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COMPUTER-AIDED SUPPORT FOR THE RAPID CREATION OF PARAMETRIC MODELS OF MILLING UNITS FOR LONGWALL SHEARERS

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Abstract:
The cutting drums are the basic working components of many mining machines. The article focuses on differences in the design of cutting drums depending on the expected working conditions. Then, the unique calculation procedure is presented which allows to determine the load on the unit by reducing the forces acting on a single pick, taking into account the picks bent on the cut-off disc. Until now, this has been omitted in the literature. The results of the calculations for the selected cutting drum performed in MATLAB are also presented. The further section proposes to use Autodesk Inventor Professional's iLogic Tool for quick modelling of cutting drums. The principles of creating parameterized models and compositions using programming elements in the form of iLogic scripts are presented. The articles presented a ready-made units generator, taking into account the possibility to determine values of selected numerical parameters of the unit: diameter, web, number of patches and cutting pitch. The generator also allows you to select the type of pick holders, conical pick types, as well as the choice of pick system for repositioning or matching picks.

Key words: *cutting drums, computer-aided support, units generator, unit load, parametric modelling, iLogic, Audodesk Inventor Professional*

INTRODUCTION

Engineering design in its widest sense makes use of computer-aided work support. In mechanical engineering, software is used as a basic tool for creating virtual models, compositions, systems and documentations (CAD – Computer Aided Design). It is increasingly used to simulate phenomena, verify assumptions and concepts, and to optimize solutions (CAE – Computer Aided Engineering), as well as to produce machine parts (CAM – Computer Aided Manufacturing). However, despite the use of powerful programmes, their potential and capabilities are often only exploited to a limited extent.

Cutting drums are examples of typical, parametric engineering objects, which can be conveniently and quickly generated using the functions available in many CAD programs. This article describes the use of Autodesk Inventor Professional's iLogic tool. The creation of a parametrised automatic generator of cutting drums enables a quick obtaining of a conceptual model necessary at the stage of collision analysis or presentation of the solution to the contractor, as well as a detailed composition, which together with the related technical documentation constitutes a complete design to be implemented. The subject of parametric design with the use of various test programs is known and widely used in mechanical engineering, however, until now iLogic has not been used and cutting drums have not been parameterized [13, 14].

An important issue at the stage of selecting and designing the units is the load generated by the milling process and the demand for power. Until now, the literature has known various methods for determining the load of a knife (pick) during milling, as well as formulas for reducing the load to determine the load of a longwall shearer arm. However, these formulas did not take into account the knives swinging out on the cut-off disc, which were treated as knives on the cutting and loading part of the unit [6, 10]. In this case, the MATLAB program was used to execute scripts calculating the unit load.

In the paper [1] a wide analysis of the influence of the arrangement of radiant knives on the variability of the unit load for different parameters was carried out. Attention was paid to the need to optimize the knife system in order to obtain an even load of all tools and the lowest possible dynamics of work of the whole head.

CUTTING DRUMS

The milling units are the main elements in the milling of many machines, such as cutting shearers, rock milling machines and road and floor milling machines. Milling units are designed to mine various types of natural and artificial mineral materials. They differ in construction, kinematical and energy parameters, and these differences result from the place of their application, i.e. the type of mined material. The wide range of applications is mainly due to the possibility of implementing two processes at the same time, i.e. the process of cutting and loading.

The cutting drums of longwall shearers are designed for specific mining and geological conditions. Seemingly, the units of longwall shearers differ only in size, i.e. in diameter and web, but despite their similar appearance their parameters related to the process of loading and milling are very different. In particular, they differ in the number of patches, the angle of winding of the patches and the parameters of the knife system, such as the cutting pitch [6, 7].

The cutting process, carried out by the mining machine with the aid of cutting tools of the unit, consists in mechanical separation of rock particles from the undisturbed soil. The cutting tools are mounted in the appropriate knife holders. The most commonly used cutting tools mounted on milling units are tangential-rotary knives [6, 7].

