PARAMETRIC DESIGN USED IN GENERALIZED MODELS OF CUTTING TOOLS

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Abstract: *The article deals with parametric design used for generation of generalized CAD models in connection with an Excel databases. The association of the CAD-database environment leads to the creation of models with multiple versions generated by parameters taken from the database or parameters calculated or chosen from values provided by catalogues or derived from design experience. Thus, the CAD model is customized by choosing various values of the dimensional parameters. Moreover, the generalized model contains 3D entities that belong to its various versions. They can be activated or deactivated depending on the desired version. The concept is applied and validated for a case study in the case of the parametric design of the generated model of a disc milling cutter.*

Key words: *disc milling cutter, CAD model, CAD parameters, calculated parameters, database, model versions.*

1. INTRODUCTION

Historically, the creation of the geometry of parts and assemblies in mechanical engineering can be done using two possible methods (corresponding to the specific software), namely in nonparametric and parametric CAD systems. The sub-classifications of the two systems are presented in Fig. 1 [1].

The most common method involves constraints only at the 2D level, at the sketch level. These are used for 3D operations (3D history) to create entities called features, characterized by parameters. Changes can be made both at the 3D entity level and at the sketch level followed by updating the model.

3D variational design involves applying constraints at the 3D modeling level [2].

Parametric catalogues of a part family allow pre-defining the shape of a part determined by some key dimensions. The use of this approach requires a parametric model and a table with key, calculated or constant parameters or other externally provided information [3].

In many fields, one can find constructions based on characteristic shapes or stereotyped shapes that can be predefined and saved in libraries [4, 5].

Parametric modelling has become a common three-dimensional modelling tool in many fields where virtual models are needed to eliminate real or reduced-scale models that are expensive and time- and resource-consuming. Parametric design is a different concept from classical design. It is mainly characterized by providing the user with an internal model database that contains named dimensional parameters and the possibility to
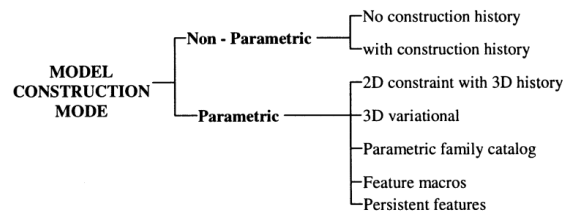

Fig. 1. Types of CAD model construction modes [1].

change their values with the updating of the model, but also to create mathematical relationships between them.

Moreover, the parameterization can also be extended to the level of geometric relations between 2D elements (at the sketch level) but also 3D (at the 3D model level). These constraints can be made visible/invisible or deleted. In addition, there is the possibility of recording in the model tree of all created entities, and relationships with other entities. Each entity can be edited and made active or inactive.

Using an external database (e.g. Excel) and connecting it to the internal database of the model can lead to the creation of a number of variants of the model. These variants can have sizes in a certain range. A correlation of the model's internal parameters with the parameters in the database must be made. In the Excel file, information zones corresponding to different geometric types of the model can be created.

The purpose of this paper is to demonstrate the power of parametric modelling by integrating a database, using Microsoft Excel, that contains the parameters of a type of cutting tool and which will be linked to the generalized 3D model of the cutting tool made in Inventor Professional. To create the model, a 3D model of a disc cutter was represented and the parameters were entered in Excel file to be able to obtain different versions of the model by changing the diameter, thickness, height of the teeth, the size of the hub and the angles that belong to the functional geometry.

