Parametric Modeling of Gear Cutting Tools

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Abstract. A toolkit of parametric modeling in the application to the tasks of designing and studying a gear-cutting tool operating according to the contour machining method and the generating method is proposed. Specialized programs for constructing parametrized profiles of a disk-type gear milling cutter and a gear-cutting hob for machining gear wheels and spline shafts have been developed. Construction procedures of specialized graphic primitives for modeling a rack contour, an involute and spline profile, and a transition curve of the milling tooth flank surface have been proposed. The program of parametric modeling introduces a method for verifying permissible variants of the non-working part contours for the mill profile, by taking into account restrictions in the form of a message variable. The features of the parametric profiles interaction in the 2D-graphics editor APM Graph with the subsequent export to the 3D-editor APM Studio are considered. Three-dimensional solid models of disk-type gear milling cutter and a gear-cutting hob in the APM Studio editor based on parameterized graphic primitives are built. The study of the stress-strain state of the tooth cutter by finite element method is performed.

Keywords: Parametric modeling · Gear cutting tools · Graphic primitives · Tooth contour · 3D model

1 Introduction

Modern metal-cutting tools and tool systems (TS) represent complex assembly structures, including tool storage, tool positioners, auxiliary and cutting tools. The ubiquitous transition to the multivariate design of TS and their components is associated with exceeding the normative terms for designing, and fulfilling a large amount of duplicate design activities. Similar problems arise when modeling the important properties of the cutting and auxiliary tools under study. The solution of these problems is associated with the creation of reference models and parametric modeling of graphical procedures that are flexibly set up to change the number and composition of the alternatives considered.

The parametrized 3D models libraries, orientated for designing tooling of the Bridgeport DIN 69871 type, as a component of a three-axis milling machine TS are proposed in [1]. As an auxiliary tool used arbor ISO 230 series, which correspond to the equipment of small-sized machines (first and second dimension type). As part of the machine tooling system, there is disk tool storage with 14 tool positions. There is a problem of introducing the approach proposed by the author to machines of other

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dimension type, and, consequently, creating the corresponding sets of tool storages 3D models of and rigging for them.

On the basis of the developed spindle assembly 3D model with a set of tooling for milling, new approaches that research the static rigidity field of the working space for a high-performance computerized CNC machine [2] is considerated. In the boundaries of this method, a parametric model of a shaping unit equipped with TS taking into account to six directional static rigidity for designing and evaluating its values in the scale of the machine working space has been created. The results for further discussions on the evaluation and reduction of processing errors under various loads are used.

Work [3] is devoted to the development of methods for designing metal-cutting tools using parametric 3D modeling. For each type of cutting tool, a parametric prototype is created with the same type of image fragments, which differ only in size. As geometrical interrelations, the specified angles and distances between the planes of the cutting part of the tool surface and the planes of sketches of the model being created are exemplified by a boring tool. It should be noted that for a cutting tool complex profile, the description of the relationship between graphic objects is not limited to angles and distances. So for a disk-type gear milling cutter with a module up to 8 mm, a set of 8 cutters are used, intended for cutting wheels with a certain number of teeth [4, 5]. For cutters No. 1–5, the tooth contour is outlined by a type I profile (graphic primitive I) consisting of a circular arc, straight line and evolving. A profile of type II (graphic primitive II) is characterized by another combination – a straight line segment, an arc, and an involute (cutters No. 6–8). This complicates the parametric description procedure by introducing variables such as the cutter number, type of profile, etc.

An analysis of the above work has shown that the questions of parametric models development and 3D modeling of tooling based on parametric models for machining gears have not found proper application. The specificity of the tool production objects for machining gears, which is associated with unification, a wide range of different types of cutting and auxiliary tools, makes it efficient to use the parameterization technology when creating models of TS component designs.

In modern computer aided design systems, the presence of a parametric model is embedded in the ideology of the CAD system itself [6]. The existence of an object parametric description is the basis for the entire design process. Almost all systems, such as Autodesk Mechanical Desktop, Unigraphics, CATIA, I-DEAS, etc., use one universal parameterizer of the British company – D-CUBED. The parametrizer D-CUBED, focused on 3D modeling, is ineffective in 2D drawing. The mathematics that successfully works on tens of profile lines in the 3D system sketcher can't handle with thousands of interrelated elements of drawings.

In the well-known T-FLEX CAD [7, 8], both directions were simultaneously developed and evaluated - parametric drawing and parametric solid modeling. One very useful use of parameterization is the creation of standard element libraries. The cost of creating a parameterization diagram pays off by reusing libraries.

