Automation as a disruptive factor and sustainability element in rock drilling in open pit mines

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**Abstract:** This article seeks to describe some of the results obtained during the research work carried out to prepare the master's dissertation on the use of technology and digital transformation in the process of drilling rocks in open pit mines. The use of automation is presented as a disruptive factor and a driving element of improvements that provide sustainability in rock celebration. Seven main operational parameters were used to combine the measurement during drilling (MWD) with other information generated by the equipment during the drilling of blast holes, in four different lithologies in an iron mine, located in the central region of Minas Gerais. Adjustments and corrections were made to the data collected to minimize external influences, in addition to those of the rock itself, to guarantee the effectiveness of the analyses. Finally, we sought to compare the performance of the drilling process in manual mode and in automatic mode of operation.

**Keywords**: Automation. Digital Transformation. Rock celebration. Measurement during drilling (*MWD*). Operational parameters.

1. INTRODUCTION

The deepening of open pit mines with increasingly inclined mineral bodies, the presence of rock masses with geotechnical characteristics that change with each meter drilled, demand the development of new technologies capable of allowing a better use of mineral deposits. Without going into detail, a greater demand for blast holes is therefore required, as well as an improvement in quality during their execution. According to Lopes (2012), approximately 85% of the total volume dismantled (considering ore and waste) depends on the use of explosives. Each hole drilled is a different story! In this way, open pit mines have been, over the years, seeking greater recovery of the mineable reserve, thus maximizing the use of their existing assets.

Remote and autonomous drilling operations are no longer futuristic thoughts, they are the reality in several mines around the world, in the search for better operating conditions, safety, and more sustainable production processes.

In this context, a comparison between drilling holes operated in manual mode and automated drilling becomes almost inevitable. Under this bias, that the present article is justified, with the objective of presenting the possible gains arising from the use of new technologies inserted in the rock drilling process. This is a relatively new topic, under increasing discussion, with more recent references, and which deserves further study.

A more structured analysis based on the relationship between technology and sustainable development may contribute to the understanding and explanation of this event.

1. DATA OVERVIEW

**2.1Test location**

The mine chosen for the study is located in the central-eastern region of Minas Gerais, covering the municipality of Itabira, which has lithologies rich in iron oxides, with a predominance of compact itabirites (with iron content in the range of 40 to 50%).

In addition to the Itabirites, there are ferruginous dolomites and hematitic phyllites that make up a set of metamorphic iron formations.

Table 1 lists the lithologies analyzed in the study along with the UCS value assigned from geological reports and the ore/waste classification. A reference image of each rock type is also included.

Table 1 - Mine lithologies

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Rock Type | Schist | Gneiss | Itabirite Compact | Hematite |
| UCS (Mpa) | 49 | 113 | 429 | 239 |
| Ore/  Sterile | Sterile | Sterile | Ore | Ore |
|  | |  | | --- | |  | | |  | | --- | |  | | |  | | --- | |  | | |  | | --- | |  | |
|  |  |  |  |  |
| Pictures |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

Source: Prepared by the Author.

**2.2 Drilling Equipment**

Three Epiroc model PV275 drills with an embedded control system called RCS (rig control system) were used, identified in this work as P50, P51, and P53. These machines are considered a staple in the mineral extraction industry thanks to their proven performance and reliability. With a bit load capacity of up to 85,000 lb (42.5 tons), they can use rotary tricone bits up to 12-1/4” (311 mm). These equipment can be used to drill rocks in the most diverse types of lithologies, from copper to iron ore. See figure 1.

Figure 1- Epiroc PV275 Drill



Source: Prepared by the Author.

**2.3 Available data**

The RCS embedded system has four data logging options available in IREDES (extension of XML files) and text (extension of text) data formats:

* MWD Record (Measurement During Drilling) – Includes annotations of events (anomalies) and equipment status (drilling, locomotion, etc.). The file is saved after the holes are completed;
* Quality registration - It is applied when using the global positioning system (GPS), in this case, the file is generated when the hole is completed.
* Status Log – Shows the operating status of the equipment.
* Event Log – Provides proof of operator input/output, in addition to recording drilling conditions, locomotion, leveling, user-defined delay codes, consumables (drilling tools), and production failures.