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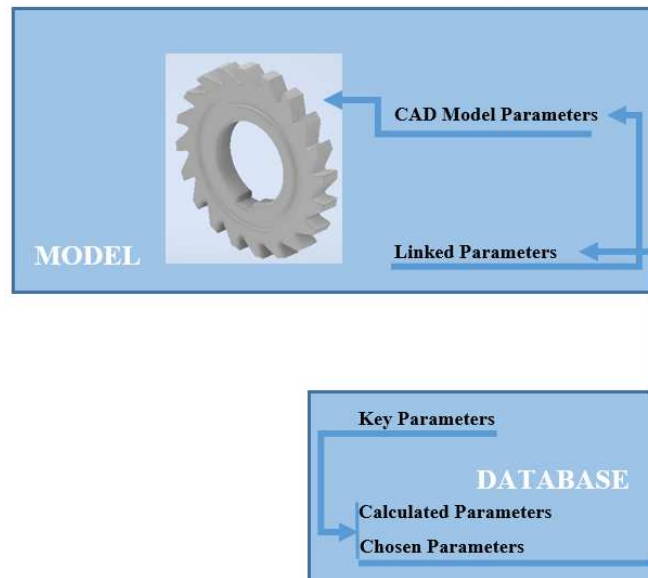E-mail addresses: *george.constantin@icmas.eu* (G. Constantin).

Fig. 2. Parameter correlation between CAD model and database (adapted after [6].

2. PARAMETRIC DESIGN CONCEPT AND DATABASE INTEGRATION

The materialization of the principle of integrating the parameters of a generalized CAD model with the corresponding parameters from a database can be achieved as follows [6, 7, 8] (Fig. 2):

1. Generation of the basic sketch that is transformed into a 3D entity through a specific process (extrusion, rotation, etc.).
2. Next is the creation of other 3D entities specific to the construction.
3. An external calculation file is generated in which the basic design parameters and the calculated parameters are entered, which will have a name and a mathematical expression based on key ones or which can be chosen based on the design experience from lists of numerical values.
4. The connection is made between the database and the model parameters table, after which the user parameters table belonging to the model is generated.
5. Correspondence is made between each parameter of the CAD model with the corresponding parameter chosen by name from the table with the user's parameters.
6. Values of named parameters from the database can be changed by updating the shape and dimensions of the CAD model.
7. If necessary, 3D entities can be activated or deactivated to create one of the constructive variants.

3. PARAMETERS USED IN THE CONSTRUCTION OF THE DISC MILLING CUTTER

3.1. Constructive aspects of the milling cutter

Disc milling cutters are cylindrical or cylindrical-front milling cutters with a small width in relation to the diameter. According to the distribution of the teeth, they are distinguished [9]:

- Milling cutters with a one row of cutting edges arranged on the cylindrical surface;
- Milling cutters with two rows of cutting edges, arranged one on the cylindrical surface and one on the frontal surface;
- Milling cutters with three rows of cutting edges arranged one on the cylindrical surface and the other two on the two front faces.

The disc milling cutters are with a holder (Fig. 3) for diameters between 4 mm to 45 mm and with a bore with diameters from 30 mm to 1000 mm (Fig. 4).

Disc milling cutters can be block made entirely of high-speed steel, with the active part of high-speed steel and the tail (body) of construction steel, they can be reinforced with metal carbide plates glued or mechanically fixed. The arrangement of the teeth can be straight (axial), for milling cutters with one or three rows of teeth, inclined on one side for milling cutters, for disc milling cutters with two rows of cutting edges and zigzag for milling cutters with three rows of cutting edges.

The case study is done for a disc milling cutter with a single row of cutting edges. The basic parameter is the outer diameter D [mm]. There are a number of parameters calculated or chosen from design recommendations such as [9]:

The outer diameter D and width B are determined according to needs:

D = 30–100 mm;
B = 3–20 mm;
Inside diameter – d = 16–32 mm;
Number of teeth (for bore cutters) – $Z = (2$–$2.4)\sqrt{D}$;
Angular pitch – $\delta = 360/Z$;
Linear pitch – $p = D\cdot\sin\delta /2$;
Shape of the teeth is with a flat back having an angle – ν = 55°–60°;
Tooth height – $h = (0.4$–$0.5)\, p$;
Fillet radius at the tooth root – r = 1.5–2 mm;
Width of the clearance facet for the bore cutters – f_1 = 0.8–2 mm;
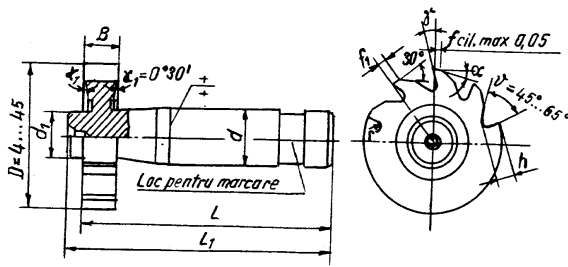
Fig. 3. Disc milling cutter with tool holder.
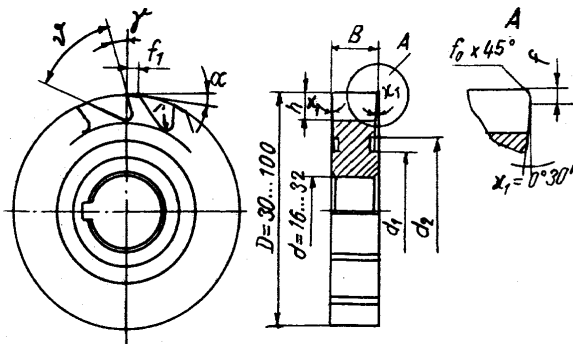

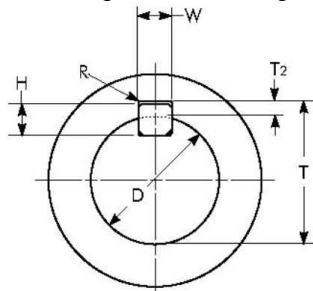**Fig. 4**. Disc milling cutter with one edge and bore.

Fig. 5. Keyway dimensions (where $T = D + T_2$).

Table 1

Keyway dimensions for shaft diameter d = (16–32) mm

Shaft diameter d [mm] over	Key width W [mm]	Key Height H [mm]	Keyeay Width W [mm]	Keyway Depth (max) T2 [mm]	Keyway Radius (max) [mm]
10	4	4	4	1.9	0.16
12	5	5	5	2.4	0.25
17	6	6	6	2.9	0.25
22	8	8	8	3.5	0.25
30	10	10	10	3.5	0.40

Clearance angle at the tooth tip – α = (4–8)°;
Rack angle at the tooth tip – γ = 5–15°;
An angle κ_1 = 0° 30' is provided to reduce the friction of the front surfaces during cutting, but near the peaks the side faces are preserved f = 1–1.5 mm with κ_1 = 0°.
The keyway dimensions are shown in Fig. 5 and detailed in Table 1.

3.2. Generalized CAD model

In order to ensure the level of generalization of the model from the point of view of the dimensional parameters, a basic sketch is made that contains the approximate graphic elements of the tooth profile, but also of the milling cutter body on approximately one angular step. Because the connection at the bottom of the tooth is a connection between the clearance surface of the current tooth and the back surface of the adjacent tooth, the represented area expands (see dark area, Fig. 6,*a*). During a subsequent 3D generation (extrusion followed by circular pattern) for the multiplication of teeth, the overlap of volumes does not appear to be a problem, because the program automatically removes the overlapped volumes.

A different way of considering the basic sketch is to consider a cylindrical body of the milling cutter, and a sketch containing the profile of the gap between two consecutive teeth (Fig. 6,*b*).

It can be observed that no dimensions are placed on the sketch, with the exception of the two which are mandatory for the representation (angular step and connection radius) but which will be modified later together with the other parameters (subsequently inserted in the sketch).

It should be noted that the introduction of the dimensional parameters in the sketch would be done as much as possible in the order of the calculation steps of the calculated parameters. The parameters in the *Parameters* table should be accompanied by a comment representing the name of the parameter (Fig. 7). This will make a connection between the default name of form $\underline{d}_n$ received through the program, and the name suggested in *Comment* column. Similar parameter names should be found in the Excel spreadsheet that will be associated with the CAD model.

Another requirement is to introduce 2D elements and 3D ones which are note dependent through constraints one to the other in order to keep the model able to be updated when design parameters are changed.