The tangential-rotary knives, placed on the patches and on the cut-off disc, form a knife system which allows the machining process to be carried out by milling. The knives are exposed to abrasive wear due to their direct contact with the undisturbed soil. This is an unavoidable process, but the correct design of the mining unit, the appropriate selection of parameters of the milling process as well as the optimal selection of tools allow to minimize and control and predict the wear of the knives [4, 5, 8, 9, 15]. It is worth noting that a similar problem also occurs with the mining of other natural materials, such as wood [11, 12]. In both cases, steel mining tools, carbide blades and possibly wear-resistant coatings are used.

The mining units mounted on the arms of longwall shearers (Fig. 1), are designed for mining coal and rocks surrounding the coal undisturbed soil. Due to their design and working method, they are called milling augers. Regardless of the method of manufacture (welded or cast), the units are made of hub *2*, inside which there is a sleeve transferring torque from the shaft on which it is mounted. On the surface of hub *2* there are patches *4*, forming a cylindrical contour of the unit, to which the holders of cutting knives are welded *5.* The hub is usually equipped with a cut-off disc *3*, which is formed by a plate in the shape of a wheel with a specified width and diameter. Mining units used in underground mining are equipped with external and internal sprinkler systems, where in the patches of the unit and the cut-off disc there are ducts of water supply to the sprinkler nozzles, located behind the handle and knife. Sprinkling is used to reduce dust and sparks in the workplace and to increase the durability of cutting knives [5, 6, 7]. Apart from the typical auger construction, the milling units can be either drum or spatial [2, 3].

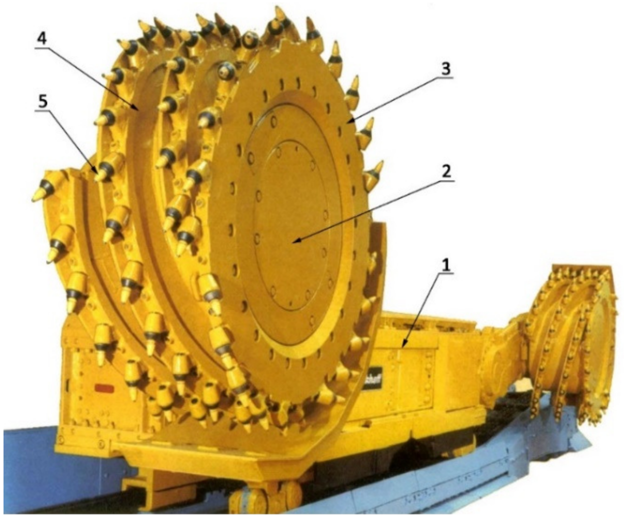

Fig. 1 Milling augers mounted on mining longwall shearer
1. longwall shearer, 2. hub, 3. cut-off disc, 4. patches, 5. grip with conical pick
Source: [7].

LOAD OF MILLING AUGERS

During the cutting process, every knife in contact with the undisturbed soil is exposed to the forces of resistance in mining process. These resistances were assumed to be represented by three forces perpendicular to each other: P_s – cutting force (tangential), P_d – pressure force (normal), P_b – side force (Fig. 2a). Mechanical cutting of fragile materials (e.g. coal) has been and still is the subject of numerous studies. To determine the components of the cutting resistance forces, an empirical model can be successfully used, which is the result of many years of research on the issues of the coal cutting process [1, 6]. During milling, the knife moves in a compound motion due to the feed speed of the machine and the rotational speed of the unit. As a result, the knife makes one cut of the shape shown in the Figure 2b. The depth of cut changes from zero to maximum and then decreases to zero again.