The files are generated by the "Refresh Rate" setting and come to the MWD record which is saved as “DSxxxxxx.xml” where xxxxxx is based on the date and time the event was generated.

There are two ways to collect data from machines:

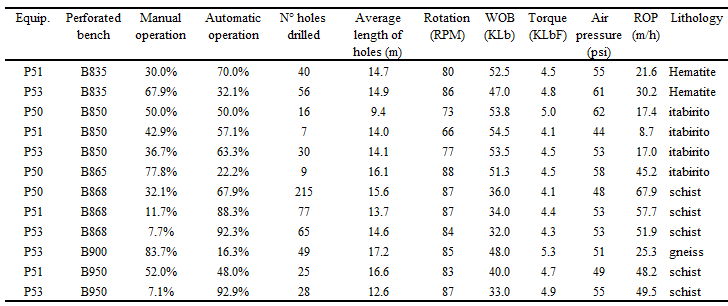
1ª. Using a USB memory stick connected to a USB hub or port in the machine cabin;

2ª. Using CCI (Common Communication Interface - Machine Server) which sends the information to another external server.

In this study, the USB method was used for data collection, since the machines were not connected to the mine's data network.

Table 2 describes the data collected in the field via systems embedded in the machines, it also presents the mode of operation and the type(s) of rock identified from the geological reports.

Table 2 - Drilling data

Source: Prepared by the Author.

1. DATA ANALYSIS

**3.1 Data processing**

In general, the data generated by the embedded systems, as well as the MWD, are directly affected by the conditions of application of the equipment and using its operational control system. In this way, uncertainties are attached to the data, these must be corrected to prioritize changes in parameters that depend on the rock properties.

A priori is a simple process that starts with a filtering to remove unrealistic values (for example, negative WOB values that can give rise to an idea of fluctuation in advance systems of machines). Then, the peaks of values that exceed the capacity must be removed.

Equipment mechanics, as an example, we can mention the high penetration rate (ROP). Finally, corrections must be made depending on the influence of hole depth.

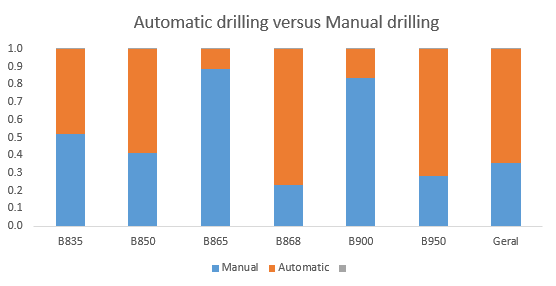
* 1. Conversion of negative values of weight on the bit (WOB)

Sometimes production data include unrealistic values of high and low performance of the equipment, which can generate difficulties, doubts when analyzing and interpreting them.

The experimental probability distribution is composed of the values of the data sample collected from May 21 to September 1, 2021, comprising 617 holes sampled every 0.05 m, totaling more than 10,000 lines with information.

To facilitate the analysis and discussion, the data were divided into six blocks that correspond exactly to the six different mining fronts where they were generated, with three ore banks located in the altimetric quotas (835, 850 and 865) and three of the barren in the positions with topographical dimensions (868, 900 and 950). Figure 2 illustrates the distribution of holes on the work front and the drilling techniques used.

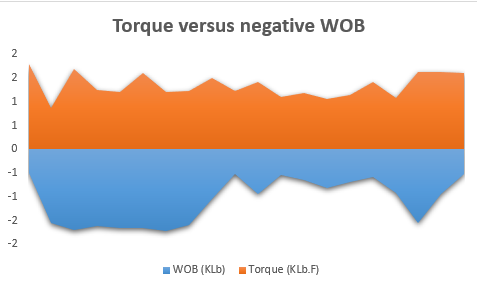
Figure 2 – Graphic drilling technique used.



