Received: 19 March 2024 | Revised: 28 June 2024 | Accepted: 9 July 2024 | Published online: 31 July 2024

Archives of Advanced Engineering Science
2025, Vol. 3(2) 67–72
DOI: 10.47852/bonviewAAES42022859

BON VIEW PUBLISHING

RESEARCH ARTICLE

Estimation of the Maximum Angular Position for Cutting Roof Rock Material

Yong Sun[1,*], Xingsheng Li[1] and Hua Guo[1]

[1]*Mineral Resources, Commonwealth Scientific and Industrial Research Organisation, Australia*

Abstract: In the mining and construction industry, the picks on an excavation machine often need to cut different rock types within the same drum revolution. If a rock type is much stronger than others, cutting this type of rock will often have a significant impact on the failure rates and performance of the picks and excavation machine. Therefore, it is necessary to understand the maximum angular position for cutting this type of rock, especially when it is hard rock. The accuracy of the maximum angular position for cutting the hard rock in a drum revolution affects the accuracy of the analysis of the maximum depth of cut for cutting the hard rock. It also affects the drum balance. In this paper, a method is developed to accurately calculate the maximum angular position for hard rock cutting based on the roof rock cutting in coal mining. In some cases, a simple but approximate method can be used to estimate the maximum angular position. One such case is when the strength differences between different rock types are not significant. The comparison of the influences of the accurate results on the pick performance analysis with that of the results given by the approximate method is also conducted. It shows that when the ratio of the height of the roof rock being cut to the tip-to-center cutting radius is 0.5, the maximum depth of cut in a drum revolution is less than 73 mm and the tip-to-center cutting radius is greater than 700 mm, the relative analysis error caused by the approximate method is less than 6%.

Keywords: rock, angular position, depth of cut, mining, construction, rock cutting

1. Introduction

Rock is a type of common material that needs to be cut in the mining and construction industries. Rock has different compositions with different hardness and other material properties. In industry, picks are typically installed on a drum of an excavation machine to cut tunnels and coal faces [1–5]. Therefore, many studies have been conducted to understand the various aspects of pick applications [2, 6–11]. A major goal of the studies is to reduce the failure probability of picks during production [5, 10, 12–14]. Research showed that the working load on the pick is a major factor affecting the failure rate of a pick [15]. The working load is closely related to the rock strength and the depth of cut of the pick [15–17]. An increase in rock strength will significantly increase the cutting force on cutters or picks [17–20]. Research also showed that the cutting force acting on the pick or other types of cutting tools during rock cutting increases with the depth of cut [4, 17, 21, 22]. As a result, an increase in the depth of cut will generally increase the failure risk of a pick [15, 18]. Furthermore, the effect of the depth of cut on pick failure rate becomes higher when the rock is harder [15]. For example, tungsten carbide (WC) picks were used to cut granite rock with a uniaxial compressive strength of 149 MPa in rock cutting tests [10]. The test result showed that the WC picks were unable to effectively cut the rock even at a depth of cut of only 5 mm [10].

To reduce the failure rate of picks and machines, it is better to reduce the depth of cut. However, reduction in the depth of cut will generally cause deduction in productivity. Therefore, it is important to accurately calculate and control the depth of cut in the industry applications, especially when hard rock cutting is involved. Many studies have been conducted to analyze the variation of the depth of cut and the cutting force during rock cutting using a drum [23, 24]. Research showed that the depth of cut of a pick in a drum revolution (a cutting cycle) is a function of pick's angular position. The angular position of a pick is its angle of rotation used to determine its position during a drum revolution. It is usually measured from the vertical upward position of the drum. Various formulas have been developed to calculate the depth of cut at a given angular position approximately or accurately [11, 23]. Once the depth of cut at a given angular position is known, the cutting force on pick at this angular position can be estimated [11, 23, 25].

However, in existing studies, the influence of different rock types being cut in the same drum revolution has not been adequately considered. Most of the studies only considered a single type of rock during a drum revolution. As a result, these studies may not be able to meet the need of the industry applications. In reality, a tunnel or a coal face panel often consists of different rock types. For example, in coal mining, machines typically need to cut two distinct rock types: the hard rock of the roof and floor and the coal seam between the roof and floor. Coal is usually much softer than the roof and floor rocks. In this case, cutting hard roof and floor rock often plays a critical role in the determination of the pick's service life and machine productivity. Therefore, to reduce pick failure risk and improve productivity, it is necessary to estimate the range of the angular positions that involves cutting the hardest rock part in a drum revolution. The corresponding maximum depth of cut also needs to be calculated.

