RESEARCH RESULTS ON MODELING AND SIMULATION OF THE CUTTING DRUMS OF A LONGWALL MINING SHEARER

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Abstract: Longwall mining shearers equipped with drum-type mechanisms have become widely applied equipment in underground coal exploitation. The constructive evolution, quality, reliability, and functional performance of these machines, influenced by technological advancements in materials and manufacturing, is nonetheless overshadowed by their adaptability to various geological and mining conditions, particularly concerning the parameters of the cutting mechanism. A judicious correlation of geometric, dimensional, kinematic, and functional parameters with the characteristics of the coal seam provides a vast field for research. For this reason, we have approached this type of equipment, with special emphasis on the working components, in a study where computer-based methods can prove their utility.

Keywords: shearer, longwall mining, cutting drum, simulation

1. LONGWALL CUTTIGN MACHINES - SHEARERS

Exploiting coal deposits under modern conditions is achieved through the use of longwall mining combines, which allow the overlapping of technological operations during the cutting process. Additionally, modern longwall mining combines, which perform both shearing and niche cutting at the ends of the longwall, reduce unproductive times. Underground mining methods have led to the development of two categories of longwall mining combines: those for longwall fronts (Figures 1 and 2) and those for shortwall or room fronts (Figure 3).

The displacement of rocks using longwall mining combines is characterized by rhythm, and continuous utilization is ideal. This aspect contributes to the improvement

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of working conditions underground and the control of mining pressure. The rhythmic (potentially continuous) operation of longwall mining combines leads to an increased utilization rate of cutting equipment as well as equipment within the transportation flow.

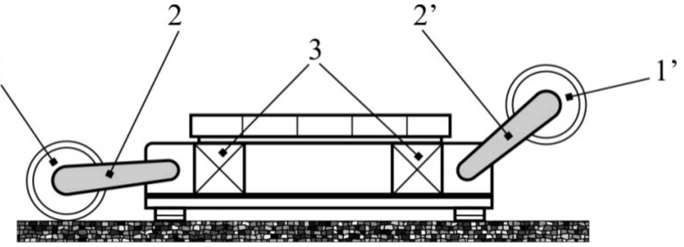

Fig. 1. Components of a Longwall Mining Shearer 1, 1’ - Drum-type cutting mechanism, 2, 2’ - Drum support arms, 3 - Electric motors driving the drums

