilling machine to move from the 1st well to the 2nd well (between the wells). Speed of movement for Epiroc PV 231E (table 2) ϑ_h at maximum value: 0,86 m/sec. The distance between the boreholes: l= 2.5 m

$$t_h = \frac{1}{\vartheta_d}; \quad t_h = \frac{2,5}{0,86} = 2,9\ sec.$$

3. t_m is the speed of movement of the drilling tower (during the calculation, we take this value as 70% of the time taken for the rise and fall of the drill assembly):

$$t_m = t_{k/t} \cdot 70\%; \quad t_m = 0,32 \cdot 70\% = 0,22 \text{ sec}.$$

- t_m for Epiroc PV 231E at maximum value: 0,22 sec.
- $t_{k/t}$= 0,32 sec.
- t_h = 2,9 sec. (for movement from well 1st to well 2nd)

The determined values were presented in the maximum value according to the technical instructions of the drilling machine.

$$T_a = t_{k/t} + t_h + t_m; \quad T_B = 0,32 + 2,9 + 0,22 = 3,44 \quad sec.$$

T_a - the time taken for auxiliary processes during the shift is 3,44 seconds between the 1st and 2nd wells.

III.The shift productivity of drilling machines:

- T_{shift} = 8 hours
- $T_{sf}+T_t$ = 0,5 hour (same for all two samples)
- T_a = 3,44 sec. = 0,00095 hours (1 va 2-between wells)
- ϑ_d = 19,6 m/s

$$A_d^{sh} = \frac{T_{shift} - (T_{sf} + T_t)}{\vartheta_d^{-1} + T_a} = \frac{8 - 0,5}{\frac{1}{19,6} + 0,00095} = 144,5\ metr \quad per \quad shift$$

The Epiroc PV 231E drilling machine has the ability to drill 144,5 meters of wells with maximum power during 1 shift (time for 8 hours).

Conclusions and further research directions

Based on the calculations above, it is known that the Epiroc PV 231E drilling rig can drill 144.5 meters of borehole in 8 hours (one shift), which is nearly 23 meters more than the SBSH-250MNA 32 drilling rig. The necessary factors for the calculations include the technical speed of the drilling rig and the time spent on auxiliary processes during the shift. The more time spent on auxiliary processes, the lower the productivity. However, the Epiroc PV 231E rig spends significantly less time on auxiliary processes.

Table 4

Necessary values and results for practical calculation

Indicators necessary for practical results	Epiroc Pit Viper 231E	SBSH-250 MNA32
Technical speed of drilling	19,6 m/sec	17,28 m/sec
Calculation time taken for auxiliary processes during the shift	3,44 sec	20,4 sec
The result (shift productivity of drilling machines)	144,5 meters per shift	121,3 meters per shift

The Epiroc Pit Viper 231E drilling rig is superior to the SBSH-250 MNA32 not only in terms of productivity but also in several other aspects. The advantage of the remote-control system in this modern drilling rig offers significant opportunities, enhances worker safety, and reduces labor-related costs.

An important point to consider in this study is the price difference between the two drilling rigs and the associated economic implications. While the Epiroc Pit Viper 231E rig is more expensive than the SBSH-250 MNA32, this price difference should not be viewed as a significant obstacle. The higher cost is justified given the superior efficiency, safety, precision, and overall economy of the Epiroc Pit Viper 231E, which represents the most advanced technology available today. Therefore, comparing these two rigs based solely on price is not particularly relevant or concerning.

In conclusion, the adoption of advanced technologies in the mining industry and mastering their operation are essential requirements of the modern era. The extensive use and practical implementation of the Epiroc Pit Viper 231E drilling rigs, in particular, result in significantly higher efficiency. This technology allows for precise control over both productivity and worker safety. Furthermore, the remote-control system of the Epiroc Pit Viper 231E offers a strong incentive for reducing key operational costs.

Future research directions should focus on further optimizing the integration of advanced drilling technologies, such as the Epiroc Pit Viper 231E, into the mining processes.

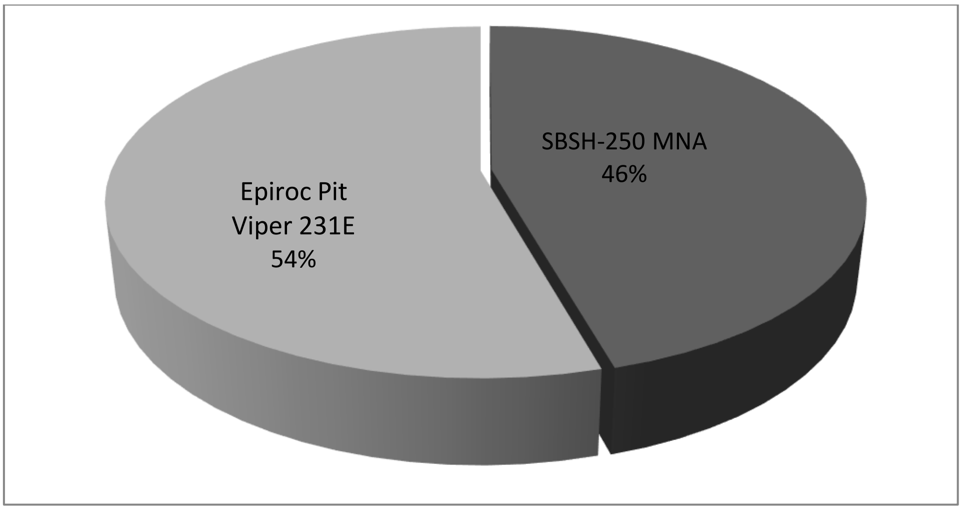

Fig. 5: Percentage share of the shift productivity of drilling machines

Specifically, investigations could be aimed at improving the interaction between automated drilling systems and other stages of the mining cycle, such as ore transport and processing, to ensure seamless operation and enhanced efficiency across the entire production chain. Additionally, there is a need for in-depth studies on the long-term economic impact of adopting these technologies, particularly in varying geological and operational conditions, to assess their broader applicability and cost-effectiveness.

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