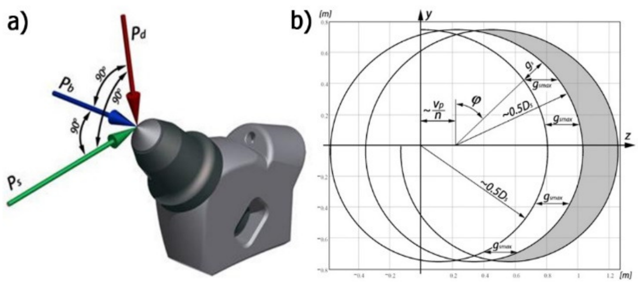

Fig. 2 Forces implied on pick (a) and pick blade trajectory on the unit during mining (b)

The formulae describing the mining resistance allow to estimate the value of forces acting on a single tool in a specific position on the unit [6]. To obtain a reduced load imposed on the unit, the following values must be determined for each knife in contact with the undisturbed soil:

$$\begin{gathered} P_x = P_s \sin(\varphi) - P_d \cos(\varphi) \\ P_y = P_b \\ P_z = -P_s \cos(\varphi) - P_d \sin(\varphi) \end{gathered} \quad (1)$$

$$M_x = -P_b z_i - [P_s\,cos(\varphi) + P_d\,sin(\varphi)]y_i$$
$$M_y = 0{,}5D_s P_s \quad (2)$$
$$M_z = P_b x_i + [P_d\,cos(\varphi) - P_s\,sin(\varphi)]y_i$$

Knife blade position:

$$x_i = 0.5D_s\,cos(\varphi)$$
$$z_i = 0.5D_s\,sin(\varphi) \quad (3)$$

A diagram of the distribution of the cutting force components on a single tool, with the length of the working part H_n, shows Fig. 3. The *xyz* coordinates system is located in the unit axis at its end (from the side of the sidewall). The x_n'yz_n'' coordinate system is rotated as a result of changing the position of the tool on the unit. This position is described by an angle φ_o The described diagram and formulae refer to the knives located on the mining and loading part of the unit, i.e. on the cylindrical surface of the unit. In addition to the knives placed on the side of the hull, the milling units are also reinforced with knives on the cut-off disc. The knife on the cut-off disc is tilted so that it protects the handle and the unit against contact with the undisturbed soil by cutting. The knife angle on the cut-off disc can exceed 45, which significantly affects the distribution of the load on the unit. Fig. 4 shows the force distribution diagram for the knife tilted by the angle φ_o, for the backward rotation of the unit. For overshop rotations, both diagrams are analogous. When creating the load diagram for the tilting knife on the cut-off disc, it was assumed that the cutting force is a tangential force acting in the direction of the blade's movement. The vectors of the pressure and side forces, on the other hand, have been deflected from the axis by an angle of φ_o. Taking into account the position of the knife on the unit, a system of x_n'yz_n' coordinates was obtained, similarly to an inclined knife. The pressure and lateral force shall be tilted by an angle of φ_o in the x_n'y plane.

After the power distribution diagram had been developed, the load reduction formulas were derived from the swivel blade:

$$P_x = P_b\,sin(\varphi_o)\,cos(\varphi) + P_s\,sin(\varphi) - P_d\,cos(\varphi_o)\,cos(\varphi)$$
$$P_y = P_b\,cos(\varphi_o) + P_d\,sin(\varphi_o) \quad (4)$$
$$P_z = P_b\,sin(\varphi_o)\,sin(\varphi) - P_d\,cos(\varphi_o)\,sin(\varphi) - P_s\,cos(\varphi)$$

$$M_x = [P_b\,sin(\varphi_o)\,sin(\varphi) - P_d\,cos(\varphi_o)\,sin(\varphi) - P_s\,cos(\varphi)]y_i \ldots - [P_d\,sin(\varphi_o) + P_b\,cos(\varphi_o)]z_i$$
$$M_y = P_s[0.5D_b + H_n\,cos(\varphi_o)] \quad (5)$$
$$M_z = [P_d\,cos(\varphi_o)\,cos(\varphi) - P_b\,sin(\varphi_o)\,cos(\varphi) - P_s\,sin(\varphi)]y_i \ldots + [P_d\,sin(\varphi_o) + P_b\,cos(\varphi_o)]x_i$$

Knife blade position:

$$x_i = (0.5D_b + H_n\,cos(\varphi_o))\,cos(\varphi)$$
$$z_i = (0.5D_b + H_n\,cos(\varphi_o))\,sin(\varphi) \quad (6)$$