***Corresponding author:** Yong Sun, Mineral Resources, Commonwealth Scientific and Industrial Research Organisation, Australia. Email: Yong.Sun@csiro.au

Another important reason for calculating the range of the angular positions is that angular position is a key parameter in drum design. The angular positions of picks on a drum can affect the load fluctuations of the drum [25]. Load fluctuations can cause unwanted vibrations in the drum and machine structure, which will often damage the pick and machine [26]. The load on a drum is the combination of forces on all the picks at the same point in time on the drum. One of major goals of drum design is to minimize load fluctuations. However, existing studies generally assume that all picks on a drum cut the same type of rock or coal. The effect of rock changes on the forces on the individual picks is ignored in the drum load fluctuation analysis. This simplification may result in a poorly balanced drum if the strengths of the rocks cut in a drum revolution are significantly different. Therefore, to optimize drum design, accurate analysis of the range of the angular positions and the depth of cut for cutting different rock types is also needed.

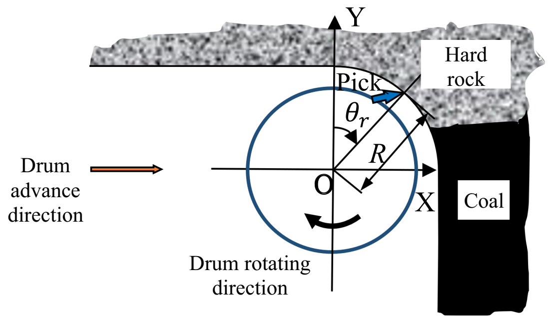
However, the required estimation methods have not yet been developed although some studies have considered cutting different types of rocks in a drum revolution [24]. To address this issue, a method to accurately calculate the maximum angular position and the maximum depth of cut for a given thickness of hard rock is developed in this paper. The method is developed based on the roof rock cutting in the coal mine roadway development. The main reason for choosing this cutting scenario is that it requires consideration of not only the failure risk of picks and excavation machine but also the risk of frictional ignition [14, 27]. Frictional ignition is a significant hazard in coal mining. Cutting hard rock generally requires more energy and produces higher temperatures than cutting soft coal. Hence, cutting hard rock is more likely to cause frictional ignition. Since only roof rock cutting is considered, the minimum angular position for rock cutting is always zero. As a result, the calculation of the range of the angular positions is simplified to only calculate the maximum angular position. Furthermore, to facilitate the on-site analysis, an approximate method is also proposed to simplify the accurate calculation method. To understand the suitability of the proposed approximate method, the errors of the approximate method compared to the accurate method are discussed based on various scenarios. Their impact on pick performance is also investigated. Although the calculation method is developed based on a scenario in the coal mining industry, the analysis method can be applied to other scenarios.

2. Calculation of the Maximum Angular Position for Cutting Roof Rock

In the coal mining industry, continuous miners are usually used for roadway development and long shearers are typically used for longwall mining. These machines are equipped with one or two drums. Each drum is installed with a number of picks. During production, the drum often needs to cut different rock types in a drum revolution. As an example, Figure 1 shows a scenario where the drum involves cutting hard rock on the roof and coal seam under the roof rock. For simplicity, only one pick is shown in Figure 1. In this figure, blue arrow represents a pick, R is the radius of pick tip to the drum center (called the tip-to-center cutting radius), and θ_r is the angular position of the pick which is measured from the upright position (i.e., from Y axis).

When cutting into the tunnel face in coal mining roadway development and cutting working face in longwall mining, the drum will continue to rotate while advancing. Therefore, the following analysis is carried out based on this type of drum movement. However, the developed analysis method can also be used to other types of drum movement.