Source: Prepared by the Author.

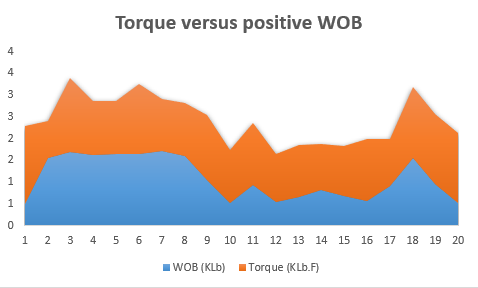
According to Thomas (2004), rocks are drilled basically, by the action of rotation and weight on the drill bit (WOB). From a technical point of view, some may find many of the definitions and units of measurement used when approaching the topic of drilling confusing. It should be noted that several of the terms and units used in drilling have a history that dates to the beginnings where this process was based more on people's practical experience than on engineering standards. For many users and equipment manufacturers, the feed force is commonly referred to as "Weight on Bit" (WOB), expressed in lb (pounds) or kilogram gram (kg). The “weight on the bit” is defined as a downward force that acts on it, generated by the hydraulic energy of the advance cylinder and added to the weight of the drill string. As weight is a vector quantity directly influenced by gravitational action, it is impossible to conceive the idea of negative values for the WOB variable in a drilling process, whether manual or automated. If it were possible, it would indicate a probable situation of fluctuation of the drilling tool on the rock mass, where the torque values should be null. To avoid misinterpretations and to ensure greater precision in the analyses, a multiplicative constant of value (-1) was inserted to transform the negative WOB values into positive values, since their torque torques present different values of zero, as we can see in Figures 3 and 4.

Figure 3 – WOB graph negative values.



Source: Prepared by the Author.

Figure 4 - WOB chart positive values



Source: Prepared by the Author.

* 1. Values above the mechanical limits of the equipment

There are several studies and efforts to optimize the operational parameters during drilling, to determine the best possible option for rotation (RPM) and weight of the drilling tool (WOB). The main aim is to obtain a maximum penetration rate (ROP). Many times, a maximized ROP is not possible, therefore, a desired penetration rate with minimum energy consumption must be sought. This is an arduous task, which is undoubtedly one of the most complicated, difficult, and necessary issues for an effective drilling process.

There are several complicating factors that tend to lead to a limitation in the advance speed of the drill (cleanliness of the bottom of the hole, rock condition, risk of drill string, jams, and operational limits of tools and machines).

For Rocha et al. (2007), an interesting strategy capable of allowing a more assertive productivity is to set a maximum limit for ROP. Thus, it is essential to know what is the maximum possible rate to be obtained with the selected drill model. The trivial solution involves determining the correct pair of forward force (WOB) and rotation (RPM). Although it seems to be easy in practice, it is a very difficult and complicated action, as it involves several variables that directly influence ROP. There is a strong tendency to seek a better penetration rate (ROP) by exclusively changing the force on the drill (WOB). According to Aadnoy (2009), an inadequate adjustment in drilling parameters can cause serious disruption to drilling with unnecessary energy expenditure.

Excess energy is dissipated in the form of heat, noise and returns to the machine generating vibrations. These are extremely harmful to the drilling process, as they will cause loss of productivity, unwanted equipment downtime, and buckling of drill pipes. One must seek the most adequate relationship between weight and rotation capable of generating the lowest specific mechanical energy, efficiency, optimization in drilling involves the adoption and use of optimal operational parameters capable of generating an ROP that we can also consider it as being great.

The lack of a reliable model for ROP prediction is an obstacle that prevents the sustainable development of the rock drilling process. There are few models that lend themselves to this purpose (MAURER, 1965; YOUNG, 1969; BOURGOYNE and YOUNG, 1974), but all of them have serious limitations, which prevent them from being used universally, quickly and safely.