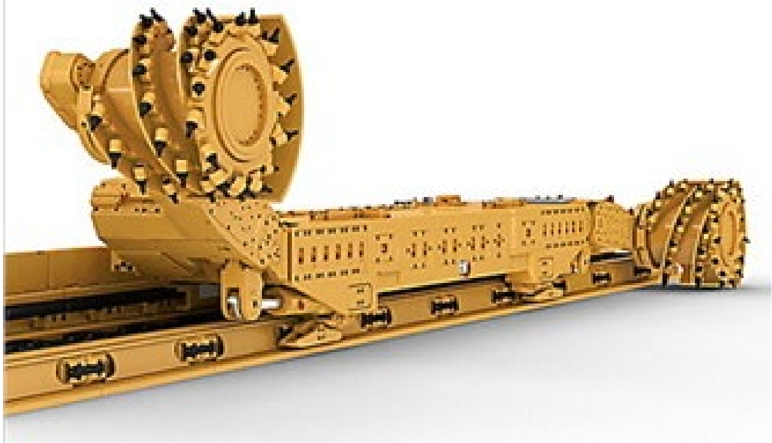

Fig. 2. Longwall Mining Shearer for large coal faces

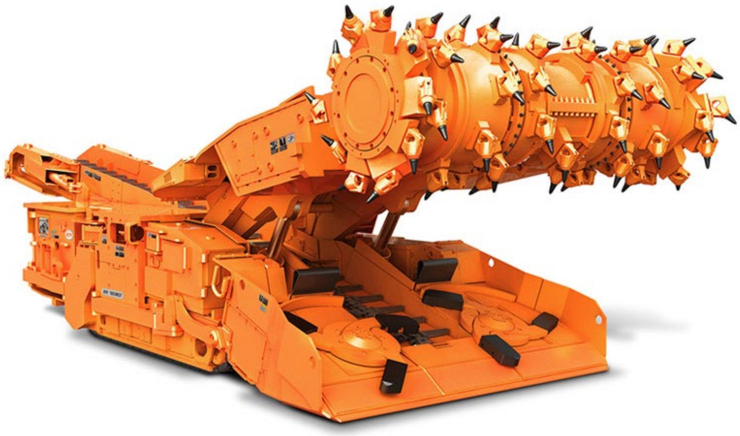

Fig. 3. Longwall Mining Combine for short fronts (Room-and-pillar/Shortwall Mining)

2. WORKING REGIME OF SHEARERS

2.1. The characteristics of the cutting regime in longwall mining sheares

It can be considered that the kinematic analysis of the movement of blades on the cutting organ of longwall mining combines will form the basis for the kinematic analysis of the movement of blades on the cutting organ of partially advancing combines.

Modern longwall mining combines have a cutting organ in the form of a helical drum. The cutting blades are arranged along the periphery of the drum in a helical curve, and due to its movement, they dislodge coal from the seam. The cutting organ performs a rotational movement around its own axis and an advancing or pivoting movement due to the longitudinal displacement of the combine along the front (Figure 4).

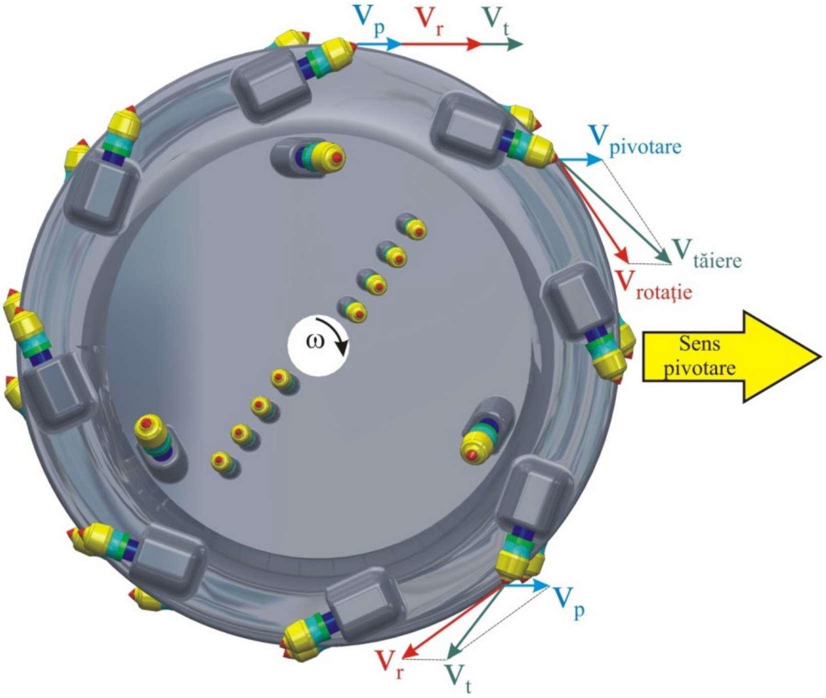

Fig. 4. Composition of tangential rotation speed with pivoting speeds

The lifespan and cutting capacity of cutting blades are influenced by the cutting speed. As depicted in Figure 4, the cutting speed is determined by composing the vector of tangential rotational speed of the cutting organ with the vector of pivoting or advancing speed of the combine. Because the magnitude of the tangential rotational speed is several times greater than the magnitude of the pivoting speed, in many situations, a good approximation can be made by considering the cutting speed equal to the tangential rotational speed.

The study of the cutting regime must take into account the specific interactions between the cutting organ and the coal seam under real operating conditions.

The kinematic study of a cutting blade mounted on a cutting organ implies that, in a plane perpendicular to the rotation axis and parallel to the advancing direction, the blade undergoes a roto-translational movement and traces a trajectory in the form of a quasi-cycloidal path (Figure 5).