Figure 1
Continuous rock cutting process



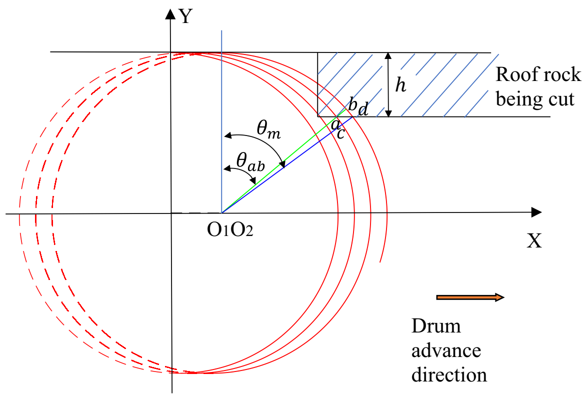
When a drum continues to rotate while advancing, the locus of a pick tip on the drum is affected by the drum advance speed v_a (m/min), drum rotational speed n (RPM), and the tip-to-center cutting radius R (mm). According to Liu and Roxborough [23], the coordinates of the locus of the tip at time t (sec), (x,y), are given by:

$$x = \frac{50}{3} v_a t + R\sin\left(\frac{\pi n t}{30}\right) \tag{1}$$

$$y = R\cos\left(\frac{\pi n t}{30}\right) \tag{2}$$

Figure 2 shows the trajectory of a pick tip during a rock cutting process (red line). In Figure 2, the hatched area represents the roof rock being cut, with a height of h (mm). Point a is the intersection of the tip trajectory in the cutting cycle before the current one and the bottom line of the roof rock. Point b is the intersection of the extension line formed by point a and the drum center location O_1 and the tip trajectory in the current cutting cycle. Point c is the point where the tip just exits the roof rock in the cutting cycle before the current one. Point d is the intersection of the extension line formed by point c and the drum center location O_2 and the tip trajectory in the current cutting cycle. The line from b to O_1 (or the line from d to O_2) is called tip-to-center line. The length of the tip-to-center line is the tip-to-center cutting radius. During the rock cutting process, the tip-to-center line rotates with the rotation of the pick. Therefore, the angle between the tip-to-center line and Y axis is the angular

Figure 2
Trajectory of a pick tip during a rock cutting process



position of the pick. In Figure 2, the angle θ_{ab} (degrees) is the maximum angular position of the pick corresponding to the accurate maximum depth of cut for cutting the roof rock (section $\overline{ab}$). This angle is referred to herein as the maximum angular position for hard rock cutting, or simply the maximum angular position. The angle θ_m (degrees) is the maximum angular position of the pick when its tip can still touch the roof rock. The depth of cut corresponding to θ_m is section $\overline{cd}$. For simplicity, the rock surface is depicted as a straight line. In reality, the rock surface is more likely to be uneven. In this case, the height of the rock being cut is specified for each cutting cycle. The maximum angular position for hard rock cutting is calculated accordingly for each individual cutting cycle.

Accurate calculation of θ_{ab} needs to accurately find out point a and point b. To calculate the coordinates of point a, $(x_a,\ y_a)$, and point b, $(x_b,\ y_b)$, the current cutting cycle (named as cycle 2) and the cutting cycle before the current one (named as cycle 1) are considered. In the following analysis, it is assumed that the change in the thickness of the roof rock being cut in two consecutive cycles can be ignored.

According to Equations (1) and (2), the coordinate of the locus of the tip at time t_1 (s), $(x_1,\ y_1)$, in cycle 1 ($0 \to 2\pi$) is given by:

$$x_1 = \frac{50}{3} v_a t_1 + R\sin\left(\frac{\pi n t_1}{30}\right) \tag{3}$$

$$y_1 = R\cos\left(\frac{\pi n t_1}{30}\right) \tag{4}$$

The coordinate of the locus of the tip at time t_2 (s), $(x_2,\ y_2)$, in cycle 2 ($2\pi \to 4\pi$) is given by:

$$x_2 = \frac{50}{3} v_a t_2 + R\sin\left(\frac{\pi n t_2}{30}\right) \tag{5}$$

$$y_2 = R\cos\left(\frac{\pi n t_2}{30}\right) \tag{6}$$

In addition, the coordinate of drum center at time t_2, $(x_c,\ y_c)$, is:

$$x_c = \frac{50}{3} v_a t_2 \tag{7}$$

$$y_c = 0 \tag{8}$$

It is noted that time t_1 changes from 0 to $\frac{60}{n}$ (s) and t_2 from $\frac{60}{n}$ to $\frac{120}{n}$ (s). When the tip trajectory in cycle 1 reaches point a,

$$y_a = R - h \tag{9}$$

Substituting y_a into Equation (4) gives the time t_{1a}:

$$t_{1a} = \frac{30}{\pi n}\cos^{-1}\left(1 - \frac{h}{R}\right) \tag{10}$$

Therefore,

$$x_a = \frac{50}{3} v_a t_{1a} + R\sin\left(\frac{\pi n t_{1a}}{30}\right) \tag{11}$$

