MODELING OF RUNNING CUTTERS FOR SHAPING OF IMPROVED NONINVOLUTE TOOTH GEARS

Tatyana **TRETYAK**[1], Yury **GUTSALENKO**[2], Alexander **MIRONENKO**[3]
National Technical University "Kharkov Polytechnic Institute", Ukraine
[1,3]Associate Professor, [2]Senior Staff Scientist
[1,3]geargroup@ukrmash.com, [2]gutsalenko@kpi.kharkov.ua

Abstract: *The questions of tooling design for production of advanced gears are considered. Engineering is based on the special applied development of the mathematical theory of multiparametric mappings of space. In fulfilled engineering of gear cutting tools for shaping of noninvolute gears it is provided for exclusion of distorted profiling after tool regrinds. There are proposed calculation algorithms, which may be used in dataware of respective CAD/CAM systems of maintenance for tooling backup. Among developed tools there are assembled shaping cutters with prismatic and round cutters. Compensatory possibilities of proposed assembled shaping cutters are ensured by repositioning of shaped cutting edges after their regrindings: by linear displacement of prismatic shaped cutters and angular displacement of round ones respectively.*

Keywords: advanced gearing, constant normal pitch, gear cutter, multiparametric mappings of space

1. INTRODUCTION

At the advanced production associations the great attention is given to creation of united information platforms and development of simulation modeling. Simulation modeling is most successfully applied in tool production as in the high technology field of machining. Proposed in this paper a model of running tools is a set of geometrical and physical-mechanical components. Shaping for such tools is carried out by surface generation method at which work and machine-tool gearings coincide. It allows to increase considerably speed and accuracy of products processing.

At resharpening of monolithic shaped gear cutter for processing of noninvolute gears the form of a cutting edge changes. Besides, the form error of tooth gear to be machined occurs due to reduction of center-to-center spacing at displacement of gear cutter. In this connection the problem of development of tools, after resharpening of which noninvolute profile of tooth gear to be machined does not change geometrically, becomes topical.

Assembled gear cutters with prismatic and round shaped cutters can be considered as the types of running gear cutting tools for generation of geometry of tooth gear with noninvolute profile. Their advantage is that the form of cutting edges is not deformed when resharpening. Displacement of prismatic cutters by the relevant distance or rotation of round cutters about relevant angle after each resharpening compensate shaped cutting edges displacement relatively gear cutter axis caused by such resharpening. Besides, proposed assembled gear cutters allow quantity of resharpenings several times as much in comparison with the monolithic ones.

2. PROFILING OF ASSEMBLED SHAPING CUTTERS

The sequence of shaping of these tools is defined by the fact that gear cutter as running tool is a set of shaped cutters (generating ones in relation to a tool surface and contacting ones in relation to a tooth gear surface to be formed) [1, 2].

The first stage of profiling of assembled gear cutters consists in finding of a tool surface as an envelope. Tooth flank surfaces of gear to be machined and tool surface of the cutting tool are profiled cylindrical ones, they are located in reference points $x_1y_1z_1$ and $x_2y_2z_2$ (fig. 1, example for assembled gear cutter with prismatic shaped cutter).

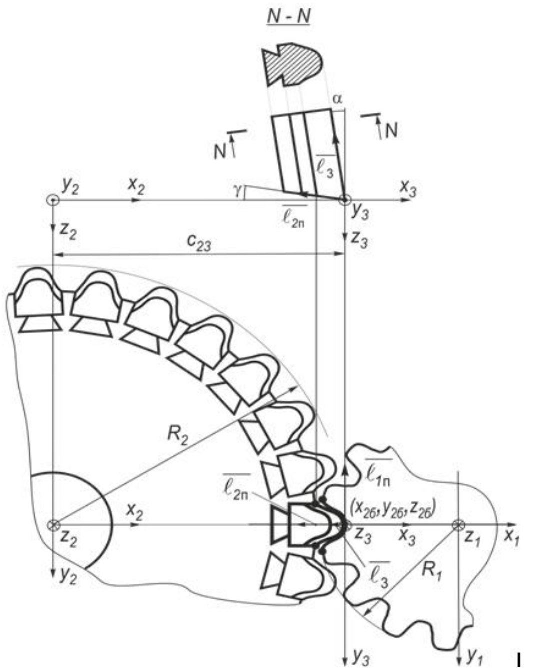

Figure 1: *To calculation of the profile of assembled shaping cutter with prismatic shaped cutters*

The initial information at the first stage is the coordinates of points of a profile of processed gear x_{1K}, y_{1K} in gear reference point $x_1y_1z_1$ and the greatest radius of generating gear R_2. Coordinates of points of profile of tool surface $x_{1И}$, $y_{1И}$ in gear cutter reference point $x_2y_2z_2$ are unknown quantities.