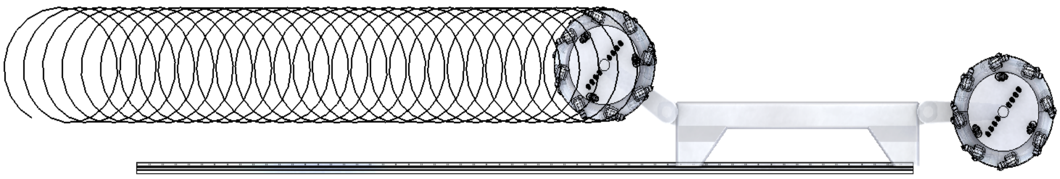

Fig. 5. Quasi-cycloidal trajectory of the longwall mining combines cutting blade

The quasi-cycloidal trajectory of the tip of a cutting blade on the cutting organ of the longwall mining combine can be described by the following parametric equation:

$$\begin{cases} x = v_a \cdot t + \dfrac{D}{2}\sin \omega t \\ y = \dfrac{D}{2}\cos \omega t \end{cases} \tag{1}$$

where:

- v_a represents the advancing (or pivoting) speed of the cutting organ;
- D is the cutting diameter (at the tip of the cutting blade);
- ω is the angular velocity of rotation of the cutting organ.

Translating the ordinate by a distance of $D/2$, then equation (1) becomes:

$$\begin{cases} x' = \dfrac{D}{2}\left(k_a \omega t + \sin \omega t\right) \\ y' = \dfrac{D}{2}\left(1 + \cos \omega t\right) \end{cases} \tag{2}$$

in which k_a is the cutting coefficient of the cutting organ, and can be calculated using the following relationship:

$$k_a = \frac{v_a}{\omega \cdot \dfrac{D}{2}} \tag{3}$$

2.2. The trajectory of the blade and the longitudinal section of the chip

As previously demonstrated, the cutting blade on the cutting organ of mining combines undergoes a quasi-cycloidal movement that depends on the cutting coefficient k_a. Depending on the values of this coefficient, the following situations can be distinguished:

- if $k_a = 0$ (because $v_a = 0$) the trajectory of the blade tip is circle;
- if $k_a = 1$ (because $v_a = v_t = \omega \cdot \frac{D}{2}$ a) the trajectory of the blade tip is a cycloid;
- if $k_a \in (0,1)$ (because $0 < v_a < v_t$) the trajectory of the blade tip is a quasi-cycloidal curve.

As observed in Figure 6, the area enclosed between two successive lines of the quasi-cycloid, located in a plane parallel to the working front, represents the longitudinal section of the chip. Considering the constant pivoting speed of the combine and the angular velocity of the cutting organ, the chip has a thickness h that varies within the range $[0, h_m]$.

At a given moment, the longitudinal thickness h of the chip is determined by the position of the cutting blade in the coordinate plane x and y. This position can be expressed as a function of the angle $\alpha = \omega \cdot t$, which can take values in the interval $[0, \pi]$.

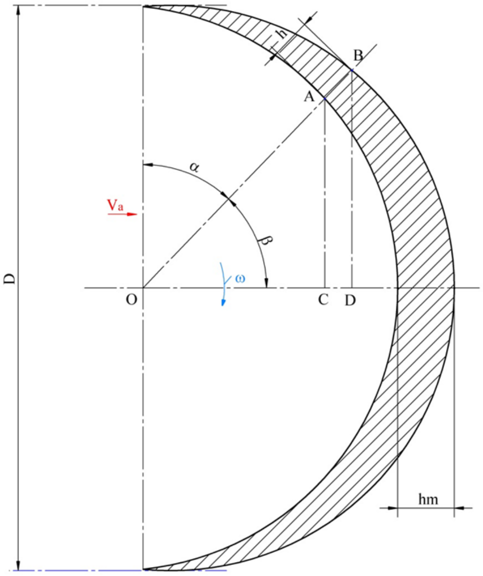

Fig. 6. Longitudinal section of the chip

Thus, the maximum thickness h_m of the longitudinal section of the chip can be expressed as a function of the advancing speed v_a of the combine and the angular speed ω of the cutting organ:

$$h_m = v_a \cdot \frac{2\pi}{\omega} \tag{4}$$

The calculation relationship for the chip thickness can be explicitly expressed, highlighting its dependence on the time variable in the form:

$$h = (h_m - h_t)\sin\alpha + \frac{D}{2} - \sqrt{\left(\frac{D}{2}\right)^2 - (h_m - h_t)^2\cos^2\alpha} \tag{5}$$

where:

- $h_t = v_a \cdot t$
- t it is the phase delay in the quasi-cycloidal motion.

Since, as previously mentioned, the cutting speed is much greater than the advancing speed ($v_t >> v_a$), we can consider in equation (5) that h_t and the expression $(h_m - h_t)^2\cos^2\alpha$ tend towards zero. Therefore, the value h of the chip thickness is expressed as a sinusoidal function of the form:

$$h \ = \ h_m \cdot \sin(\alpha) = h_m \cdot \sin(\omega t) \tag{6}$$

As seen in Figure 6, the longitudinal section of the chip has a sickle-shaped form. With the approximations made, the chip thickness is characterized by equation (6) and can take values in the in1terval $[0, h_m]$.

In the dislocation working face, the blades detach chips that have a variable section dependent on the angle α, and the surface of the cross-sectional area of the chip is characterized by the relationship:

$$S \ = D \cdot h_m \cdot \sin(\alpha) \tag{7}$$

Analyzing equation (7), it follows that during cutting, the angle α takes values between 0 and π, and the value of the ratio $\frac{h}{D}$ continuously changes, taking values between 0 and $\frac{h_m}{D}$. This causes not only the area of the cross-sectional surface of the chip to vary over time $(\alpha = \omega \cdot t)$, but also its shape.

In the situation where there are multiple blades on the cutting line, and we express the angular velocity $\omega = 2\pi \frac{n}{60}$ of the cutting organ as a function of its rotation speed n, then equation (4) becomes:

$$h_m = \frac{100 \cdot v_a}{c \cdot n} \tag{8}$$

where:

- c represents the number of blades on the cutting line for the cutting organ in question;
- n is the rotation speed of the cutting organ, rotations/minute;
- v_a is the advancing speed, meters/minute.

The instantaneous thickness of the chip can be calculated using the equation:

$$h = \frac{100 \cdot v_a}{c \cdot n} \cdot \sin(\alpha) \tag{9}$$

where $\alpha \in [0, \pi]$.

3. THE CUTTING ORGAN OF LONGWALL MINING COMBINES

In longwall mining combines, the cutting organ is a subassembly that performs the following functions:

- detaches the mined mass from the seam;
- fragments the cut mined mass;
- loads the dislocated mined mass onto the transport means.

The most commonly encountered cutting organs in longwall mining combines are helical drums (Figure 7). Compared to other cutting organs, they have the advantage of better material evacuation and loading onto the conveyor.

Fig. 7. Cutting organ in the form of a helical drum

The most commonly encountered variant of the cutting organ is the drum type, which has the rotation axis perpendicular to the pivoting plane of the mobile arm. This type of cutting organ has become prevalent due to the following advantages:

- reduced specific energy consumption;
- provides the possibility of efficient dislocation with narrow strips;
- allows for advantageous placement relative to the body of the combine;
- enables complete extraction from fronts with variable heights;
- corresponds to the movement of the combine on the conveyor;
- can ensure bidirectional cutting in continuous flow.

The most widely used construction variant of the drum is the helical drum, as shown in Figure 8. This type of drum currently equips over 80% of longwall mining combines.

