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Modelling of cutting block cut surface at faceted surfaces machining using planetary gear set

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Abstract. The article resolved the relevant problem to assign process parameters for polygonal turning machining ensuring the component has its pre-set characteristics. To accomplish this, the authors modelled the machining process and described the cut surface formed by the cutter block edge during machining.

Today cylindrical components with multi-faceted surfaces have found application in various areas of the economy, in particular: machine construction, instrument engineering, robotics, agriculture, mining and even the medical industry [1].

Fig 1. Examples of details with polyhedral surfaces

The conducted analysis of the production methods for faceted surfaces helped to choose the planetary motion method of the turning machine cutting edges. This method works as follows: the planetary gear set assigns a complex curve trajectory (trochoid) to the cutting tool point Fig.1 [1].

To determine the planetary gear set structural parameters, the authors resolved the problem of the rectangle side approximation error calculation with the prolonged trochoid section [1]. However, to assign the machining process parameters the component has its pre-set characteristics, it is necessary to model the machining process, namely, to make a cut surface model.

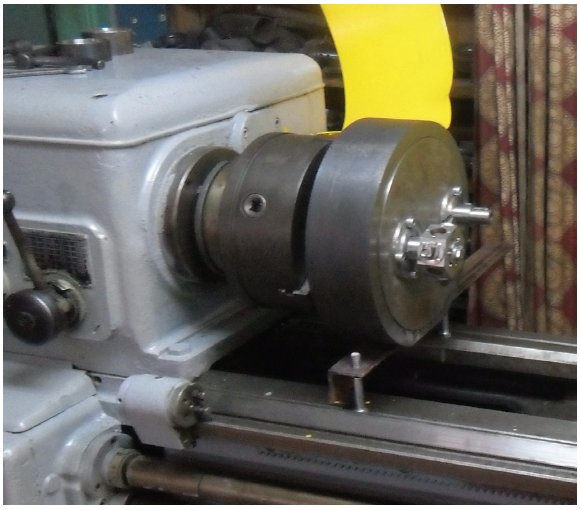

Fig. 2. Planetary Gear Set

Generally, the cut surface is described by the formula

$$Q_i(\varphi(t), \theta(t)z(t), S) == {}^{6}A(\varphi(t))\,{}^{2}A(R-r)\cdot{}^{6}A(-\theta(t))\cdot r_{ui}(S) \quad (1)$$

Where

$\varphi(t) = \frac{\pi n}{30}\cdot t$; $\theta(t) = \frac{R}{r}\cdot\frac{\pi n}{30}\cdot t$; $z(t) = \frac{S_{мин}}{60}\cdot t$, $S_{мин}$ – feed per minute, N – number of the cutting block rotations in relation to the workpiece.

Let us build a model for cutting block edges. Fig. 3 presents a square indexable insert.

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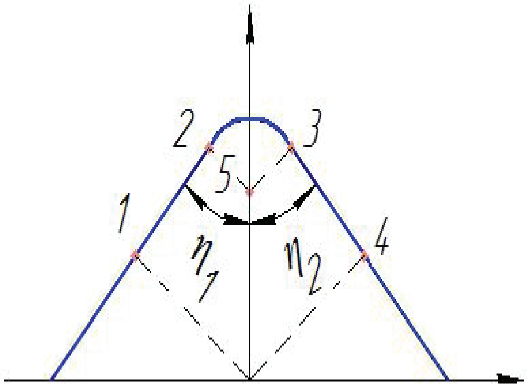

Fig. 3. Design model for the indexable insert cutting edge points: 1,2,3,3 5 – reference points; η1 η2 – angles between the X axis and the insert surface

Let us determine the generating points coordinates
Point 1 coordinates:

$$x_1 = 0{,}5d \cdot \sin\eta_1\,;\; y_1 = 0{,}5d \cdot \sin\eta_1$$

Point 2 coordinates:

$$x_2 = \frac{\sqrt{2}}{2} d \cdot \cos\eta_1\,;\; y_2 = -r \cdot \sin\eta_1$$

Point 3 coordinates:

$$x_3 = x_2\,;\; y_2 = -y_2$$

Point 4 coordinates:

$$x_4 = x_1\,;\; y_4 = -y_1$$

Point 5 coordinates:

$$x_5 = \frac{\sqrt{2}}{2} d - r \cdot \sqrt{2}\,;\; y_5 = 0$$

$$r_\Pi = [x(S), y(S), z(S), 1]^T$$

where

$$y(S) = \begin{cases} y_1; S \le 0 \\ y_1 + S; 0 < S \le y_4 - y_1 \\ y_u; S > y_u - y_1 \end{cases} \tag{2}$$