One proceeds to the 3D modelling corresponding to a tooth (Fig. 8,*a*) or a gap between teeth (Fig. 8,*b*), both generated on an angular step.

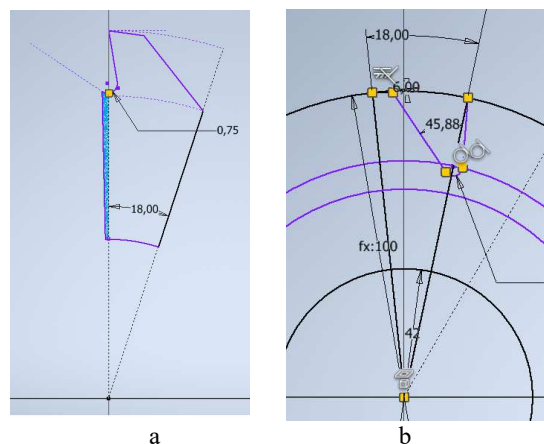For the complete generation of the milling cutter, a circular pattern multiplication is performed with a

a   b

Fig. 6. Basic sketch on an angular pitch: *a* – tooth and body; *b* – gap between teeth.

Fig. 7. Default name and explicit name of the CAD model parameters.

number of items equal to the number of teeth calculated in the database (*Numberofteeth*) and the wheel axis identical to the axis of the cutting tool (Fig. 9, *a* and *b*).

Modelling continues with the creation of 3D entities specific to the construction. The annular clearance on the faces of the milling cutter is modelled (Fig. 10, a and b). This has a particular aspect, namely that the maximum diameter must be below the foot of the tooth. Width and depth can be constant or chosen from a list of several values.

The lateral bevelling of the tooth with the angle κ_1, in order to have a general character, is done starting from a sketch in an axial plane that also contains the tips of the tooth profile (Fig. 11). The triangular area used for cutting is based on a tip of the blade and is attached to the outer circle of the annular clearance. In this way, it changes both with the outer diameter of the milling cutter and with the outer diameter of the clearance.

Other features created to define the model are keyway profile (Fig. 12), tooth chamfering at picks (Fig. 13) and chamfering of hole edges (Fig. 14).
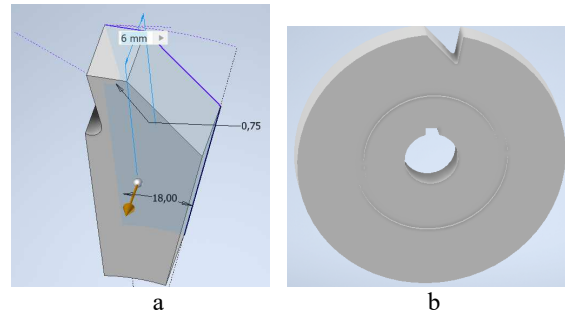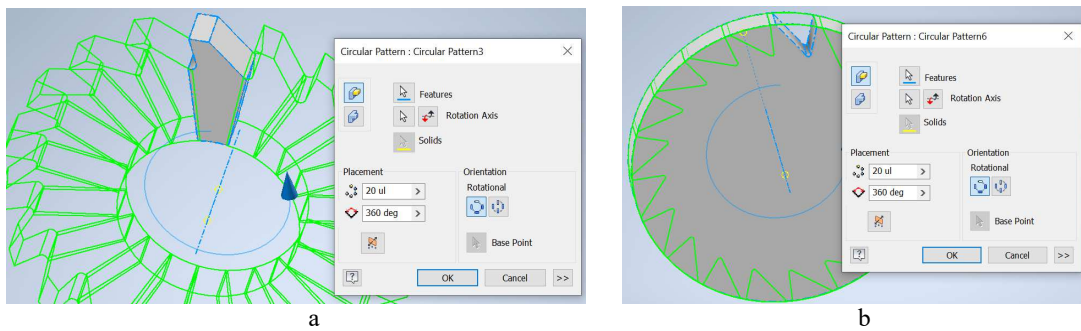

Fig. 8. Tooth and body model generated based on sketch.

