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Selecting the Cutting Edge of a Shaping Tool

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Abstract—The determination of the cutting-edge parameters in sharpening a shaping tool is considered, for purposes of automatic design.

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In most machines, torque is transmitted by a coupling consisting of a shaft and a bush. With equal loads, it is preferable to use complex couplings, since they are smaller and have better performance than slotted and tongued couplings [1, 2].

The machining of complex parts by means of a shaping tool is expedient, thanks to the use of the same equipment for the shafts and bushes. That ensures the necessary surface quality of the coupling's components. Burnishing is economically justified for the components of complex couplings.

The familiar design method for the shaping tool permits the determination of its contour in the null cross section [3, 4]. Tool performance throughout its working life is ensured by timely and precise sharpening. The sharpening of complex tools calls for special numerically controlled machine tools that do not distort the intended cutting edge (Fig. 1a). However, their considerable cost makes them unsuitable for most manufacturing enterprises. In sharpening special shaping tools on standard equipment (Fig. 1b), it is difficult to determine and specify the distortion of the projection of the cutting edge onto the basic plane (Fig. 2) as a function of the front and rear sharpening angles [5, 6].

Research shows that the contour of the cutting edge in the null cross section may be approximated by a circle. In that case, the rear surface takes the form of a cone with an axis passing through the point O_C and perpendicular to the basic plane (Fig. 3). The shape of the rear surface may be described by the equation of a cone with its vertex at the origin

$$z(x_{co}, y_{co}) = \sqrt{x_{co}^2 + y_{co}^2}\frac{1}{\tan\alpha},$$

where α is the sharpening angle of the cutter at the rear surface; x_{co} and y_{co} are the coordinates of points on the conical surface.

We place the cone at a point K (Fig. 3), which is a distance h from the plane, where h is the height of the cone: $h = R_C/\tan\alpha$; R_C is the radius of the circle approximating the cutting edge.

In the classical approach, R_C may be determined from the equation of the circle

$$(x_{cir} - x_C)^2 + (y_{cir} - y_C)^2 = R_C^2,$$

where x_{cir} and y_{cir} are the coordinates of points on the circumference; x_C and y_C are the coordinates of the center of the circle.

The equation of the circle approximating the cutting edge for point A takes the form (Fig. 4)

$$(x_A)^2 + [y_A - (R_t + \Delta_{max} - R_C)]^2 = R_C^2,$$

where R_t is the radius of the circle inscribed within the profile of the shaping tool; Δ_{max} is the distance between the inscribed and circumscribed circles.

Point A has the Cartesian coordinates $(R_t + \Delta_{max}) \times \cos\left(\frac{\pi}{2N}\right)$ and $(R_t + \Delta_{max})\sin\left(\frac{\pi}{2N}\right)$, where N is the number of faces of the complex shaft (bush).

(a) (b)

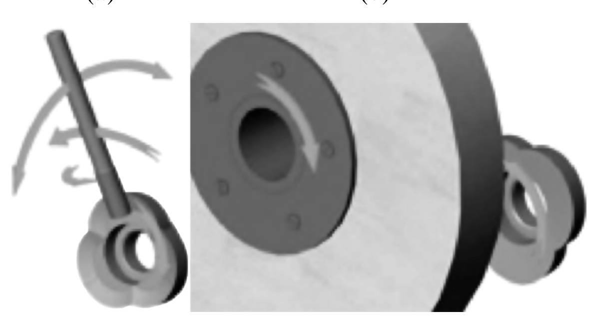

Fig. 1. Methods of sharpening the front surface of the tool: (a) by sectors; (b) from the center.

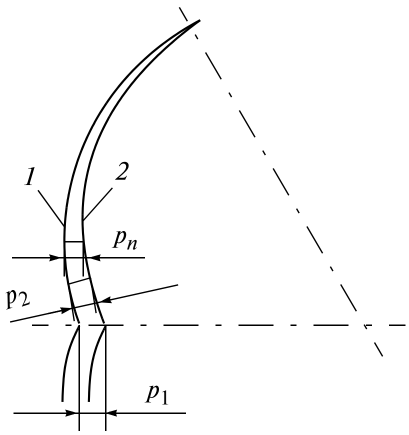

Fig. 2. Projecting the null contour *1* and cutting-edge contour *2* of the shaping tool onto the basic plane: p_1, p_2, p_n, deviations of tool contour *2* from contour *1* obtained in null-section design at the corresponding points.

Substituting these values for *x* and *y*, we obtain

$$\left[R_t \cos\left(\frac{\pi}{2N}\right)\right]^2$$

$$+\left[R_t \sin\left(\frac{\pi}{2N}\right) - (R_t + \Delta_{max} - R_C)\right]^2 = R_C^2.$$

This solution may be transformed using Mathcad software to obtain

$$R_C = \frac{R_t + \Delta_{max} - R_t \sin\left(\frac{\pi}{2N}\right)^2 + R_t^2 \cos\left(\frac{\pi}{2N}\right)^2}{2\left[R_t + \Delta_{max} - R_t\left(\frac{\pi}{2N}\right)\right]}.$$

Hence, the equation of the cone takes the form

$$z(x_{co}, y_{co}) = \sqrt{x_{co}^2 + y_{co}^2}\frac{1}{\tan\alpha} + \frac{R_C}{\tan\alpha}. \quad (1)$$

In selecting the front cutting angle γ, we consider the cross section of the conical surface formed by a plane passing through the points *A*, *B*, and *C* at this angle. In that case, the equation of a plane takes the form

$$z_{pl} = ky_{pl} + b,$$

where z_{pl} and y_{pl} are the coordinates of the plane; *b* and *k* are unknown constants.