$$x(S) = \begin{cases} x_1; S \le 0 \\ (x_2 - x_1)\cdot(y(S) - y_1)/(y_2 - y_1) + x_1; 0 < S \le y_2 - y_1 \\ x_5 + \sqrt{r^2 - (y(S) - y_5)^2}\,; y_2 - y < S \le y_3 - y_1 \\ (x_4 - x_3)\cdot(y(S) - y_3)/(y_4 - y_3) + x_3; y_3 - y_1 < S \le y_4 \\ x_4; S < y_4 \end{cases}$$

$$N_\Pi(S) = \left[-\bar{j}\cdot\bar{r}_s(S)\cdot\sin\gamma_\Pi; \bar{i}\cdot\bar{r}_s(S)\cdot\sin\gamma_\Pi; -\cos\gamma_\Pi; 0\right]^T$$

$$N_3(S) = \left[-\bar{j}\cdot\bar{r}_s(S)\cdot\cos\alpha_\Pi; \bar{i}\cdot\bar{r}_s(S)\cdot\cos\alpha_\Pi; \sin\alpha_\Pi; 0\right]^T$$

Further, let us set the indexable insert parameters; the transition to the coordinates system 1 is the first action

$${}^{01}A = {}^{2}A(-d)\cdot{}^{6}A\left(\frac{\pi}{2}\right)\cdot{}^{5}A\left(-\frac{\pi}{2}\right) \tag{3}$$

Rotation for the angle λ is the second action

$${}^{12}A = {}^{6}A(-\lambda) \tag{4}$$

After that, let us set the insert for the angle

$$\gamma_g = \gamma_K - \gamma_{\Pi K}$$

$${}^{23}A = {}^{4}A(-\gamma_g) \tag{5}$$

Move to the rotation center

$${}^{34}A = {}^{2}A(-S_\Pi)\cdot{}^{3}A(-r_\Pi) \tag{6}$$

If $\varphi \ne \varphi_2$, set the angle φ

$${}^{45}A = {}^{5}A(\varphi) \tag{7}$$

$${}^{56}A = {}^{6}A(-(0{,}5d + m - r)) \tag{8}$$

$${}^{67}A = {}^{6}A\left(\frac{\pi}{2}\right)\cdot{}^{2}A\left(-\frac{\pi}{2}\right) \tag{9}$$

The setting matrix calculation in the coordinates system
Reference data:
$\bar{j}_{21}$ - vector $\bar{j}_2 = [0,1,0,0]^T$ presented in the coordinates system x_1, y_1, z_1
$\bar{k}_{21}$ - vector $\bar{k}_2 = [0,0,1,0]^T$ presented in the coordinates system x_1, y_1, z_1
$\bar{r}_{21}$ - vector defining the position of the coordinates x_2, y_2, z_2 origin within the system x_1, y_1, z_1

The A_{21} matrix elements are determined by the system

$$\begin{cases} \bar{j}_{21} = A_{21}\cdot\bar{j}_2 \\ \bar{k}_{21} = A_{21}\cdot\bar{k}_2 \\ [\bar{j}_{21}\times\overline{k_{21}}] = A_{21}\cdot\bar{i}_2 \\ \bar{r}_{21} = A_{21}\cdot e^4 \end{cases} \tag{10}$$

where $\bar{i}_2 = (1,0,0,0)^T$

$$A_{21} = \begin{bmatrix} \bar{i}_1\cdot[\bar{j}_1\times\bar{k}_{21}] & \bar{i}_1\cdot\bar{j}_{21} & \bar{i}_1\cdot\bar{k}_{21} & \bar{i}_1\cdot\bar{r}_{21} \\ \bar{j}_1\cdot[\bar{j}_1\times\bar{k}_{21}] & \bar{j}_1\cdot\bar{j}_{21} & \bar{j}_1\cdot\bar{k}_{21} & \bar{j}_1\cdot\bar{r}_{21} \\ \bar{k}_1\cdot[\bar{j}_1\times\bar{k}_{21}] & \bar{k}_1\cdot\bar{j}_{21} & \bar{k}_1\cdot\bar{k}_{21} & \bar{k}_1\cdot\bar{r}_{21} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{11}$$