Using the coordinates $(x_2,\ y_2)$ and $(x_c,\ y_c)$, a family of linear functions with t_2 as a variable can be established to describe the position of the tip-to-center line at different times in cycle 2. With the coordinate $(x_a,\ y_a)$, the specific time t_{2b} when the tip-to-center line passes point a can be calculated by solving the following equation:

$$\cos\left(\frac{\pi n t_{2b}}{30}\right)\left[x_a - \frac{50}{3} v_a\left(\frac{60}{n} + t_{2b}\right)\right] - (R - h)\sin\left(\frac{\pi n t_{2b}}{30}\right) = 0 \tag{12}$$

If the tip-to-center line never passes point a, time $t_{2b} = 0$.

Once t_{2b} is known, the exact angular position θ_{ab} can be calculated using the following equation:

$$\theta_{ab} = 6 n t_{2b} \tag{13}$$

Substituting t_{2b} into Equations (5) and (6) gives the coordinate $(x_b,\ y_b)$. Then, a linear function of the tip-to-center line can be obtained using the coordinates of points b and O_1. Furthermore, the coordinate $(x_{a1},\ y_{a1})$ of the intersection point of this linear function and the bottom line of the roof rock can be obtained. In most cases, the coordinate $(x_{a1},\ y_{a1})$ is the same as the coordinate $(x_a,\ _a)$. However, if $t_{2b} = 0$, these two coordinates will be different. Once the coordinates $(x_{a1},\ y_{a1})$ and $(x_b,\ y_b)$ are known, the exact maximum depth of cut for cutting the hard roof rock, D_{rm} (mm) can be calculated as follows:

$$D_{rm} = \sqrt{(x_b - x_{a1})^2 + (y_b - y_{a1})^2} \tag{14}$$

From the above analysis, it can be seen that accurately calculating the angular position θ_{ab} is complex. On the other hand, Figure 2 shows that angular position θ_m is close to the angular position θ_{ab}. If θ_m can be used to replace θ_{ab}, the calculation becomes much simpler. The angle θ_m can be approximately calculated as follows:

$$\theta_m = \cos^{-1}\left(1 - \frac{h}{R}\right) \tag{15}$$

The corresponding depth of cut D_m (mm) can then be approximately calculated using the formula given in Hurt et al. [11]:

$$D_m = D_{max}\sin\theta_m \tag{16}$$

where D_{max} (mm) is the maximum depth of cut of the pick in a drum revolution. It is dependent on the drum's advance speed, drum rotational speed, and drum design. When one pick cuts one line, the following approximate formula is often used to estimate D_{max} [11]:

$$D_{max} = \frac{1000 V_a}{n} \tag{17}$$

More studies on the calculation of the depth of cut can be found in literature such as references [11, 23]. Existing studies show that the depth of cut is also affected by other factors such as number of cutting sequences [11] and the number of picks per line [23].

It can be seen that using Equation (15) to calculate the maximum angular position is much simpler than solving Equations (12) and (13). Therefore, if Equation (15) could be used as an approximate formula to calculate the maximum angular position for hard rock cutting, it will be beneficial to on-site analysis. Using Equations (15) and (16) to calculate the maximum angular position and the corresponding depth of cut is an approximate method. To investigate the situations where the errors caused by using the approximate method are acceptable, what-if analyses are performed in the next section.

3. What-If Analysis and Discussions

In Equation (15), the angular position θ_m is only a function of the ratio of h and R (i.e., h/R), but from Equations (12) and (13), it can be seen that the exact maximum angular position of roof hard rock cutting is affected not only by the ratio h/R, but also by R and drum operating parameters. To understand the influences of these factors on the maximum angular position and the errors could be caused by using the approximate method, what-if analyses are conducted. Since the drum rotational speed is rarely adjusted, the investigation focuses on three factors: R, the h/R ratio, and the drum advance speed.

As an example, Figure 3 shows the effect of R on the calculated maximum angular position with four different ratios ($h/R = 0$, 0.05, 0.5, and 1), drum advance speed of 3.1 m/min, and drum rotational speed of 42 RPM. Figure 4 shows the effect of the h/R ratio on the calculated maximum angular position for $R = 500$ mm. Figure 5 shows the effect of the drum advance speed on the calculated maximum angular position with $R = 500$ mm, a drum rotational speed of 42 RPM, and a h/R ratio of 0.2. In all figures, "Approx" indicates the approximate method. "Accurate" indicates the accurate method.