The algorithm of calculation of enveloping surfaces for running tools and processed tooth gears can be used to find a profile of tool surface conjugated to the predetermined profile of the processed tooth gear [3].

The second stage of profiling of assembled gear cutters consists in a finding of a shaped cutting edge as a line of crossing of tool surface and rake face. The initial information is coordinates of points of profile of cylindrical tool surface in reference point of gear cutter $x_2y_2z_2$ and rake γ. Coordinates of shaped cutting edge in the reference point of cutter, marked in fig. as $x_3y_3z_3$, are unknown quantities.

The cylindrical tool surface is formed by action of the operator of parallel shift $\bar{\ell}$ on its profile. In reference point of gear cutter $x_2y_2z_2$ its equation has the following operator and matrix notations with parameter $\bar{\ell}$:

$$\bar{r}_2 = \bar{r}_{2И} + \bar{\ell}, \tag{1}$$

$$m_{r_2} = m_{r_{2И}} + m_{\ell} \tag{2}$$

$$\text{where } m_{r_2} = \begin{pmatrix} x_2 \\ y_2 \\ z_2 \end{pmatrix};\ m_{r_{2И}} = \begin{pmatrix} x_{2И} \\ y_{2И} \\ z_{2И} \end{pmatrix};\ m_{\ell} = \begin{pmatrix} 0 \\ 0 \\ -\ell \end{pmatrix}. \tag{3}$$

The rake face (plane) is formed by action of two operators of parallel shift $\bar{\ell}_1$ and $\bar{\ell}_2$ on base point of cutting edge with coordinates $x_{2б}$, $y_{2б}$, $z_{2б}$ [2]. Having directed the vectors of carryover as shown in figure, we will write down the operator and matrix equation of face plane in reference point of gear cutter $x_2y_2z_2$ with parameters ℓ_1 and ℓ_2 :

$$\bar{r}_2 = \bar{r}_{2б} + \bar{\ell}_1 + \bar{\ell}_2, \tag{4}$$

$$m_2 = m_{2б} + m_{\ell_1} + m_{\ell_2} \tag{5}$$

where $$m_{2б} = \begin{pmatrix} x_{2б} \\ y_{2б} \\ z_{2б} \end{pmatrix}; \quad m_{\ell_1} = \begin{pmatrix} 0 \\ \ell_1 \\ 0 \end{pmatrix}; \quad m_{\ell_2} = \begin{pmatrix} -\ell_2 \cos\gamma \\ 0 \\ -\ell_2 \sin\gamma \end{pmatrix}. \tag{6}$$

For assembled gear cutter with prismatic shaped cutters

$$x_{2б} = c_{23} - R; \quad y_{2б} = 0; \quad z_{2б} = 0, \tag{7}$$

and for assembled gear cutter with round shaped cutters

$$x_{2б} = c_{23} - R\cos\alpha; \quad y_{2б} = 0; \quad z_{2б} = -R\sin\alpha \tag{8}$$

c_{23}– center-to-center spacing of reference points $x_2y_2z_2$ and $x_3y_3z_3$, α – clearance angle, R – the biggest radius of tool.

Having equated the right parts of the equations (2) and (5), we obtain the condition of crossing of tool surface and rake face in matrix notation:

$$m_{зи} + m_{\ell} = m_{2б} + m_{\ell_1} + m_{\ell_2} \tag{9}$$

This condition includes three equations with parameters of tool surface and rake face. Their solution makes possible to define unknown parameters ℓ, ℓ_1, ℓ_2, and then by means of the equation (5) to define coordinates of points of cutting edge X_2, Y_2, Z_2 in reference point of gear cutter $x_2y_2z_2$.

For implementation of next stage of profiling it is necessary to write down coordinates of points of shaped cutting edge in cutter reference point $x_3y_3z_3$.

The operator and matrix equations of transition from reference point of gear cutter $x_2y_2z_2$ to cutter reference point $x_3y_3z_3$ by means of coordinate operator $\bar{c}_{23}$ write down as follows:

$$\bar{r}_{3PK} = \bar{r}_{2PK} + \bar{c}_{23}, \tag{10}$$

$$m_{3PK} = m_{2PK} + m_{c_{23}}, \tag{11}$$

where $$m_{\ell_3} = \begin{pmatrix} -\ell_3 \sin\alpha \\ 0 \\ -\ell_3 \cos\alpha \end{pmatrix}. \tag{12}$$

The third stage of profiling of assembled gear cutters consists in the analytical description of shaped back surface of rotation in reference point of cutter and a finding of profile of this surface in standard cross-section. The initial information at this stage is coordinates of points of shaped cutting edge, tool clearance α, and also the maximum radius R for round shaped cutter.