The method for calculation of the residual ridges and roughness parameters

1. Define the point on the cutting edge which contacts with the component surface (shape-generating point) by solving the following equation

$$\bar{j}\cdot\bar{Q}(S,t) = 0 \tag{12}$$

In relation to the S edge parameter at t=0

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2. Calculate the A_W matrix elements for setting the sectional plane coordinates system under the set parameters

$$[0,0,-1,0]^T,[-1,0,0,0]^T,Q(S,t) \tag{13}$$

Determine the coordinates for the A point

$$r_A = A_W \cdot Q(S,t) \tag{14}$$

Determine the coordinates for the B point

$$r_B = A_W \cdot Q(S,t+T_{\text{об}}) \tag{15}$$

Determine the coordinates for the C point by solving the equation system

$$\begin{cases} \overline{i}_w \cdot \overline{A}_w \cdot Q(S_1,t_1) = \overline{i}_w \cdot \overline{A}_w \cdot Q(S_2,t_2) \\ \overline{j}_w \cdot \overline{A}_w \cdot Q(S_1,t_1) = \overline{j}_w \cdot \overline{A}_w \cdot Q(S_2,t_2) \\ \overline{k}_w \cdot A_w Q(S_1,t_1) = 0 \\ \overline{k}_w \cdot A_w Q(S_2,t_2) = 0 \\ 0 \le S_1 \le S_{m4} \\ 0 \le S_2 \le S_{m4} \\ t - \dfrac{T_{\text{об}}}{4} \le t_1 \le t + \dfrac{T_{\text{об}}}{4} \\ t + T_{\text{об}} - \dfrac{T_{\text{об}}}{4} \le t_2 \le t + T_{\text{об}} + \dfrac{T_{\text{об}}}{4} \end{cases} \tag{16}$$

In relation to the S_1,S_2,t_1,t_2. parameter

Hence $r_c = A_W \cdot Q(S_1,t_1)$

Assessment for the layers being cut

1) Define the normal vector towards the cut surface at the cut-in moment t

$$\overline{N}_{pi}(S,t) = [\overline{Q}_{is} \cdot (S,t) \times \overline{Q}_{it} \cdot (S,t)] \cdot sign\begin{Bmatrix} -[\overline{Q}_{is} \cdot (S,t) \times \overline{Q}_{it} \cdot (S,t)] \cdot {}^6A(\varphi(t)) \cdot {}^2 \\ A(R-r) \cdot {}^6A(Q(t)) \cdot \overline{N}_{3i}(S) \end{Bmatrix}$$

Let the A_j transition matrix be defined in the system of x_j, y_j, z_j coordinates with the origin in the $\overline{Q}_i(S,t)$ point and the y_j axis along the $\overline{Q}_{is}(S,t)$ vector and the z_j axis along the $\overline{N}_{pi}(S,t)$ vector

Define the cross point of the z_j axis with the cut surface of the i cutter shaped during the previous cutting block rotation

$$\begin{cases} \overline{i}_j \cdot \overline{A_j \cdot Q_i(S^*, t+\Delta t)} = 0 \\ \overline{j}_j \cdot \overline{A_j \cdot Q_i(S^*, t+\Delta t)} = 0 \\ 0 \le S \le S_n \\ t - T_{\text{об}} - \dfrac{T_{\text{об}}}{N_r} < \Delta t < t - T_{\text{об}} + \dfrac{T_{\text{об}}}{N_r} \end{cases} \tag{17}$$

The system is solved in relation to the S^* and Δt parameters

Define the thickness $Q_1(S,t)$

$$Q_1(S,t) = F_1(S,t) \cdot \overline{k}_i \cdot \overline{A_j \cdot Q_i(S^*, t+\Delta t)} \tag{18}$$

Let the thickness value of the layer being cut limited by the workpiece material be defined as follows:

Solve the equation system in relation to the U and V parameters

$$\begin{cases} \overline{i}_j \cdot \overline{A_j \cdot PR_z(U,V)} = 0 \\ \overline{j}_j \cdot \overline{A_j \cdot PR_z(U,V)} = 0 \\ 0 \le U \le 2\pi \\ 0 \le V \le H_{\text{заг}} \end{cases} \tag{19}$$

where $H_{\text{заг}}$ - workpiece thickness.

2) Calculate the thickness $a_2(S,t)$

$$a_2(S,t) = F_1(S,t) \cdot \overline{k}_j \cdot \overline{A_j \cdot QPR \cdot (U,V)} \tag{20}$$

The thickness for the layer being cut is calculated as

$$a(S,t) = \min(a_1(S,t), a_2(S,t)) \tag{21}$$

Basing upon the model built for the cut surface, it is possible to calculate assessment parameters for the multi-faceted surfaces machining with further determining of the rational values for the polygonal turning parameters.

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