The reduced unit load can be calculated by summing up the determined forces and moments acting on each tool that is in contact with the undisturbed soil.

$$P_{xo} = \sum_{i=1}^{n} P_{xi}\,,\ P_{yo} = \sum_{i=1}^{n} P_{yi}\,,\ P_{zo} = \sum_{i=1}^{n} P_{zi} \quad (7)$$

$$M_{xo} = \sum_{i=1}^{n} M_{xi}\,,\ M_{yo} = \sum_{i=1}^{n} M_{yi}\,,\ M_{zo} = \sum_{i=1}^{n} M_{zi} \quad (8)$$

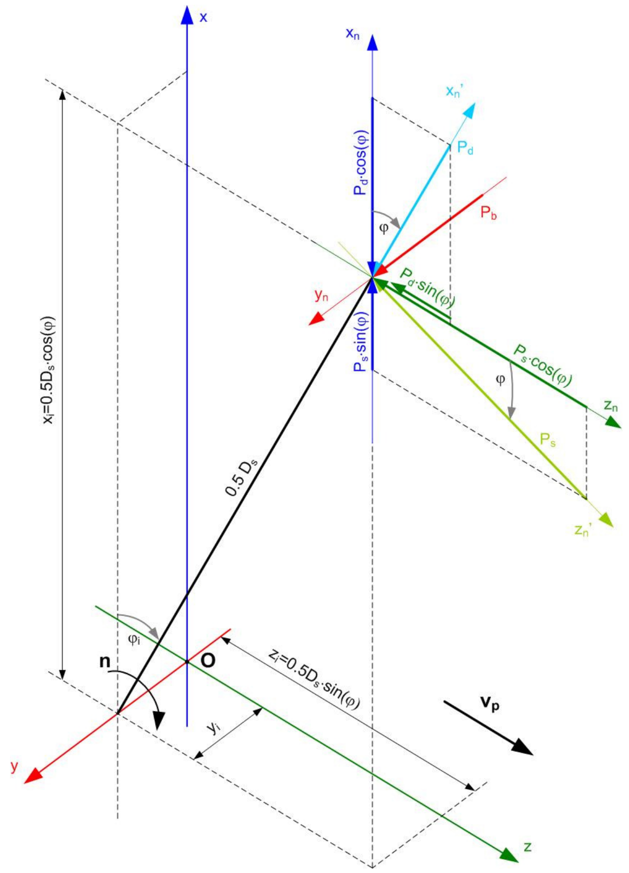

Fig. 3 Diagram of the distribution of the component forces of the cutting resistance on a single tool

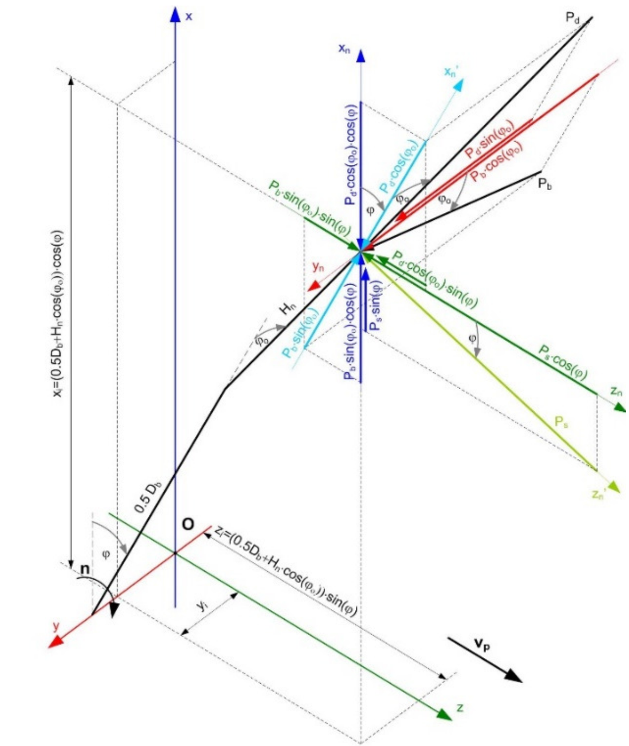

Fig. 4 Diagram of the distribution of cutting forces on the blade of a tilted knife - backward revolutions