From Figure 3, it can be seen that at the two extreme conditions ($h = 0$ and $h = R$), both methods give the same results. Neither of the

Figure 3
The effect of the tip-to-center cutting radius R on the calculated maximum angular position

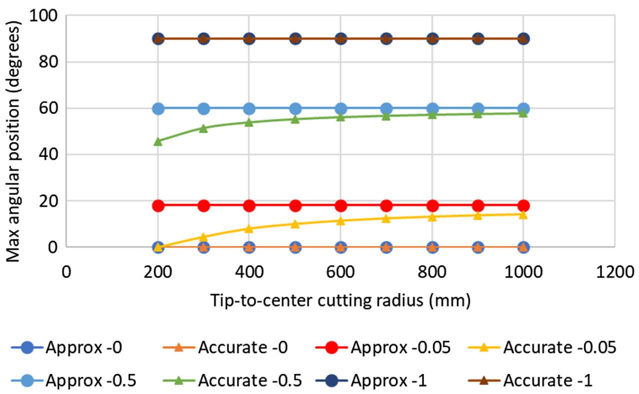


Figure 4
The effect of the h/R ratio on the calculated maximum angular position

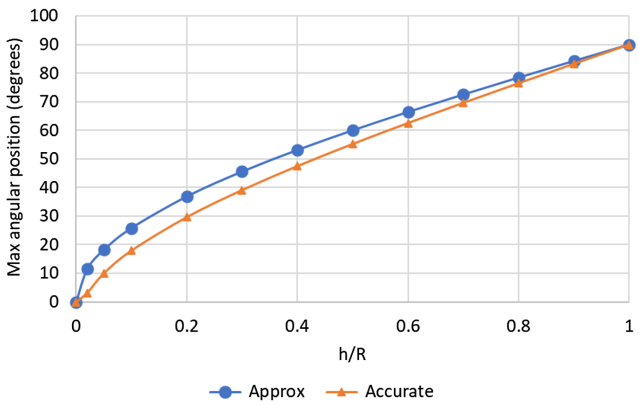
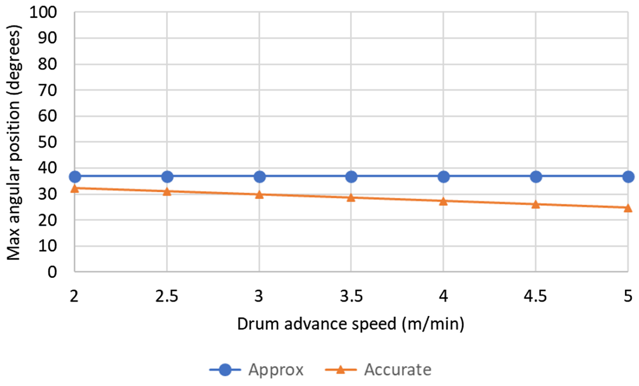


Figure 5
The effect of the drum advance speed on the calculated maximum angular position



results are affected by the tip-to-center cutting radius. When $h/R = 0.05$ and 0.5, the approximate result is still not affected by the tip-to-center cutting radius, but the exact result is. Moreover, it can be seen that the exact result is generally lower than the approximate result. The difference between the two results decreases with the increase of h/R ratio. It also decreases with the increase of the tip-to-center cutting radius. When h/R ratio equals to 0.5 and $R > 700$ mm, the increase in the maximum angular position becomes very small. Therefore, the increase in the maximum angular position in this case can usually be ignored. In addition, the relative error between the approximate result and the exact result in this case is less than 6%, so the approximate method can be used to calculate the maximum angular position.