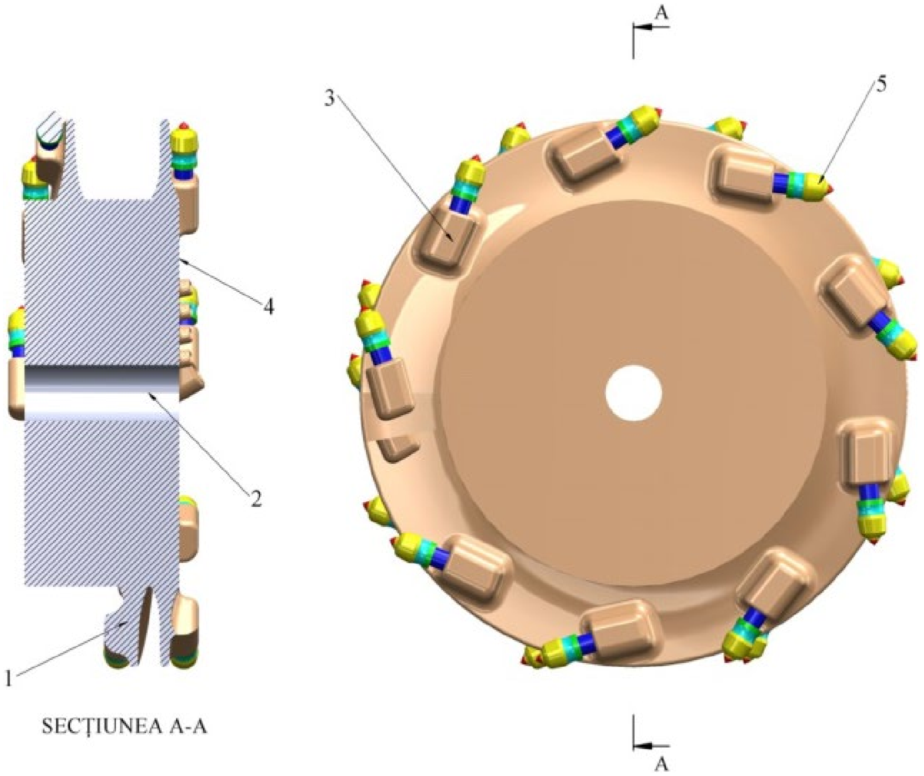

Fig. 8. Helical drum type cutting organ
1.helical body, 2. hub, 3. knife holder, 4. cylindrical drum, 5. cutting blades

The helical drum-type cutting organ, besides dislocating the material from the seam, also ensures its evacuation and loading onto the conveyor while maintaining a fine granularity of the extracted coal. It is equipped with frontal blades, allowing it to cut and advance transversely in the face, self-introducing into the seam. Thus, there is no need to cut a niche using other means to introduce the drum into the seam.

Typically, the blades are mounted in a tangential position, while the blades on the frontal and corner sides usually have a radial position. The distribution of blades on the drum must ensure a balanced load on the dislocation system, which should have variations in the drum shaft moment that do not exceed 5% of its average value. The aforementioned factors, combined with the continuous extraction process, explain the prevalence of using these drums and the integration of combines into mechanized complexes (Figure 9).