In the well-known APM WinMachine CAD/CAE system [9–11], the expensive adopted parametrizer is not used, but its own software is implemented to create the drawing and graphic parametric editor APM Graph, which can be used both as part of the system and independently. The parametric model created in this way can be inserted into a standard drawing as a parametric unit, which is effective in the process of researching tooling. In those situations when there are a significant number of unified elements in a design that vary within a single product range, it is advisable to use a means of parameterizing these elements. The combination of parametric profiles in 2-D graphic editors with the subsequent export to the 3-D editor seems effective. Such a compromise version is constructively implemented in the well-known CAD APM “WinMachine” [10].

2 Research Problem

The task of create a specialized software package for parametric modeling of a gear-cutting tool is formulated in this article. The main emphasis will be directed on the construction of parameterized graphic primitives, on the basis of which the synthesis of the gear-cutting tool design is realized.

3 Results

Parameterization of a gear-cutting tool using the APM WinMachine toolkit is aimed at creating a specialized set of the profile: rack contour, involute profile, form-relived tooth profile, etc.

As is known, the profile and dimensions of the wheels teeth are determined by the basic rack profile and cutting contours [12, 13]. In the machine tool industry is often used a modified contour, which regulates the coefficient of the tooth addendum height h_{a0}^{*} (no more than 0.45) and the depth factor of the flank a_f^{*}.

Such a contour ensures smooth conjugating of the teeth in the process of engagement [14–16]. When creating a parametric model, one should take into account the difference in the size values of the tooth addendum height h_a (per size of the radial clearance in the gear); tooth thickness s_{n0} (increased by the amount of required backlash clearance) and the location of the flank (a_f and h_{f0}) on the root of tooth.

In the APM Graph module, parametric models of the basic rack (Fig. 1a) contours and cutting (Fig. 1b) contours (Graphic primitive “Contour”) are built.

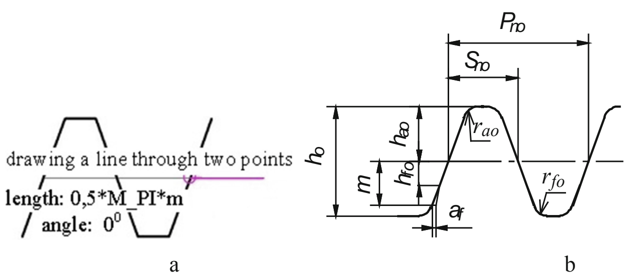
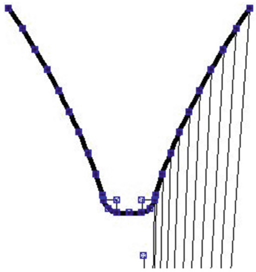


Fig. 1. Standard contour: a – basic rack profile; b – modified profile.

For a wide range of cutting tools, a parametric model of the involute tooth profile is built. It is considered as a parameterized graphical primitive "Involute profile" (Fig. 2a) using the analytical relationships in the APM WinMachine syntax (Fig. 2b).



a

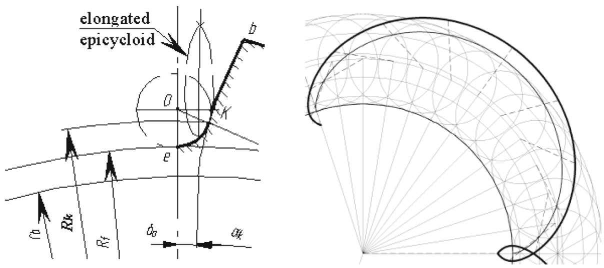
deltad	M_PI/(2*z)-2*x1*tan(rad(ad))	0.0588964806	half angular width along the pitch circle
ro0	m*z/2*cos(rad(ad))	49.3338625913	radius of base circle
invad	tan(rad(ad))-rad(ad)	0.0149043839	involution of pressure angle
delta0	(deltad-invad)*180/M_PI	2.5205614745	half angular width along the base circle
da	m*z+2*(ha+x1)*m	120	diameter of addendum
df	m*z-2*(ha+c-x1)*m	97.5	diameter of dedendum
roa	da/2+.2*m	61	polar radius of end point involut
rof	df/2+.2*m	49.75	polar radius of initial point involute
dro	(roa-rof)/(p0-1)	1.25	radius vector increment
ro1	rof+dro	51	polar radius of first point evolvent
a1	acos(ro0/ro1)*180/M_PI	14.6857942527	угол давления 1-й точки
inva1	(tan(rad(a1))-rad(a1))*180/M	0.330289647	angle involution of first point
ro2	rof+2*dro	52.25	radius of base circle
a2	acos(ro0/ro2)*180/M_PI	19.2326594845	pressure angle of second point
inva2	(tan(rad(a2))-rad(a2))*180/M	0.7564692876	angle involution of second point

b

Fig. 2. Parametric model of the involute tooth profile: a – construction; b – analytical form in the APM Graph variables window.