On the other hand, when $R = 200$ mm and $h/R = 0.05$, the approximate method gives an angle of 18.2 degrees, but the exact maximum angular position is 0 degrees. This large error of the approximate result may affect the drum balance design. Further analysis shows that the maximum depth of cut of the pick for cutting the roof rock given by the approximate method is 23 mm, while the exact value is 10 mm. The approximate method resulted in an overestimation of the maximum depth of cut by 13 mm. When cutting hard rock, increasing the depth of cut by 13 mm will significantly increase the cutting force. The increased cutting force can significantly affect performance and increase pick failure rates. In order to quantitatively illustrate the influence of the overestimated depth of cut on the predicted cutting force, the formula given by Goktan and Gunes [16] is used for quantitative analyses. According to Goktan and Gunes [16], when the depth of cut is D (mm), the mean cutting force acting on a pick, F_c (kN), is:

$$F_c = 4\pi\sigma_{Bt}D^2 \sin\left[0.5(90 - \alpha_r) + \alpha_{fr}\right] \tan\left(0.5(90 - \alpha_r) + \alpha_{fr}\right)/1000 \tag{18}$$

where σ_{Bt} is the tensile strength of rock (MPa), α_r is rake angle (degree), and α_{fr} is angle of friction between the rock and the cutting tip of the pick (degree).

Then, the cutting force estimated using the approximate depth of cut F_{ap} and the force estimated using the exact depth of cut, F_{ac}, are as follows:

$$F_{ap} = 4\pi\sigma_{Bt}23^2 \sin\left[0.5(90 - \alpha_r) + \alpha_{fr}\right] \tan\left(0.5(90 - \alpha_r) + \alpha_{fr}\right)/1000 \tag{19}$$

and

$$F_{ac} = 4\pi\sigma_{Bt}10^2 \sin\left[0.5(90-\alpha_r)+\alpha_{fr}\right]\tan\left(0.5(90-\alpha_r)+\alpha_{fr}\right)/1000 \tag{20}$$

Since the calculation of cutting force is beyond the scope of this paper, the specific cutting forces are not calculated here. Instead, only the relative error of the cutting force estimated by the approximate method is analyzed as follows:

$$\frac{(F_{ap}-F_{ac})}{F_{ac}} \times 100\% = 429\% \tag{21}$$

The relative error caused by the approximate method in this case is huge. Further analysis shows that when R increases to 400 mm, 600 mm, 800 mm, and 1000 mm, the exact values of the maximum depth of cut become 16.3 mm, 18.5 mm, 19.7 mm, and 20.3 mm, respectively. Despite the increase in the exact values, the relative errors of the cutting forces estimated by the approximate method are still large, reaching 99.1%, 54.6%, 36.3%, and 28.4%, respectively.

The above analysis shows that the maximum depth of cut given by the approximate method in all five cases is much larger than the exact values. Since the overestimated depth of cut will usually result in a significant overestimation of the cutting force acting on the pick, such overestimation needs to be avoided in production. A significant overestimation of the cutting forces usually leads to a significant overestimation of the failure risk of the pick and the machine. To reduce the overestimated failure risk, the actual depth of cut may be unnecessarily reduced, resulting in considerable productivity losses. Therefore, the approximate result should not be used to determine drum operating parameters when $h/R = 0.05$ and $R < 1000$ mm.

From Figure 4, it can be seen that as the h/R ratio increases, the difference between the approximate and accurate results first increases rapidly from zero to a maximum value and then gradually decreases to zero. From Figure 5, it can be seen that an increase in drum advance speed decreases the exact maximum angular position but does not affect the approximate result. According to Equation (16), when drum rotational speed remains unchanged, increasing drum advance speed means increasing D_{max} (the maximum depth of cut of the pick in a drum revolution). For better understanding, Figure 6 shows the relationships between the calculated maximum angular position and D_{max} for two different drum rotational speeds n42 ($n = 42$ RPM) and n52 ($n = 52$ RPM).

Figure 6
The effect of the maximum depth of cut of the pick in a drum revolution on the calculated maximum angular position

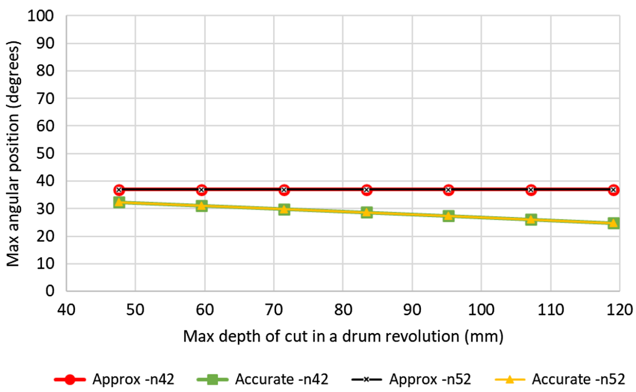


Figure 6 shows that the maximum angular position for roof rock cutting decreases proportionally with the increase of D_{max}, but the approximate results are not affected by D_{max}. As a result, the error caused by the approximate method increases with the increase of D_{max}. As can be seen in Figure 6, the lines with a drum rotational speed of 42 RPM completely overlap with the lines with a drum rotational speed of 52 RPM. This phenomenon indicates that as long as the maximum depth of cut in a revolution remains the same, changes in the combination of drum rotational speed and drum advance speed will not affect the maximum angular position results. This means that the maximum depth of cut in a revolution can be used as a single variable in place of drum rotational speed and drum advance speed for the maximum angular position analysis.