Another point to be made is that the market for drilling tools and equipment lacks accurate information on achievable productivity levels, that is, unlike other mining products, there is no “safe source” or production manuals with reliable data in regard to drilling. This justifies the search and highlights the need to obtain a model for ROP prediction. From the observations made by Maurer in the laboratory, where he concluded that an increase in the rotation of the drilling tool generates an increase in ROP and that this is only possible when there is a certain weight on the drill bit; we can obtain an equation capable of providing the maximum penetration rate for it. Once we know the upper limit (the maximum possible capacity), we can establish an optimal ROP range that must be met during the drilling process.

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This drilling rate prediction model is shown in Equation 1.

ROP = Pb x RB (1)

Where: ROP is the penetration rate (m/h), Pb is the penetration depth of the button in the rock (m), and RB is the bit rotation (RPM).

Field studies show that the ideal point of penetration of the button, where it is possible to obtain a maximum penetration rate, is in the range of 70% to 75% of the height of the button embedded in the rock. We have to emphasize that a maximum WOB value does not necessarily mean a maximum ROP, since it is necessary to maintain a distance between the face of the drill bit and the rock mass so that an efficient cleaning is capable of removing the chips (gravel) from the bottom of the hole. Table 3 shows the minimum and maximum values of the estimated ROP as a function of the type of drill used in the mine (Epiroc series 60 tricone drill).

Table 3 estimates ROP for a Series 60 Epiroc drill bit

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Triconic Drill | Specified Rotation (RPM) | WOB Specified by inches of diameter (KLb) | Estimated ROP (m/h) | Estimated Air Pressure  (PSI) |

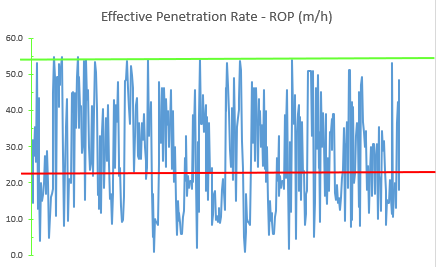
|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| IADC | Button height (mm) | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. |
| 6 | 11.0 | 50 | 120 | 4 | 7 | 23.1 | 55.4 | 40.0 | 65.0 |

Source: Adapted from the Epiroc Tricone Drill Manual.

The penetration rates performed can be seen in Figure 5. The upper and lower limits coincide with the minimum and maximum values estimated based on the height of the drill buttons.

It can be seen that 71.5% of the ROP values are within the confidence interval and 28.5% were below the minimum estimated value.

Figure 5 - ROP rate performed

Source: Prepared by the Author.

* 1. Influence of hole depth

The last step regarding the refinement of the data is the correction of the influence of the hole depth. Although there are several authors who have addressed this issue, unfortunately, analyzes of this nature for open pit mines are rare. According to Navarro et al. (2019), variations with depth may be related to energy loss and/or hole cleaning.

According to Atlas Copco, 15% to 30% of the air generated by the compressor is diverted to clean and cool the drill bearings. Factors such as pressure and volume directly affect drill life and hole cleanliness. Two other factors that affect hole cleanliness are the moisture content and lithology of the rocks. Wet rock due to massif conditions or excessive water injection increases the specific weight of chips (gravel), making it difficult to remove them from the bottom of the hole. Fractured lithologies tend to divert airflow and cause a reduction in cleaning speed. In such cases, the actual volume of air required may be much higher than the direct theoretical calculations indicated. Hole cleaning must be prioritized so that the drilling tool remains in constant contact with the rock mass, otherwise the penetration rate will be compromised. The longer the (deeper) the hole, the greater the effort to remove the fragmented particles out of the hole. To ensure efficient cleaning, the concept of cleaning speed is used, which depends on the tube diameter, drill diameter, and, mainly, the actual flow rate of the air compressor.

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Of these three variables that we have access to is the actual diameter of the drilled hole, therefore, the cleaning speed must be calculated and based on this, the configuration of the entire drill string must be made. According to Atlas Copco, under normal rock conditions with low moisture content and low density, the cleaning speed (VLP) should be in the range of 5,000 to 7,000 ppm (feet per minute). In situations where the rock is a denser, heavier material or with high moisture contents, the ideal speed is in the range of 9,000 to 10,000 ppm. Values above 10,000 ppm will drastically reduce the life of drilling tools.