The formulae given allow to calculate the reduced load of the mining unit on the basis of the diagram of the knife system and the assumed [6] or determined mining resistances on a single tool. On this basis, MathWorks MATLAB developed a script to calculate the desired unit load and the expected power requirement. Fig. 5 shows the reduced force and torque curves at the end of the unit shaft. The presented curves were prepared for the unit of ϕ1130x800 and the adopted kinematic parameters. The power requirement determined at the moment of cutting resistance M_y and the rotational speed of the unit n was below 120 kW.

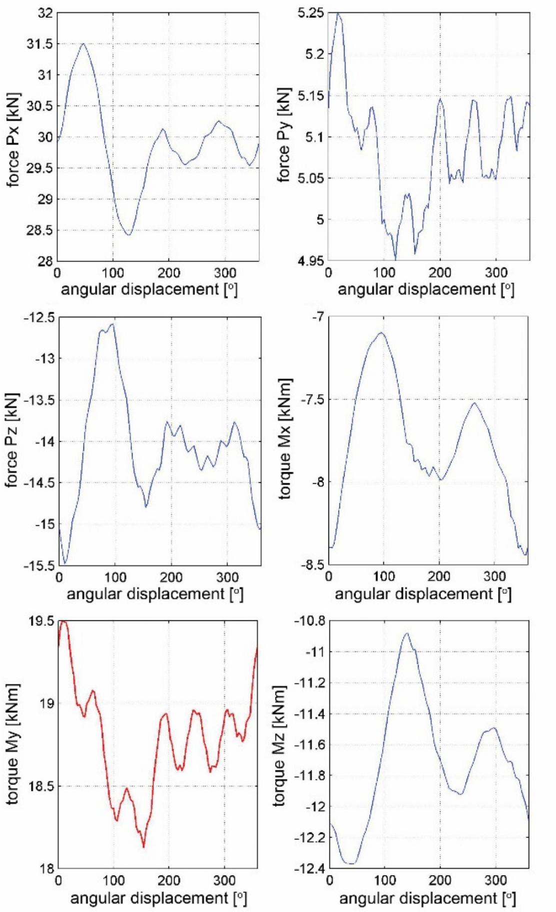

Fig. 5 Reduced load on the milling unit

The unit load and its variability depend to a large extent on the diagram of the knife system, therefore it is important to control the correct insertion of knives position into the script. The position of the knives entered into the program is used to plot the unit diagram. The control of data input consists in comparing the obtained graph with the designed knife system. Fig. 6 shows a knife system for which force and moment curves, which are relevant for the load on the mining machine, have been plotted in the drawing.

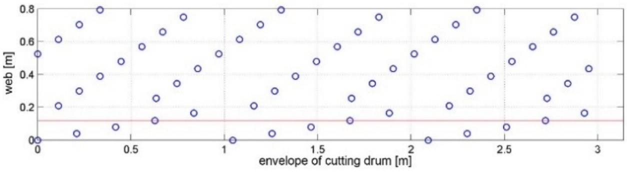

Fig. 6 Picks system of the unit generated by means of a script

GENERATOR OF MILLING AUGERS

The applications of the configurator (or in other words – the generator) of the milling units of the longwall shearer enable a quick range of solutions without additional effort. The generator first of all enables quick creation of the initial design of the unit as a hull assembly and a specific type of knife holders with the appropriate type of tangential-rotary knives. Therefore, the hull was treated as one element, as in case of cast units. Breaking the hull into individual elements is not a problem and allows to generate a detailed model for welded units.