4. Conclusion

In the mining and construction industry, an excavation machine often needs to cut different rock types with different strengths in a drum revolution. In this case, accurate analysis of the range of angular positions for cutting each type of rock, especially the strongest rock, is important for accurately controlling the depth of cut of the picks. The accurate control of the depth of cut is imperative for reducing the failure rate and improving the production safety and productivity of the machine and the picks on the machine.

A method for the accurate calculation of the maximum angular position for cutting roof rock is developed based on the coal mining scenario. An approximate method is also proposed to simplify the calculation. Analysis shows that the maximum angular position for roof hard rock cutting is affected by the ratio of the height of the roof rock being cut to the tip-to-center cutting radius (*h/R* ratio), tip-to-center cutting radius, and drum operating parameters. Drum rotational speed and drum advance speed can be combined into a single variable – the maximum depth of cut in a drum revolution, for the maximum angular position analysis.

An increase in the *h/R* ratio and drum tip-to-center cutting radius increases the maximum angular position. The effect of the tip-to-center cutting radius on the maximum angular position is greatly affected by the *h/R* ratio. This effect can be ignored when the *h/R* ratio equals to 0.5, the maximum depth of cut in a drum revolution is less than 73 mm and the tip-to-center cutting radius is greater than 700 mm. On the other hand, an increase in the maximum depth of cut in a drum revolution decreases the maximum angular position nearly in a linear relationship.

The calculation errors caused by the approximate method vary depending on *h/R* ratio, drum tip-to-center cutting radius, and drum operating parameters. When *h/R* ratio is less than 0.2, the rock is very hard, or the maximum depth of cut in a drum revolution is greater than 90 mm, the approximate method should not be used due to large errors.

Although the accurate method in this paper was developed based on roof rock cutting in coal mining, the analysis method can be applied to other scenarios straightforwardly, for example, floor rock cutting in coal mining.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Yong Sun: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Xingsheng Li:** Formal analysis, Writing – review & editing. **Hua Guo:** Conceptualization, Writing – review & editing.

References

[1] Bołoz, Ł. (2019). Directions for increasing conical picks' durability. *New Trends in Production Engineering*, *2*(1), 277–286.

[2] Zhou, J., Dai, Y., Tao, M., Khandelwal, M., Zhao, M. S., & Li, Q. Y. (2023). Estimating the mean cutting force of conical picks using random forest with salp swarm algorithm. *Results in Engineering*, *17*, 100892.

[3] Sifferlinger, N. A. (2023). Challenges in mechanical excavation in mining and need for robotization of tool change. In *Proceedings of 26th World Mining Congress*, 3785–3779.

[4] Gunes Yilmaz, N., Yurdakul, M., & Goktan, R. M. (2007). Prediction of radial bit cutting force in high-strength rocks using multiple linear regression analysis. *International Journal of Rock Mechanics and Minning Sciences*, *44*(6), 962–970.

[5] Sun, Y., Li, X. S., & Guo, H. (2022). Performance of thermally stable diamond composite as rock cutting tips under varied resultant force angle. *Materials Science Forum*, *1076*, 13–18.

[6] Wang, X., Su, O., & Wang, Q. F. (2022). Distribution characteristics of rock chips under relieved and unrelieved cutting conditions. *International Journal of Rock Mechanics and Mining Sciences*, *151*, 105048.

[7] Wang, S. F., Shi, X. L., & Wu, Y. M. (2024). DEM-based 2D numerical simulation of the rock cutting process using a conical pick under confining stress. *Computers and Geotechnics*, *165*, 105885.

[8] Bilgin, N., Demircin, M. A., Copur, H., Balci, C., Tuncdemir, H., & Akcin, N. (2006). Dominant rock properties affecting the performance of conical picks and the comparison of some experimental and theoretical results. *International Journal of Rock Mechanics and Minning Sciences*, *43*(1), 139–156.