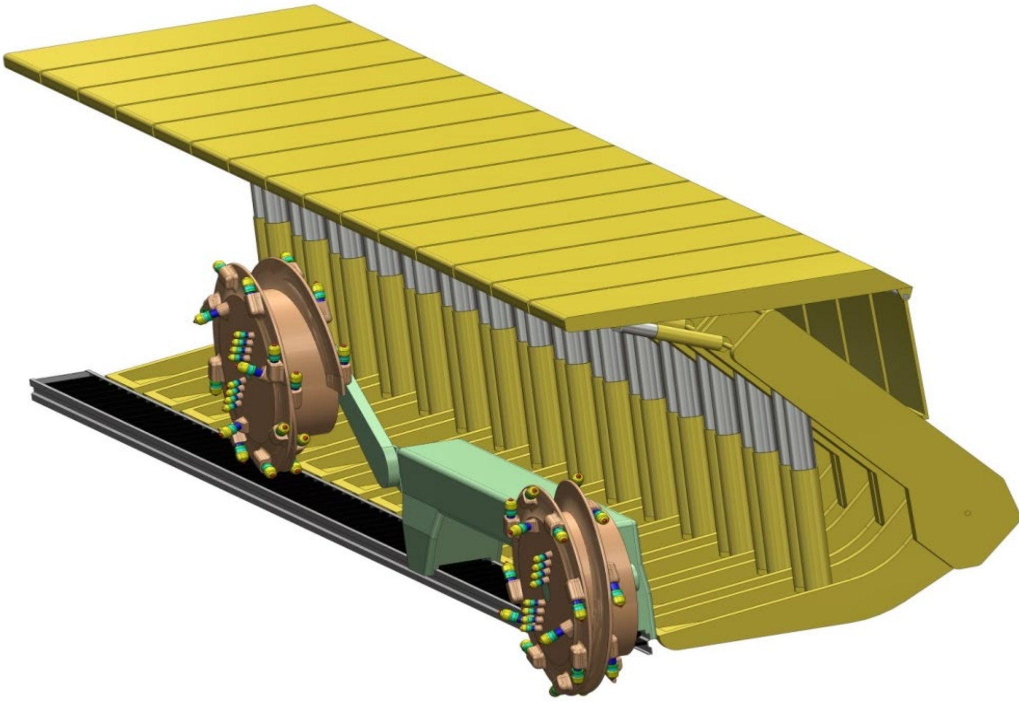

Fig. 9. Longwall mechanized face complex

The screw on the hub is wound to the left or right and can have 1-2 up to 3-4 starts. In Figure 10, models of two drums created in the SOLIDWORKS application are presented. The drums are component parts of the longwall mining combine, which is part of the assembly of the mechanized complex shown in Figure 10.

It can be observed that one drum has a left-wound screw, while the other has a right-wound screw, with a single start. The blades mounted on the drum's screw are conical and have a tangential arrangement. It can be seen that on the working face side of the drums, there are blades designed to facilitate its self-introduction into the face. During the advance of the combine, these blades reduce friction with the coal on this drum surface.

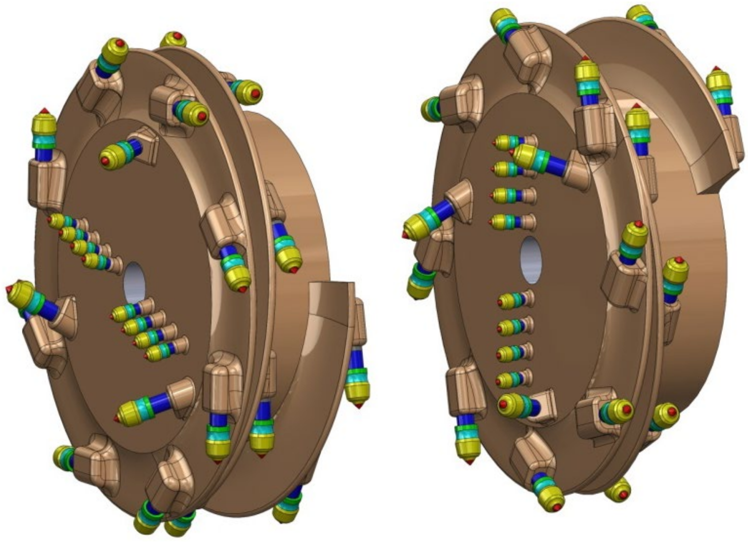

Fig. 10. Drums with left and right winding

4. CALCULATION AND SELECTION OF WORKING PARAMETERS FOR LONGWALL MINING COMBINES

For longwall mining combines, achieving high dislocation capacities with low energy consumption requires establishing correlations between the drum's shape, its dimensions, and geometric and constructive parameters. Figure 11 presents a series of geometric sizes that characterize the functionality of a drum.

Firstly, there is the outer diameter D of the working organ. This depends on the cutting diameter and the active height that exceeds the periphery of the screw of the knife-holder-knife assembly. The calculation relationship is:

$$D = D_t - 2h_c \tag{10}$$

where h_c it is the active height of the cutting blade mounted on the cutting organ.