Based on an analysis of the currently used units, the values that the user can assign to achieve the desired solution with the specified parameters have been selected. The following parameters are taken into account in this configurator together with their range of values:

- unit diameter: smooth change from 1400 mm to 2600 mm,
- spacing of the knife system: discrete values 30 mm, 40 mm, 50 mm, 60 mm,
- system arrangement: inversed or compatible (check box: yes or no),
- web (automatic change): 800 mm – for diameters up to 2000 mm, 1000 mm – for diameters from 2000 mm including 2000 mm,
- number of patches (automatic change): three for diameters up to and including 2000 mm, four for diameters from and including 2000 mm,
- type of knives and knife holders: tangential-rotary knives and appropriate knife holders according to catalogue (Fig. 7),
- number of handles and knives (automatic change) used: 48 – from 1400 mm (including) to 1700 mm (including), 52 – from 1700 mm to 2100 mm (including), 68 – from 2100 mm to 2600 mm (including),
- other automatically generated values, such as the thickness of the patches, the winding angle of the patches, the thickness of the other plates and the dimensions of fastening are in accordance with good engineering practices, but can be included as user-defined values in the generator.

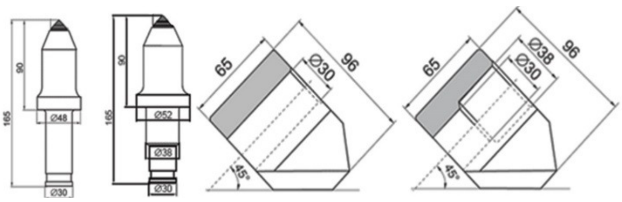

Fig. 7 Conical picks designated for the generator together with compatible grips of Gonar-Bis Ltd.

The first edition of Inventor was in 1999. The basic and most frequently used functions of the program are: 3D modelling of parts, creation of compositions consisting in adding bonds and relations between parts and creating technical documentation based on created models of parts and compositions. In addition to an advanced panel for creating complex models and a rich library with ready-made parts, Inventor is enriched year by year with new possibilities. Working on models and parametric units is possible thanks to such features as iFeature, iPart, iAssembly and iMate. However, one of the functions that is undoubtedly most developed in the context of parametric design is "iLogic". The principle of iLogic operation is to create rules that define logical conditions, equations, and automated routine actions within a part, composition, or drawing of a technical documentation. By creating a simple script and using appropriate operators, you can influence the parameters and features of a given object using an intuitive form. This feature allows you to standardize and automate design by creating models, compositions, and documentation in a parametric manner, as well as reusing work that you've previously done without creating them for iLogic purposes.

iLogic consists of several functions, where the basic one is "*Add Rule*". This function allows you to name a new rule and then create its content for selected parameters of the automated design using templates of codes sorted in appropriate categories (Fig. 8). The second essential feature of the iLogic tab is the "*iLogic Browser*", which is used to edit all the created rules, to enable or disable them and to change the order.

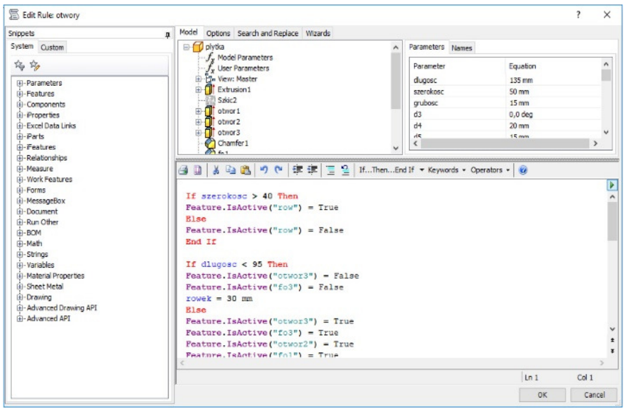

Fig. 8 "Add rule" function window in iLogic

The "*forms*" tab is crucial for the future user of the configurator, because it is used to create the menu of parameters and options selection. The menu is created using standard elements such as buttons, sliders, selection fields and text fields. In addition, it is possible to change the appearance by adding a picture, changing the fonts and colours of some elements (Fig. 9).