[9] Hurt, K. G., & Evans, I. (1980). A laboratory study of rock cutting using point attack tools. In *The 21st U.S. Symposium on Rock Mechanics (USRMS)*, ARMA-80-0112.

[10] Sun, Y., Li, X. S., Harbers, C., Williams, D., & Boland, J. N. (2023). Wear and cutting temperature of thermally stable diamond composite tipped pick in hard rock cutting. *Wear*, *523*, 204848.

[11] Hurt, K., Morris, C. J., & MacAndrew, K. (1982). The design and operation of boom tunnelling machine cutting heads. In *14th Canadian Rock Mechanics Symposium on "Rock Breaking and Mechanical Excavation"*, *30*, 54–58.

[12] Chinnasamy, M., Rathanasamy, R., Palaniappan, S. K., & Pal, S. K. (2023). Microstructural transformation analysis of cryogenic treated conical rock cutting bits for mining applications. *International Journal of Refractory Metals and Hard Materials*, *110*, 105995.

[13] Song, D., & Venugopal, C. (2023). A novel coal-rock cutting state identification model based on the Internet of Things. *International Journal of Cognitive Computing in Engineering*, *4*, 179–186.

[14] McNider, T., Grygiel, E., & Haynes, J. (1987). Reducing frictional ignitions and improving bit life through novel pick and drum design. In *Proceedings of the 3rd Mine Ventilation Symposium*, 12–14.

[15] Sun, Y., & Li, X. S. (2017). A probabilistic approach for assessing failure risk of cutting tools in underground excavation. *Tunnelling and Underground Space Technology*, *70*, 299–308.

[16] Goktan, R. M., & Gunes, N. (2005). A semi-empirical approach to cutting force prediction for point-attack picks. *Journal of the Southern African Institute of Mining Metallurgy*, *105*(4), 257–263.

[17] Yasar, S. (2020). A general semi-theoretical model for conical picks. *Rock Mechanics and Rock Engineering*, *53*, 2557–2579.

[18] Zeng, Q. L., Wang, Z. W., Lu, Z. G., Wan, L. R., Liu, Z. H., & Zhang, X. (2021). Research on cutting performance and fatigue life of conical pick in cutting rock process. *Science Progress*, *104*(4), 1–29.

[19] Liu, S. Y., Du, C. L., & Cui, X. X. (2009). Research on the cutting force of a pick. *Mining Science and Technology*, *19*(4), 514–517.

[20] Munoz, H., Taheri, A., & Chanda, E. (2016). Rock cutting characteristics on soft-to-hard rocks under different cutter inclinations. *International Journal of Rock Mechanics and Minning Sciences*, *87*, 85–89.

[21] Menezes, P. L., Lovell, M. R., Avdeev, I. V., & Fred Higgs III, C. (2014). Studies on the formation of discontinuous rock fragments during cutting operation. *International Journal of Rock Mechanics and Minning Sciences*, *71*, 131–142.

[22] Evans, I. (1984). Theory of the cutting force for point-attack picks. *International Journal of Mining Engineering*, *2*(1), 63–71.

[23] Liu, Z. C., & Roxborough, F. (1996). The depth of cut produced by a shearer drum. In *International Symposium on Mining Science and Technology*, 583–588.

[24] Luo, C. X., Qiao, J. B., Zhou, J. W., Sun, Z. J., & Cao, J. (2022). Fold catastrophe analysis of constitutive model of pick cutting coal with rock. *Energy Reports*, *8*, 9–15.

[25] Du, C. L., Liu, S. Y., Cui, X. X., & Li, T. J. (2008). Study on pick arrangement of shearer drum based on load fluctuation. *Journal of China University of Mining and Technology*, *18*(2), 305–310.

[26] Medolago, A., & Melzi, S. (2021). A flexible multi-body model of a surface miner for analyzing the interaction between rock-cutting forces and chassis vibrations. *International Journal of Mining Science and Technology*, *31*(3), 365–375.

[27] Ward, C. R., Crouch, A., & Cohen, D. R. (2001). Identification of potential for methane ignition by rock friction in Australian coal mines. *International Journal of Coal Geology*, *45*(2–3), 91–103.

How to Cite: Sun, Y., Li, X., & Guo, H. (2025). Estimation of the Maximum Angular Position for Cutting Roof Rock Material. *Archives of Advanced Engineering Science*, *3*(2), 67–72. https://doi.org/10.47852/bonviewAAES42022859