1. RESULTS AND DISCUSSION

Even if, in terms of production and under certain conditions, man excels in relation to technology, its use is of paramount importance in the search for better results. Overall, the automated system is faster and maintains operational consistency compared to manual operation.

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In this work, we seek to do something similar through comparative analyzes between manual and automated drilling. We seek to make a differentiated approach to a bias based on seven variables (or operational parameters) focusing on the use of the minimum specific energy possible, as shown in Table 4.

Table 4 - Operating variables

|  |  |  |
| --- | --- | --- |
| OPERATING PARAMETERS | | |
| Parameters | Acronym | Unit |
| Weight on the drill | WOB | kilo pounds - KLB |
| Drill rotation | RPM | revolutions per minute - RPM |
| Penetration rate | ROP | Meters per hour - m/h |
| Rotation torque | TQR | Kilo pounds per force - KLB.F |
| Air pressure | PAR | Pounds per square inch - PSI |
| Button penetration | PEB | Button height percentage - % |
| Minimum specific energy | MSE | Mega pascal - Mpa |

Source: Prepared by the Author.

When analyzing the data of the parameter weight on the bit, also known as feed force (WOB or pulldown), the results showed what was already predicted, in the fronts with ores, the feed force was greater, presenting values that varied from 1 to 69 KLb with a weighted average of 49.4 KLb. In sterile materials, the WOB was lower and ranged from 1 to 68 KLb with an average of 36KLb.When we analyzed, from the point of view of the operational technique used, we found that in the automatic mode there was a reduction of 16.3% of the advance force in relation to the force used in the manual operation mode, during the drilling of sterile materials. In ores, automated drilling showed a gain of 11.8% compared to manual drilling. Overall, the gain from automated drilling in terms of WOB was 18.7%, as shown in Table 5.

Table 5 – Weight of drill bit (WOB) Automatic versus Manual Drilling.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| WEIGHT ON THE DRILL - WOB (KLb) | | | | |
|  | General | Manual | Automatic | Gains |
| Minimum | 0.1 | 1.2 | 0.1 | 18.7% |
| Maximum | 68.6 | 68.1 | 68.3 |
| Average | 39.5 | 44.9 | 36.5 |

Source: Research data.

The analysis of drill rotation data (RPM) confirmed the idea, widely spread in the medium, that in materials with lower mechanical strength, more rotation and less feed should be used. In more resistant (competent) materials, the correct thing would be to decrease the rotation and increase the weight of the drill, to obtain higher penetration rates (ROP) with less energy expenditure.

There is a slight difference in the rotation values when performing manual and automatic drilling, both when drilling in waste rock and in ore. Table 6 presents the rotation values obtained during the drilling process and shows a gain of 2.4% when used in automatic mode.

Table 6 – Drill Rotation (RPM) Automatic Drilling versus Manual Drilling.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| DRILL ROTATION - RPM (RPM) | | | | |
|  | General | Manual | Automatic | Gains |
| Minimum | 38 | 38 | 46 | 2.4% |
| Maximum | 97 | 95 | 97 |
| Average | 85 | 84 | 86 |

Source: Research data.

The penetration rate (ROP) in the automatic drilling was 32.8% higher than the rate obtained using the manual mode, when drilling in steriles. In ores, the penetration rate in manual drilling was 4% higher than that performed by automated drilling. Overall, the gains in penetration rate with automated drilling were 22.6%, see Table 7.

Table 7 – Bit Penetration Rate (ROP) Automatic Drilling versus Manual Drilling.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| PENETRATION RATE - ROP (m/h) | | | | |
|  | Geral | Manual | Automatic | Gains |
| Minimum | 0.9 | 3.8 | 0.9 | 22.6% |
| Maximum | 55.0 | 55.0 | 55.0 |
| Average | 36.6 | 31.9 | 39.1 |

Source: Research data.