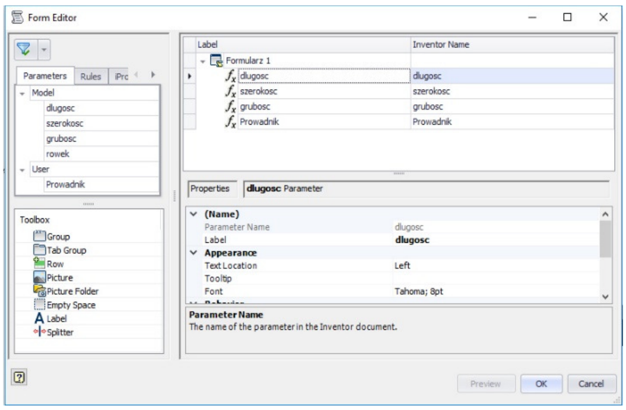

Fig. 9 Menu for creating the parameter selection form

The generator is based on basic programmable elements, such as commands of "*if... then..*", *else*, *and*, *or*, as well as turning model elements on and off. The commands are marked in violet in the code. In the developed units generator only a small percentage was used, which proves the high potential of iLogic. In addition to the mentioned commands, also the following commands of "*parameters*", "*Message.Box*", "*iLogicVb.RunRule*", "*Component.Visible*" are used to create the configurator. Selected parts of the code are shown on Fig. 10. It has to be noted that this configurator required to prepare 16 rules.

```
If Średnica_organu >= 2000 Then
d70=90
d72=90

Else If Średnica_organu < 2000 Then
d70=120
d72=120

End If
If Średnica_organu <=2600 And Średnica_organu > 2100 Then

Component.Visible("Uchwyt 2 na tarczę odcinającą:1") = 1
Component.Visible("Uchwyt 2 na tarczę odcinającą 2:1") = 1
Component.Visible("Uchwyt 2 na tarczę odcinającą 3:1") = 1
Component.Visible("Uchwyt 2:1") = 1
Component.Visible("65:1") = 1
Component.Visible("65:2") = 1
Component.Visible("65:3") = 1
Component.Visible("65:4") = 1
Component.Visible("52:49") = 0

Parameter("Uchwyt 2:1", "dopasowanie_do_kadłubu") = (Średnica_organu - 2*Parameter("Kadłub:1", "głębokość_ustawienia_noża"))/2

Parameter("Uchwyt 1:1", "d21") = (Średnica_organu - 2*Parameter("Kadłub:1", "głębokość_ustawienia_noża"))/2

Parameter("Uchwyt 2 na tarczę odcinającą:1", "d33") = (Średnica_organu - 2*Parameter("Kadłub:1", "głębokość_ustawienia_noża"))/2

Parameter("Uchwyt 2 na tarczę odcinającą 2:1", "d39") = (Średnica_organu - 2*Parameter("Kadłub:1", "głębokość_ustawienia_noża"))/2

Parameter("Uchwyt 2 na tarczę odcinającą 3:1", "d42") = (Średnica_organu - 2*Parameter("Kadłub:1", "głębokość_ustawienia_noża"))/2

Parameter("Uchwyt 1 na tarczę odcinającą:1", "d33") = (Średnica_organu - 2*Parameter("Kadłub:1", "głębokość_ustawienia_noża"))/2

Parameter("Uchwyt 1 na tarczę odcinającą 2:1", "d39") = (Średnica_organu - 2*Parameter("Kadłub:1", "głębokość_ustawienia_noża"))/2

Parameter("Uchwyt 1 na tarczę odcinającą 3:1", "d42") = (Średnica_organu - 2*Parameter("Kadłub:1", "głębokość_ustawienia_noża"))/2
If Średnica_organu < 1400 Then
MessageBox.Show("Podany organ nie mieści się w granicy generatora - zostanie wygenerowany najmniejszy z możliwych (1400mm).", "Uwaga!")
Średnica_organu = 1400

Else If Średnica_organu > 2600 Then
MessageBox.Show("Podany organ nie mieści się w granicy generatora - zostanie wygenerowany największy z możliwych (2600mm).", "Błąd")
Średnica_organu = 2600

End If
```

Fig. 10 Sample code fragments of the configurator of cutting drums

In case of the unit generator, its model consists of three basic parts: the hull, different types of knife holders and tangential-rotary knives. However, due to its construction, and in particular the presence of a variable number of patches, modelling and creation of the composition is complicated (Fig. 11). The Figure 12 shows the chosen form windows and the complete auger unit.