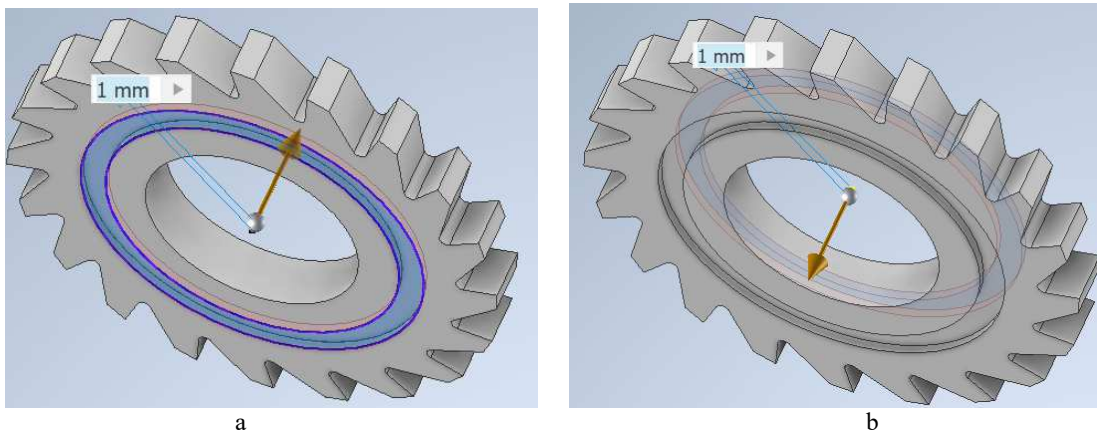**Fig. 9**. Tooth multiplication (circular pattern).
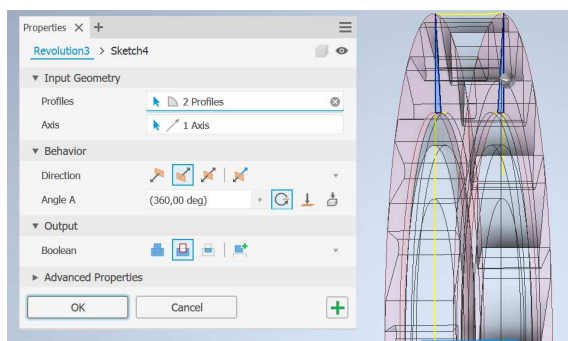

Fig. 10. Groove generation on both sides.

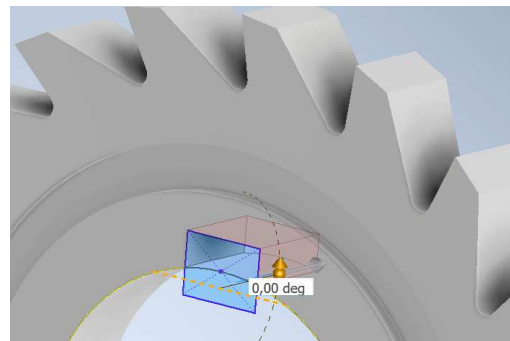**Fig. 11**. Side inclination of the tooth on both sides (revolve).

Fig. 12. Keyway profile generation (extrude).
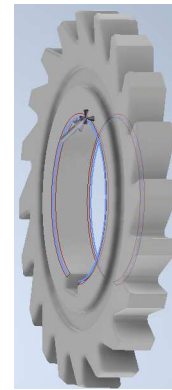
Fig. 13. Tooth chamfering at picks.