Rotating torque (TQR) is a relevant parameter for monitoring drilling. This is because an exaggerated increase or decrease of the same represents a problem with a drill string blocking to the end of the drill (Rocha et al., 2009). The automatic mode of operation showed rotation torque values 10.6% higher than those obtained in manual drilling for the holes made in waste rock and 6.4% when compared to drilling in ore. For the rotation torque parameter, the gains represented by automation were 10.6%, according to Table 8.

Table 8 – Rotating Torque (TQR) Automatic Drilling versus Manual Drilling.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| TORQUE - TQR (KLb-F) | | | | |
|  | Geral | Manual | Automatic | Gains |
| Minimum | 0.1 | 0.1 | 3.0 | 10.6% |
| Maximum | 11.7 | 10.6 | 11.7 |
| Average | 4.4 | 4.7 | 4.2 |

Source: Research data.

According to Atlas Copco, air pressure in a rotary drilling system with tricone drills has three fundamental objectives which are to keep the drill bearings clean, cool, and to clean the holes. The automatic mode obtained a gain of 16.3% in air pressure compared to the manual mode when drilling the sterile front. In ore, the gain from the automated process was 1.7%. In general, during drilling, the gain was 1.9% for automatic drilling compared to manual drilling. Table 9 shows the average values of air pressure during drilling and the gains obtained.

Table 9 - Air Pressure (PAR) Automatic drilling versus Manual drilling.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| AIR PRESSURE - PAR (PSI) | | | | |
|  | Geral | Manual | Automatic | Gains |
| Minimum | 11 | 11 | 15 | 1.9% |
| Maximum | 101 | 101 | 95 |
| Average | 53 | 52 | 53 |

Source: Research data.

The correct penetration of the button (insert) into the rock is something easy to achieve, but difficult to maintain due to the geotechnical characteristics of the rock massifs.

For Wolpp (2018), the discontinuities that affect the geotechnical behavior are: Orientation, spacing, roughness, persistence, filling, opening, and infiltration or percolation of water. As already mentioned, the ideal point of penetration of the button into the rock, which is capable of providing a maximum penetration rate of the drill, is in the range of 70 to 75% of the height of the button, that is to say that when the button penetrates this percentage of its height in the rock, the ROP tends to its maximum value.

The analyzed data show that in automated drilling, in sterile materials, the average penetration of the buttons was 77%, against 65% achieved by manual operation. In ores, during automated operation, the average penetration percentage of buttons was 38% and in manual mode this value reached 42%. Overall, automation brought a gain of 16.7% in terms of button penetration, see Table 10.

Table 10 - Button Penetration (PEB) Automatic drilling versus Manual drilling.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| BUTTON PENETRATION - PEB (%) | | | | |
|  | Geral | Manual | Automatic | Gains |
| Minimum | 4.0 | 4.0 | 4.0 | 16.7% |
| Maximum | 100.0 | 100.0 | 100.0 |
| Average | 70.0 | 60.0 | 70.0 |

Source: Research data.

According to Brito (2010), the most usual way to analyze the drilling performance is based on the direct comparison between the current performance and a historical pattern obtained from the holes already drilled. This type of analysis is often limited to comparing only the perforation rate parameter. In practice, the aim is to maximize ROP, which can lead to variations and errors due to the subjectivity of this methodology .

Authors such as Teale (1964) proposed more objective and assertive methodologies to analyze the performance of the drilling process. Teale introduced the concept of minimum specific energy and the idea of maximum efficiency when the energy employed by the drill string approaches the strength value of the drilled rock, in other words, the maximum drilling efficiency is obtained when the energy in the drill bit is equal. The minimum energy needed to break up the rock.

It is a concept that is still under development, as other authors have worked to minimize the variations resulting from the confinement of rocks and operational uncertainties, in order to optimize the drilling process through the safe knowledge of this variable.