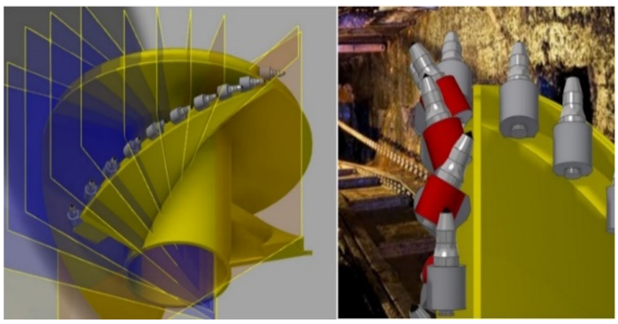

Fig. 11 Sample shots from the creation of a milling unit composition

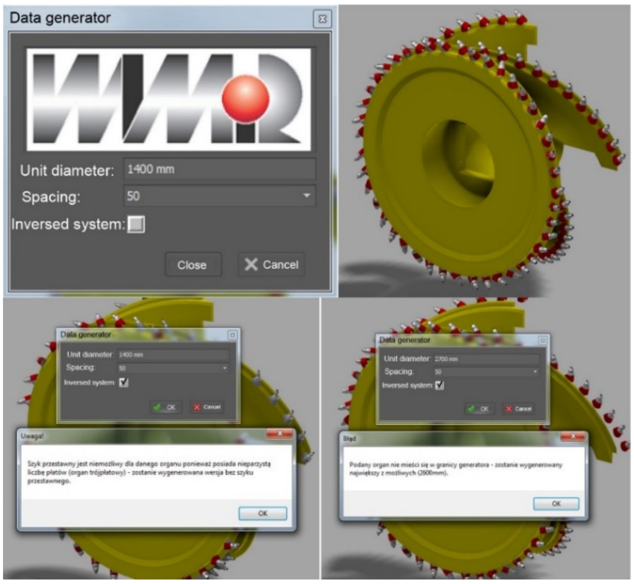

Fig. 12 Selected generator windows and messages

SUMMARY

Quick creation of solutions in the form of a concept or preliminary design is very important for the preparation of an offer for a potential customer in a short time and without unnecessary effort. At the same time, it is important for the milling units to know the expected load on the mining machine and the power requirement.

The generator has a wide range of application opportunities. For the example presented, it is possible to generate several dozen different milling units (Fig. 13). The generator is fully customizable and allows for almost unlimited expansion of the abilities by increasing the range of parameter values, adding more parameters and enlarging the base of tangential-rotary knives and handles.

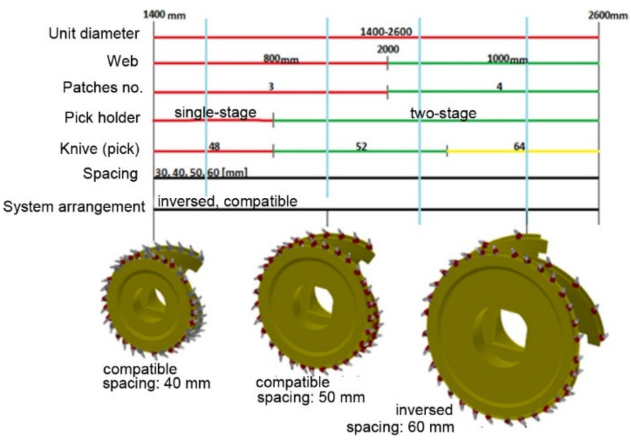

Fig. 13 List of parameters changed during the generation of an unit

Developed and verified formulae including the knives tilted on the cut-off disc allow to determine the reduced load of the milling unit and the power demand. The created script presents the variability of individual curves during one rotation of the unit, which allows to estimate the variability of the load and the dynamics of the process.

It should be noted that the presented methodology allows for the development of analogical generators for linear pavement units, floor milling machines or road milling machines.

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