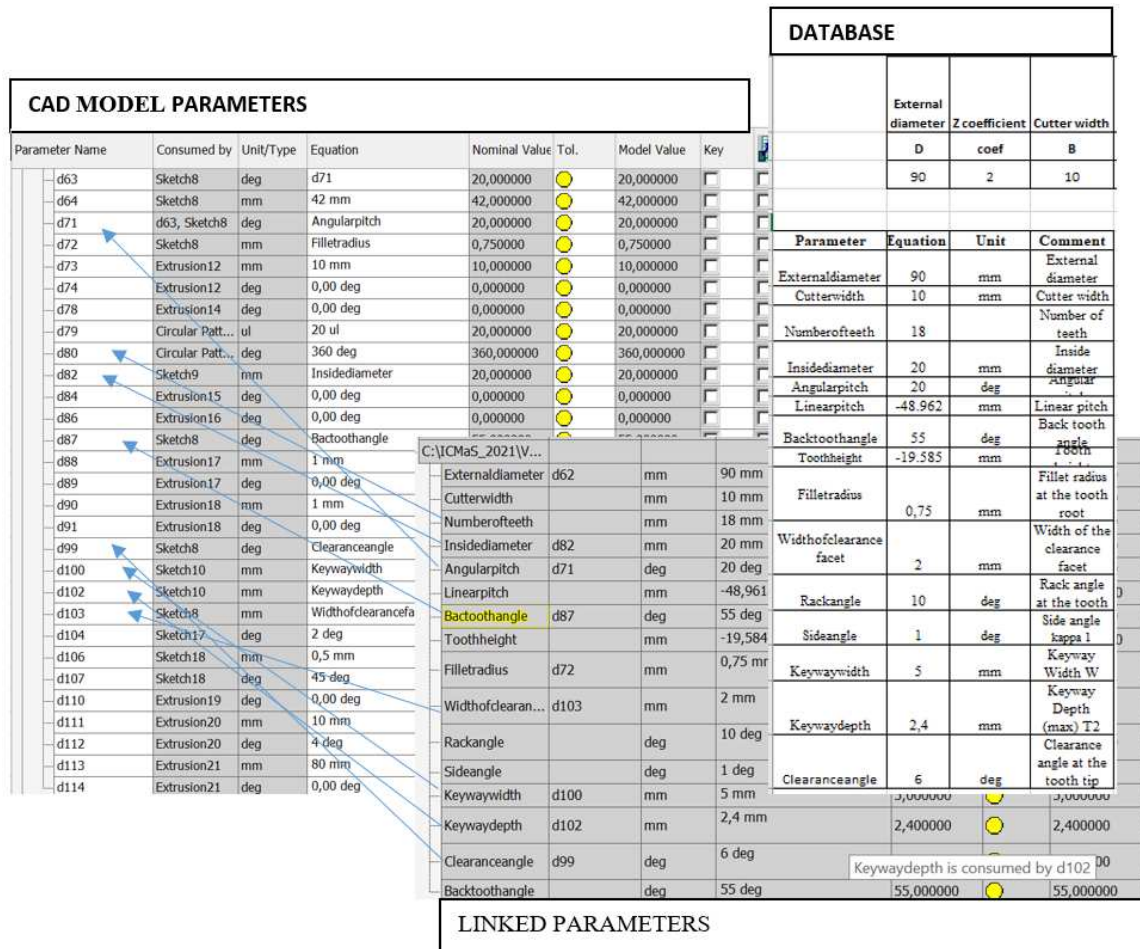**Fig. 14**. Chamfering of hole edge.

Fig. 15. Particular application of integration concept to disk milling cutter CAD model and database.

The model on which the case study was made is the one created based on the sketch of the gap between the teeth. The seven stages exposed in Chap. 2 and partially described previously have been completed. The Excel file with the basic, calculated and constant parameters correlated with the model parameters through the link parameters after connecting the database with the CAD model are represented in Fig. 15.

By changing some parameters in Excel spreadsheet obtains variants of the milling cutter model. For example, by changing the basic parameter *D* (*Externaldiameter*)

the variant of the CAD model is achieved as Fig. 16 shows for $D = (90, 150)$ mm. Figure 17 shows the variants of the tooth shape for changing the clearance angle (*Clearanceangle*) $\alpha = (4, 6, \text{and } 8)°$. The variation of the cutter width for values $B = (10, 15, 20)$ mm is shown in Fig. 18.