To determine *k* and *b*, we find the coordinates of point *B* in Fig. 4 (y_B; z_B) and point *M* in Fig. 3 (y_M; z_M) $y_B = R_t + \Delta_{max}$, $z_B = 0$; $y_M = 0$, $z_M = \tan\gamma(R_t + \Delta_{max})$.

Thus, the coordinates of point *B* are $R_t + \Delta_{max}$, 0. Those of point *M* are $\tan\gamma(R_t + \Delta_{max})$, 0.

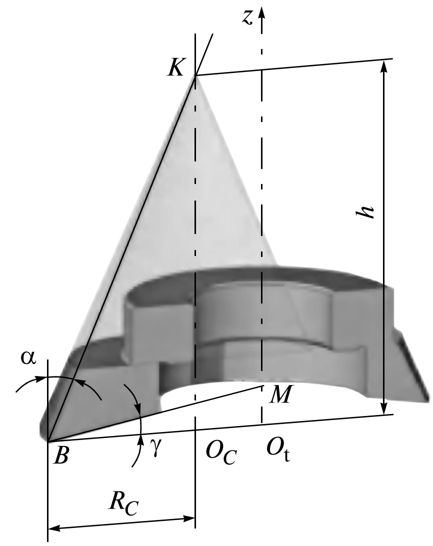

Fig. 3. Specifying the cutting edge in the null cross section: R_t, radius of the circle inscribed in the shaping tool; Δ_{max}, distance from the inscribed circle to the circle at a maximum distance from its center O_t (half the difference between the inscribed and circumscribed circles).

For point *B*, we obtain the equation

$$k(R_t + \Delta_{max}) + b = 0; \quad (2)$$

likewise, for point *M*

$$\tan\gamma(R_t + \Delta_{max}) = b. \quad (3)$$

Substituting Eq. (3) into Eq. (2), we obtain

$$k(R_t + \Delta_{max}) + \tan\gamma(R_t + \Delta_{max}) = 0.$$

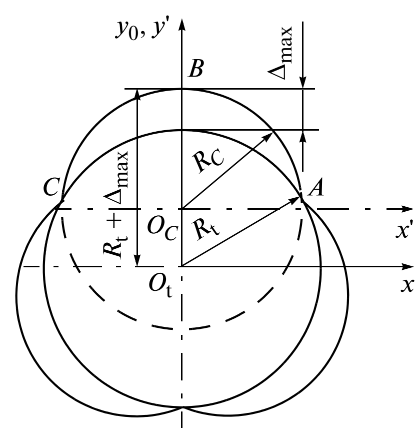

Fig. 4. Cross section of the shaping tool's conical part: O_t, geometric center of shaping tool (coordinate origin); O_C, center of conical part of the sector of the shaping tool's cutting edge; *B*, point where the cutting edge is at the maximum distance from the center O_t (the point of zero error).

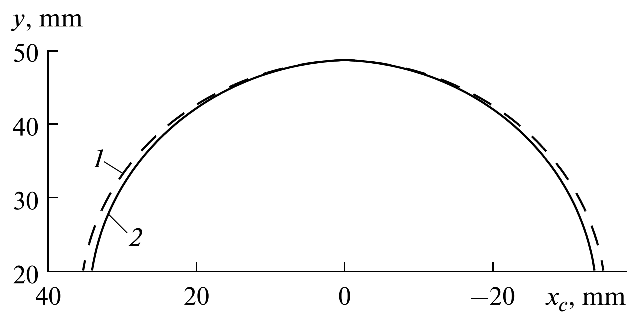

Fig. 5. Difference between the calculated *1* and actual *2* positions of the projection of the cutting edge onto the basic plane with superposition of the front and rear sharpening angles.

Hence

$$k = -\tan\gamma. \quad (4)$$

Substituting Eqs. (3) and (4) into Eq. (1), we obtain the equation of the desired plane

$$z(x_{pl}; y_{pl}) = -\tan\gamma y_{pl} + \tan\gamma(R_t + \Delta_{max})$$
$$= \tan\gamma(R_t + \Delta_{max} - y_{pl}).$$

For the sake of convenience, we shift the coordinate origin to point O_C, which is the center of the cone's base (Fig. 3); that displacement is

$$\varepsilon = R_t + \Delta_{max} - R_C.$$

Then the equation of the plane may be written in the form

$$z(x_{pl}; y_{pl})$$
$$= \tan\gamma[R_t + \Delta_{max} - y_{pl} - (R_t + \Delta_{max} - R_C)].$$

To determine the coordinates x and y at the intersection of the plane and cone, we equate Eqs. (1) and (4):

$$\sqrt{x^2 + y^2}\frac{1}{\tan\alpha} + \frac{R_C}{\tan\alpha} = \tan\gamma(R_t + \Delta_{max} - y).$$

The solution of this equation describes the contour obtained when the ellipse formed by the intersection of the conical part of the shaping tool's rear surface with a plane inclined at an angle γ to the rear surface is projected onto the basic plane. On account of its unwieldiness, this equation is not presented here. The ellipse function is determined by means of Mathcad software, with the substitution of specific values—for example, $R_t = 40.7$ mm, $R_C = 36.16$ mm, $\alpha = 8°$, and $\gamma = 5°$

$$y = 0.434 - 5.274e^{-21}\sqrt{4.470 - 3.595x^2}.$$

This formula allows the calculated and actual profiles to be plotted (Fig. 5).

Thus, the distortion of the profile of the machined tool has been determined as a function of the shaping tool's sharpening angle. The error of the shaping tool may be calculated from the change in the cutting edge, which corresponds to the intersection of the cone and a plane inclined to the cone by the front-surface angle γ.

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