It was decided to carry out an analysis of drilling from the perspective of the rational use of energy, through a narrative based on the use of the minimum energy necessary to fragment the rock, that is, the minimum specific energy. The data obtained in the research indicate that in steriles, automated drilling achieved an energy efficiency of 25.6% in relation to manual drilling.

In ores, there was an expense of about 7.8% more in the automated process compared to the manual process. Overall, the automation achieved a 22.3% efficiency gain in terms of minimum specific energy used. Table 11 presents the values ​​obtained for the minimum specific energy during drilling.

Table 11 – Minimum Specific Energy (MSE) Automatic Drilling versus Manual Drilling.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SPECIFIC ENERGY - MSE (MPa) | | | | |
|  | Geral | Manual | Automatic | Gains |
| Minimum | 2.4 | 2.4 | 12.8 | 22.3% |
| Maximum | 459.9 | 417.4 | 459.9 |
| Average | 144.4 | 168.7 | 131.0 |

Source: Research data.

1. CONCLUSION

This research demonstrated the feasibility of the automated system to drill rocks. It was found that the use and application of new technologies in unitary operations in mining, especially in drilling, is a possible, safe, effective, and sustainable process. Automated systems are reliable and operate under the most diverse conditions of severity and applications. Automation depends not only on the contribution of large resources, but also on an infrastructure capable of relating to all other activities present in the production processes of mining. Embedded systems in machines offer safety, productivity, control, and continuity of operations (gains in terms of operational efficiency). Specific conclusions are listed below:

1. The drilling parameters to be selected vary depending on the geomechanical conditions of the rock mass and must be checked at all times to obtain a better performance of the process. In manual drilling, the results obtained are directly related to the experience and expertise of the drillers; which, in a way, makes it difficult to train new employees. According to some experts, the average time to train a good operator can vary from three to six years. With the help of new technologies, automated drilling presents opportunities for training qualified operational labor in a shorter period (from six to one year), that is, in a shorter period of time it is possible to qualify a person so that it can develop drilling activities.
2. The automatic system, when compared to the manual one, applies less weight on the drill bit (WOB). On average, a gain of 18.7% was obtained with the use of automatic drilling, which means that the system seeks to prioritize and use the minimum advance force necessary to overcome the resistance of the rocks.
3. Variável torque (TQR) term influência direta no processo de elaboração dos furos, pode variar em função do material ser perfurado e da sua profundidade. Perfurações que utilizam menores valores de torque geram menos gasto energético e menores desgastes nos elementos da coluna de perfuração, principalmente, quando pensamos nas junções enroscadas dos tubos de perfuração. O modo automático possibilitou um ganho de 10,6% em comparação perfuração manual.
4. The torque variable (TQR) has a direct influence on the hole preparation process, it may vary depending on the material to be drilled and its depth. Drillings that use lower torque values generate less energy expenditure and less wear on the drill string elements, especially when we think about the screwed joints of drill pipes. The automatic mode enabled a gain of 10.6% compared to manual drilling.
5. Em termos de taxa de penetração (ROP) o sistema automatizado propiciou um ganho de 22,6% o que pode ser explicado pela otimização da perfuração em função do uso de um sistema tecnológico. Segundo *Ifekaibeya* (2011) otimização da perfuração tem como objetivo melhorar a eficiência do processo através da combinação ótima de parâmetros principais, tais como, o peso aplicado sobre a broca (*WOB*), a velocidade de rotação (RPM) e o torque (TQR) aplicado na ferramenta de fragmentação. Vários são os autores que descreveram metodologias para otimizar a perfuração, mas infelizmente, não há um modelo final acabado e consolidado que possa ser utilizado nas mais variadas situações e condições de minas. Automação se apresenta como uma opção capaz de dialogar com os modelos de otimização estabelecidos de modo maximizar os resultados, o que na prática pode ser entendido como uma otimização do processo.
6. In terms of penetration rate (ROP), the automated system provided a gain of 22.6%, which can be explained by the optimization of drilling due to the use of a technological system. According to Ifekaibeya (2011), drilling optimization aims to improve the efficiency of the process through the optimal combination of key parameters, such as the weight applied to the drill bit (WOB), rotation speed (RPM) and torque (TQR) applied to the shred tool. Several authors have described methodologies to optimize drilling, but unfortunately, there is no final consolidated model that can be used in the most varied situations and mine conditions. Automation presents itself as an option capable of dialoguing with established optimization models to maximize results, which in practice can be understood as process optimization.
7. From the point of view of the predictability of the penetration rate, the automated system works with the concept that the maximum ROP is based on an efficient removal of residues at the bottom of the hole (specifically between the drill face and the solid) and on the correct penetration of the button on rock. By improving cleaning and allowing better contact of the drilling tool, the penetration rate would tend to increase as pointed out in the study by Wardlaw (1969). On the other hand, when the button penetrates about 70 to 75% of its height in the rock, there are enough spaces for the chips of the fragmented materials to be removed and to maintain an ideal contact between the tool and rock. In practice, it means saying that there is no point in having high penetration rates, it is necessary to drill clean so that there is perfect synchronism and the drilling process can be carried out effectively. The research showed that during drilling in automatic mode, the gain was 16.7% in the penetration of the buttons into the rock and 1.9% in the air pressure for cleaning the holes. It was found that in less resistant materials the advance force (WOB) was reduced and the rotation (RPM) was increased to obtain a higher penetration rate (ROP). The opposite was also verified (reduction in rotation and increase in WOB in more resistant materials), although it seems to be simple, something logical to do, this perception of change in lithology and changes in the main operational parameters is a complex action that induces several operators (experienced or not) to errors and generate losses in productivity.