By activating some features of the model, it can become another constructive variable, such as the elements of the milling cutter's holder. The design is becoming a milling cutter with a holder, instead of one with a bore (Fig. 19).
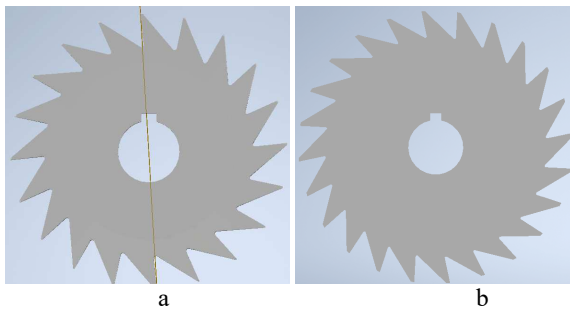
Fig. 16. Examples of model variants obtained by changing parameters: $a – D = 90$ mm ($Z = 20$); $b – D = 150$ mm ($Z = 24$).
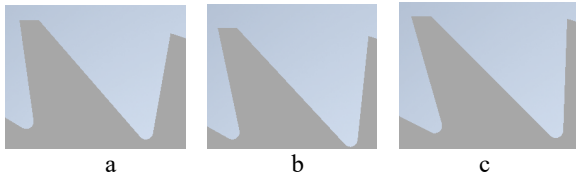

Fig. 17. Variants of the tooth shape for clearance angle modification: $a – \alpha = 4°$; $b – \alpha = 6°$; $c – \alpha = 8°$.
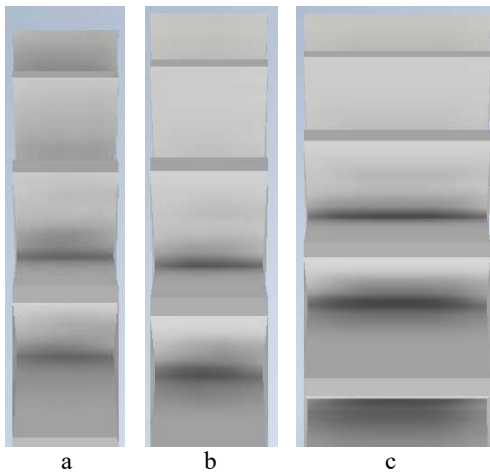

Fig. 18. Variation of milling cutter width: $a – B = 10$ mm; $b – B = 15$ mm; $c – B = 20$ mm.
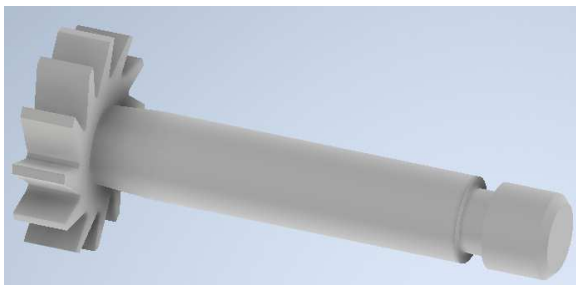

Fig. 19. Changing the tool type to a design having holder ($D = 40$ mm, $Z = 12$).

4. CONCLUSIONS

The presented concept allows, based on a generalized model (in the studied case – a mono-block disc cutter) to generate dimensional variants very quickly and with minimal efforts.

For the construction of the disc cutter studied, by changing some parameters starting with the outer diameter, the number of teeth (limited by the diameter), the thickness of the cutter, etc., dozens of dimensional-constructive variants can be generated based on the same generalized model. The lists of values of some parameters can be modified by adding new values, adding new parameters, etc.

An advantage of such a CAD-Database concept is that the system is open for changes, updates or even for the introduction of requirements of some beneficiaries into the system.

The model can be adapted to a new constructive variant, that of the milling cutter with metal carbide inserts by changing the gap between two teeth in order to create a shaped place for the insert. Of course, the transition is made from the model of a component to the model of an assembly consisting of a body and inserts soldered or even mounted by screws.

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