When profiling tools using the contour machining method, along with the involute part, it is necessary to investigate the profile of the non-working and non-involute part of the cutter, which, in turn, depends on the number of teeth of the cutting twin wheels [17–19].

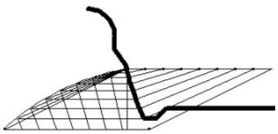
There is a known method for finding the point K defined by the radius R_k on the involute portion of the tooth profile, which is the boundary of the tooth active part profile that actually participates in the engagement. Consider the option when the radius of the base circle r_b is either equal to the radius of the root circle R_f, or exceeds it by a small amount. In this case, the radius r_b remains less than the radius R_k of the lower point of the wheel profile active part. In this case, the profile of the wheel tooth will be involute only for a distance from the addendum circle to the base circle. The segment from point K, bounded by a root circle with radius R_f, will be non-involute and will be described by a transition curve [20, 21]. In this case, a section of an elongated epicycloid (when two gears are engagement) or an elongated involute (when the wheel is rolling along the rack) is attached to point K. In Fig. 3 shows the tooth profile of a gear-cutting milling cutter with a transition curve based on a parametric model (the "Transition curve" graphic primitive).



a b

Fig. 3. The profile of the tooth cutter: a – contour profile; b – transition curve in the form of an elongated epicycloid.

When machining straight spline shafts, their profile is formed as a result of the tool bending around the spline with tool cutting edges when rolling without sliding the centroids (base straight) of the workpiece [22–24]. When constructing the theoretical profile of the cutting edge of the cutter's tooth (for machining straight-through spline shafts), a parametric model has been developed. It allows entering the “Splined profile” graphic primitive (Fig. 4).



d31		52
ds	28*(d31>25.5&d31<30)+32*(d31>=30&d31<34)+36*(d31>=34&d31<39)+4	52
d3	(ds+6)*(ds>=28&ds<=42)+(ds+8)*(ds>=46&ds<=58)	60
f	.4*(ds>=28&ds<=42)+.5*(ds>=46&ds<=58)	0.5
r	.3*(ds>=28&ds<=42)+.5*(ds>=46&ds<=58)	0.5
ds1	(ds-2.5)*(ds>=28&ds<=42)+(ds-3.3)*(ds>=46&ds<=58)	48.7
b	7*(ds>=28&ds<=36)+8*(ds>=42&ds<44)+9*(ds>=44&ds<48)+10*(ds>=48&	10
zs	6*(ds>=28&ds<30)+8*(ds>=30&ds<=59)	8

a b

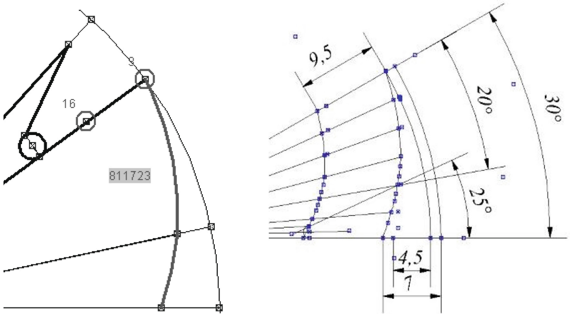
Fig. 4. Splined tooth: a – profiling diagram; b – fragment of the parametric model.

For processing complex shaped surfaces according to the generating method, a widely used form-relived tooth profile, this gives a constant and identical profile during the entire period of its operation.

In the APM Graph module, parametric models of single and double form-relived teeth profile of cutters, delineated by an Archimedean spiral, constructed as parametrized graphic primitives: “Single form-relived” and “Double form-relived” are built. In Fig. 5 shows a fragment of the program for the formation of a double form-relived tooth of a gear-cutting cutter (Fig. 5a) and the corresponding graphical plotting of the form-relived tool surfaces – single (Fig. 5b) and double (Fig. 5c).

k	ceil(M_PI*De*tan(rad(a))/z)	7	value of top sharpening
k1	M_PI*De*2*tan(rad(a))/(3*z)	4.4517	value of additional top sharpening
teta1	teta/3	10	angular pitch of the top sharpening
h	2.25*m	15.75	depth of the chip groove part

a



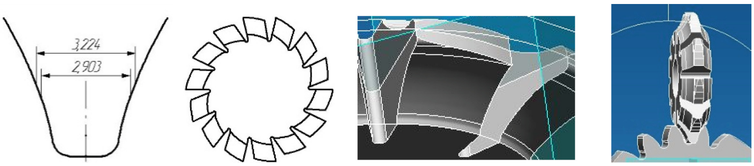
b c

Fig. 5. The profile of the form-relived surface of the tool: a – fragment of the parameterization program; b – single form-relived; c – double form-relived.