The cylindrical flank surface of prismatic shaped cutter can be formed by action of the operator of parallel shift $\bar{\ell}$ on shaped cutting edge [2]. Its equations in operator and matrix notation are as follows:

$$\bar{r}_3 = \bar{r}_{3PK} + \bar{\ell}_3, \tag{13}$$

$$m_3 = m_{3PK} + m_{\ell_3}, \tag{14}$$

where $$m_{\ell_3} = \begin{pmatrix} -\ell_3 \sin\alpha \\ 0 \\ -\ell_3 \cos\alpha \end{pmatrix}. \tag{15}$$

Flank surface of round shaped cutter can be formed by action of the rotation operator $\bar{\varphi}$ on shaped cutting edge [2]. Its equations in operator and matrix notation are as follows:

$$\bar{r}_3 = \bar{\varphi} \cdot \bar{r}_{3PK}, \tag{16}$$

$$m_{r_3} = m_\varphi \cdot m_{r_{3PK}}, \tag{17}$$

where $m_\varphi = \begin{pmatrix} \cos\varphi & 0 & -\sin\varphi \\ 0 & 1 & 0 \\ \sin\varphi & 0 & \cos\varphi \end{pmatrix}$. (18)

Let's draw an axial plane of standard cross-section N-N. Its operator and matrix equations with parameters x_{3H} and y_{3H} in cutter reference point $x_3y_3z_3$ write down as follows:

$$\bar{r}_3 = \bar{r}_{3H} , \tag{19}$$

$$m_{r_3} = m_{r_{3H}}, \tag{20}$$

where $m_{r_{3H}} = \begin{pmatrix} x_{3H} \\ y_{3H} \\ 0 \end{pmatrix}$. (21)

Having equated the right parts of the equations (14) and (20) we will obtain the condition of crossing of flank surface of prismatic shaped cutter and standard cross-section plane in matrix notation:

$$m_{r_{3PK}} + m_{\ell_3} = m_{r_{3H}}. \tag{22}$$

This condition includes three equations with parameters of flank surface and standard cross-section plane. Their solution allows to define unknown parameters ℓ_3, x_{3H} and y_{3H} and connected with x_{3H} parameter z_{3H}, and hereby to find coordinates of points of required profile of flank surface of prismatic shaped cutter in standard cross-section.

Having equated the right parts of the equations (17) and (20) we will obtain the condition of crossing of flank surface of round shaped cutter and standard cross-section plane in matrix notation:

$$m_\varphi \cdot m_{r_{3PK}} = m_{r_{3H}}. \tag{23}$$

It includes three equations with parameters of flank surface and standard cross-section plane. Their solution allows to define unknown parameters φ, x_{3H}, and y_{3H}, and thus to find coordinates of points of required profile of flank surface of round shaped cutter in standard cross-section.

3. PHYSICAL-MECHANICAL SIMULATION OF GEAR CUTTER LOADING

On the basis of the obtained set of equations, the geometrical model of tool which was a basis for the FEM strength and a heat analysis at processing is developed (fig. 2).

The adequacy of FEM model for shaping element with reproduction accuracy of boundary conditions, loading, geometry and properties of material was defined at the first stage of the investigation. Investigations on determining of total displacements (fig. 3), equidistant deformation by Mises criterion and equidistant pressure by Mises criterion (fig. 4) under condition of pressure application to surface normal, resultant of which is 4000 N (~400 kg) for the materials of high-speed steels group were carried out.