Automated drilling showed an energy gain of 22.3% compared to manual drilling. The aim is to obtain a better synchronism between the operational parameters to obtain a desired ROP with the least possible energy consumption. According to Gandelman (2012), each rock has a minimum energy required for its rupture. This energy depends on the type and conditions to which the rock is subjected (compaction, pressure, temperature, etc.). When the drill is able to transmit to the rock the minimum value necessary for its fragmentation, the drilling process will occur, otherwise, the energy will return to the equipment in the most diverse forms (noise, vibration and heat), resulting in losses, damage to the machine and the process as a whole.

Usually the benefits arising from automation in drilling are only externalized as boosting elements aimed at safety issues, optimization of work shift change intervals, and increased productivity. In this work, it was shown where automatism in drilling functions can really make a difference and be translated into tangible gains. It can be said that all benefits arising from automation contribute so that we have a more modern mining guided by good practices (operational and managerial) capable of guaranteeing the stability and maintenance of the mineral enterprise. Organizations see automation as a means of capturing data more comprehensively, improving the customer experience, reducing risk, capitalizing on developing new skills in people, and enabling innovation in their companies. Despite this positive view regarding the use of new technologies, the reality is very challenging because there is a call for automation, which develops at a frenetic pace, in which it is necessary to prioritize the areas of the company to be automated. It is necessary to understand and make an assertive technological choice among so many possible options. The progression to truly intelligent automation requires first defining and optimizing processes and then restructuring the organization around those processes, both of which can be driven by technologies hitherto unavailable in the organization. In practice, it is something that will impact the day-to-day work of all employees (individually or collectively), which will test communication, change management, and, above all, propose cooperation/synergy of all those involved in production processes. Finally, we can say that each mining company must choose the most appropriate technology for its processes, once selected, it must be used to its fullest to seek the assertiveness of the analyzed results. The routine of regular inspections and audits is a good practice that proves to be very attractive to ensure the reliability and transparency of processes and can be used in mining. The use of technology is an argument that presents itself as a competitive differential capable of bringing improvements to all and, above all, strengthening the concern for the search for an efficient and Responsible Business Management. This search demands cultural and organizational change, followed by a redefinition of the processes and responsibilities of the people involved. In conclusion, in a modern mining process guided by automation and new technologies, everyone must be updated: machines, men, and processes.

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