The hub diameter or the base diameter of the screw d_h must be determined in such a way that:

- it allows the mounting of the cutting organ;
- it allows a screw height I_e to ensure the achievement of maximum output when loading the conveyor.

The calculation relationship is:

$$d_b = D - 2I_e \tag{11}$$

The width of the cut strip B establishes the advance step of the drum in the face. It influences the length of the cutting organ. Depending on the diameter of the cutting organ and its driving power, it is recommended that the width of the cut strip have values between 0,4 … 0,8 meters.

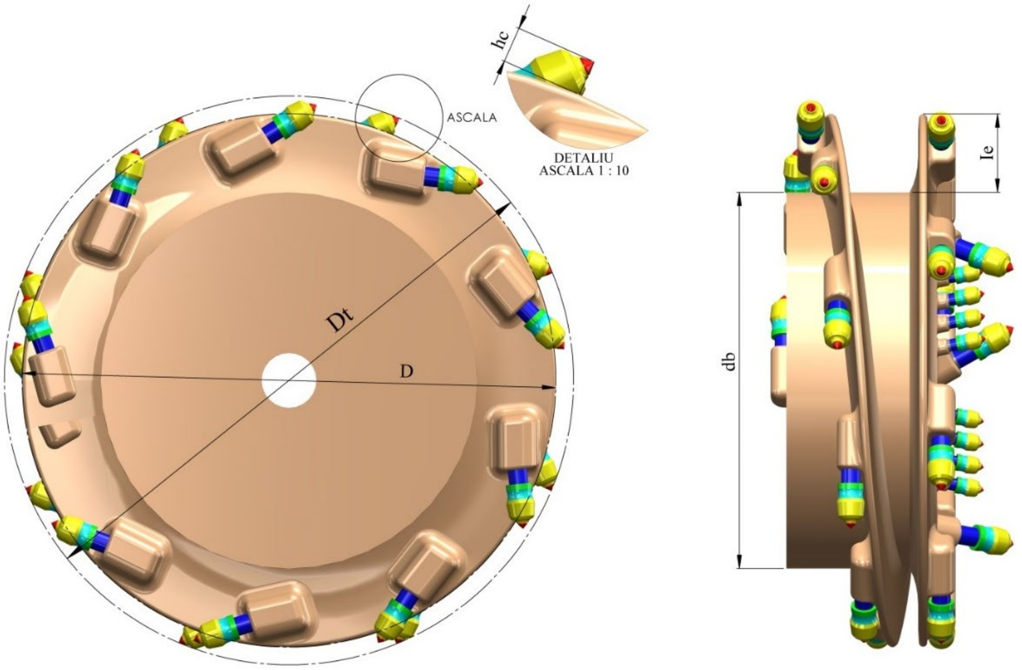

Fig. 11. Geometric dimensions characterizing the functionality of a drum

The length L of the cutting organ is determined by the width B of the cut strip. The possibility of mounting marginal knives on the screw, as well as on the frontal surface of the drum, must also be taken into account. These knives serve to prevent friction between the drum and the coal seam.

The arrangement of knives on the cutting organ with a screw is based on establishing the number of starts or the number of helical profiles generators i and the number of knives c on a cutting line.

CONCLUSION

In the presented work, various aspects related to the cutting organs of longwall mining combines have been addressed. A brief overview of longwall mining combines was provided, detailing their structure and construction based on the functionality requirements, namely the dislocation and loading of coal in longwall faces.

A study of the working regime of longwall mining combines was conducted, with a direct focus on the kinematics of the cutting organ and the interdependence relationship between its geometric and kinematic parameters and the conditions of the coal seam in which they operate.

In this regard, detailed presentations were made regarding the geometric and kinematic parameters of helical drum-type cutting organs, as well as the necessary correlations between these parameters from dimensional, geometric, kinematic, and functional perspectives.

A methodology for the calculation, selection, and verification of parameters for helical drum-type cutting organs was developed through 3D numerical modeling.

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