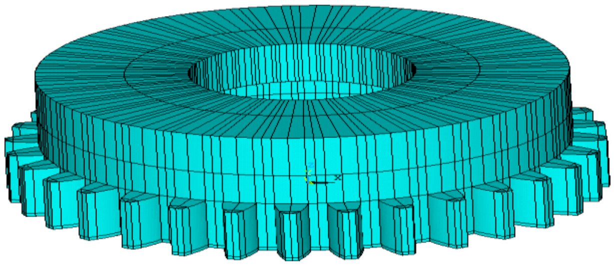

Figure 2: *Geometrical model of gear cutter (full)*

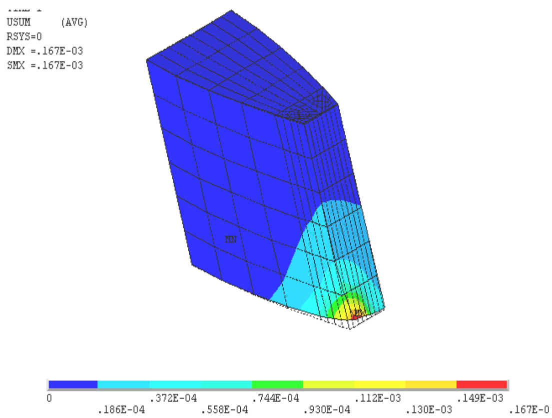

Figure 3: *Resultant displacements [m]*

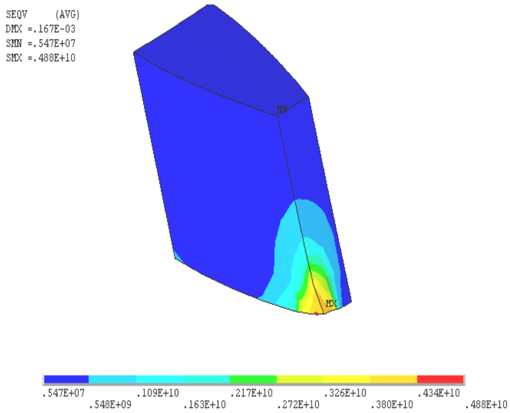

Figure 4: *Equivalent stress [Pa]*

Maximal equivalent stress according to Mises criterion, calculated with averaging on nodal point, is σ=5550 MPa.

Given calculated model is not accurate since it leads to setting stiffness too high in comparison with reality which means that it leads to occurring of error too. Distributed load application on the surface allows to decrease the error caused due to application of equivalent force. And with it the direction of distributed load should coincide with axis of cylindrical surface.

Taking into account carried out calculations and secondary analysis, the sector model which includes 5 teeth (fig. 5), fixing scheme and distributed load (fig. 6).

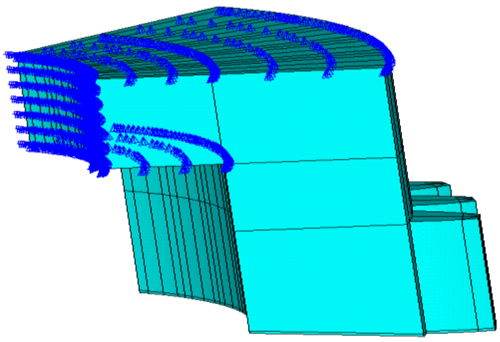

Figure 5: *Geometrical model of gear cutter sector and boundary conditions*

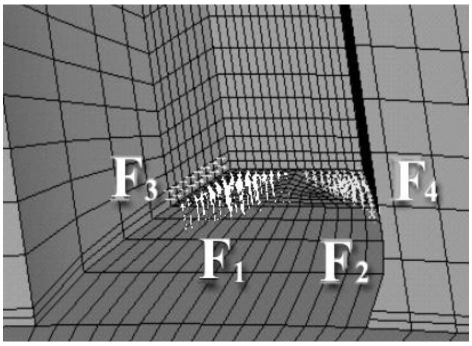

Figure 6: *FEM model of gear cutter under loading*

A set of experiments are worked out and exacted data array (fragment is presented in table 1), which permit to make conclusion on strength analysis of running gear cutting tool and change of parameters at increase of contact sites, that correspond to tool blunting, is obtained.

Table 1: *Load (F), temperature (T) and strength (σ) FEM calculation simulation*

N tooth	F1 [MPa]	F2 [MPa]	F3 [MPa]	F4 [MPa]	T1 [C]	T2 [C]	T3 [C]	σ [MPa]
1	4000	-	-	-	618	-	-	3720
2	4000	-	2000	-	611	-	314	3760
3	4000	3000	2000	-	615	408	308	3800

4. CONCLUSION

The optimized geometrical model, simulation FEM model of gear cutter, considering its physical-mechanical properties on the basis of which it is possible to recommend material and geometrical parameters of cutting elements for the assembled tool of equidistant tooth generation on noncylindrical surfaces of two-parameter gearing [4] are the findings of the carried out investigations.

REFERENCES

[1] **Rodin P.R.** Fundamentals of shaping of surfaces by cutting. K., Vyshcha shkola, 1977. 192 p. (in Russian)

[2] **Perepelitsa B.A.** Development of the theory of shaping of surfaces by cutting and cutting tools by means of mappings of affine space. D. Sc. Thesis. – Tula, 1981. – 359 p. (in Russian)

[3] **Kondusova E.B. Tretyak T.E., Krivosheya A.V.** Algorithm of calculation of profile of enveloping surfaces for running tools and components. Proceedings of the fifth International Conference “New Leading-Edge Technologies in Machining Building”, Rubachie, Ukraine, September 18-21, 1996, pp. 140-141. (in Russian)

[4] **Gutsalenko Yu., Mironenko A., Tretyak T.** Equidistant tooth generation on noncylindrical surfaces for two-parameter gearing. Fiability & Durability, Targu- Jiu, CBU, 2011, No. 2(8), pp. 67-72.