4 Discussion

The organization of a computer technology for creating tool systems is based on the formation of a complete electronic layout of a product, since it is the creation of three-dimensional electronic models that are adequate to the actually designed product, which opens up possibilities for creating better products [17]. Three-dimensional modeling is necessary as a reliable, flexible and easy-to-use tool for optimizing the design process of a complex profile tool and, finally, combining CAD/CAM tasks in the same environment [18, 19]. In situations where a design has a significant number of unified elements that vary within a single product range, it is advisable to combine parametric profiles in a 2D graphics editor and then export to a 3D editor [10].

As an example, the involute profile (graphic primitive) of a tooth for disk-type gear milling cutter (Fig. 6a) is constructed in the 2D graphic editor APM Graph; a circular array is built in the same place (Fig. 6b). It array are exported to the 3D editor APM Studio [20]. Using 3D operations in APM Studio, a three-dimensional model of the tooth is formed using the graphic primitive “Double form-relived” (Fig. 6c) and the actual disk-type gear milling cutter presented in the gear cutting diagram.



a b c d

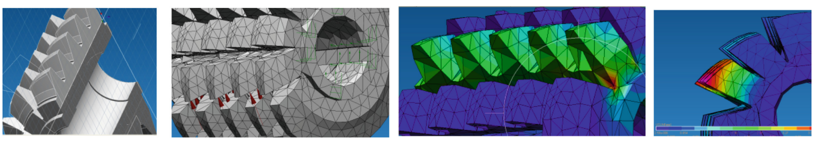
Fig. 6. The combination of 2D- and 3D editors APM: a – involute contour of the tooth; b – circular array; c – 3D model fragment; d – 3D diagram of teeth cutting.

As an example, three-dimensional models of a gear rack are shown – a graphic primitive “Contour” (Fig. 7a), a form-relived tooth of a gear-cutting hob – a graphic primitive “Single gear-cutting hob” (Fig. 7b) and a gear-cutting hob cutter (Fig. 7c) are developed in the module APM Studio.

a b c

Fig. 7. 3D models: a – toothed rack; b – single form-relived tooth; c – gear-cutting hob cutter.

In the environment of the APM Studio module, a study of the stress-strain state of a gear-cutting hob cutter (Fig. 8a) was carried out and a finite element mesh was generated with a specific partitioning step (Fig. 8b). In the finite element analysis mode, the fixings are set (displacements along the X, Y, Z axes are fixed) and forces are applied (Fig. 8b). Within the environment of the APM Studio module, a static calculation of the structure was carried out [25, 26]. The results of static calculation can be visualized in graphic and numerical form (Fig. 8c, d). Analysis of the obtained results indicates the maximum deformation at the root tooth (Fig. 8c) and the maximum displacement at the tooth addendum (Fig. 8d), which corresponds to theoretical data.



a b c d

Fig. 8. 3D modeling of a gear-cutting hob cutter: a – design; b – loading diagram; c – stress field; d – field of displacement.

Thus, in the tasks of designing a gear-cutting tool, an approach based on a combination of procedures for creating parametric profiles in a 2D graphic editor with subsequent export to a 3D editor, creating and researching a three-dimensional model of the tool design seems promising [21, 27].

5 Conclusions

1. Specialized application programs for parametric modeling of a complex-profile gear cutting tool based on the CAD APM WinMachine syntax are developed. Parametric models of the basic rack contour, the involute profile and single- and double form-relived teeth of the gear-cutting milling cutters, working both by the contour machining method and by generation method, are proposed. Developed parametrization mechanism is aimed at express analysis of the designs study for gear-cutting tool based on the constructed parametric models are used. Moreover, each new version is synthesized only by changing a limited set of source data, which reduces the time for multivariate design and the search for a rational structure.
2. Graphic primitives of contours for complex-profile gear cutting tool have been developed. Significantly increases the productivity of the designer, giving him an alternative to standard graphic primitives (line segment, arc of a circle, etc.) is a consequence of the proposed graphic primitives using. This is one of the most effective ways to improve the technical level of design decisions.
3. The proposed approach provides for the verification of permissible variants of the cutter tooth contours by entering restrictions into the parameterization program in the form of a message variable. These variables reflect the position of the non-working part of the tooth profile, with a positive distance of the transition curve from the elongated epicycloid.
4. The use of the CAD APM WinMachine parameterization toolkit makes the process of designing the gamma of a modern complex profile cutting tool a very effective procedure using the finite element analysis and solid modeling. In the environment of the APM Studio module, a three-dimensional model of a gear-cutting hob cutter was constructed and the stress-strain state of the working surface of the tooth was analyzed.

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