ISSN 1068-798X, Russian Engineering Research, 2009, Vol. 29, No. 4, pp. 388–392. © Allerton Press, Inc., 2009.
Original Russian Text © O.V. Zakharov, 2009, published in Vestnik Mashinostroeniya, 2009, No. 4, pp. 77–80.

Guide Wheels of Centerless Grinding Machines

O. V. Zakharov
Saratov State Technical University

Abstract—The geometric and kinematic calculation of guide wheels of centerless grinding machines with longitudinal supply is considered. Sample calculations of the wheel profiles are presented, for the machining of cylindrical, conical, and complex surfaces.

DOI: 10.3103/S1068798X09040133

Centerless grinding machines are widely used for the manufacture of auto and bearing components in the form of solids of revolution. The benefits of centerless grinding with longitudinal supply include high precision and productivity; simple design of the machines; and the possibility of complete automation. There are also some constraints on the manufacture of complex surfaces such as conical and cambered surfaces, on account of the need to create a complex trajectory of the blank. This is accomplished by means of lelements of the shaping system—for example, guide wheels, grinding wheels, and supporting blades.

The required machining precision in centerless grinding machines is largely determined by the trajectory of the blank, which, in turn, depends on the geometry of the guide wheel. Contact of the guide wheel and the blank (or the flux of blanks) must be linear, with crossing of their axes, so as to create a longitudinal supply. If this is accomplished with stable kinematic parameters, the machining precision will be high.

Literature data regarding the calculation of guide wheels are inadequate [1–4]. Therefore, in the present work, we derive formulas for the profile of the guide wheels in machining cylindrical, conical, and cambered surfaces, on the basis of consistent geometric and kinematic principles.

The basis of our approach is that the required longitudinal cross section of the blanks is uniquely formed by their relative trajectory in the course of machining [5]. The shaping method is based on the corresponding theory and numerical methods, while the shaping system is described as a three-dimensional mechanism with crossed axes.

The system for centerless grinding of cylindrical surfaces (Fig. 1a) includes the following basic elements: the guide wheel *3*, the grinding wheel *2*, and the supporting blade *4*. The axes of the cylindrical grinding

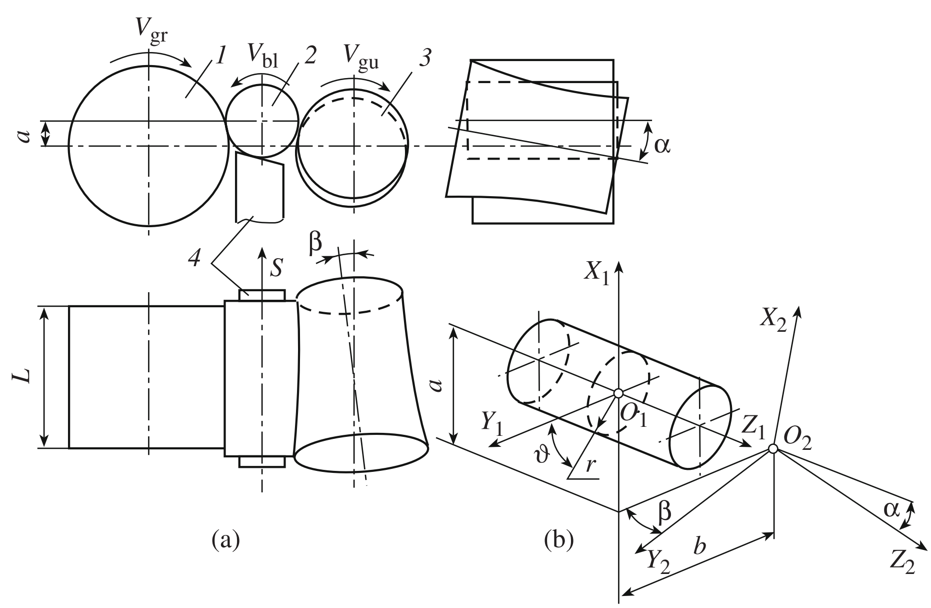

Fig. 1. Centerless grinding (a) and guide-wheel configuration in machining cylindrical surfaces (b).

Table 1

Z_2, mm	–200	–150	–100	–50	0	50	100	150	200
R_2, mm	197.641	197.378	197.130	196.899	196.683	196.482	196.299	196.131	195.979
z, mm	–200.103	–150.072	–100.041	–50.010	0.021	50.052	100.082	150.113	200.144
ϑ, deg	5.384	5.888	6.393	6.899	7.407	7.916	8.426	8.936	9.448

wheel and the blank *1* are parallel. The guide wheel ensures rotary (v_b) and linear translational (S) supply of the blank. To create the longitudinal supply by frictional forces, the axis of the guide wheel is inclined to the billet axis, at an angle α. To ensure stable shaping, the axis of the blank is a distance a above the axes of the wheel, as a rule. Several blanks are machined at once on centerless grinding machines with broad wheels (width L); this sequence of blanks may be represented as a virtual cylinder of the same radius.

The surface of the guide wheel is determined by means of the following coordinate systems (Fig. 1b): $S_1(X_1 0_1 Y_1 Z_1)$, the blank's system; and $S_2(X_2 0_2 Y_2 Z_2)$, the guide wheel's system. Relative to coordinate system S_1, coordinate system S_2 is turned clockwise around axis Y by an angle α, and turned counterclockwise around the X axis by an angle β; it is also displaced along the X axis by an amount $-a$ and along the Y axis by an amount $-b$.

The surface of the guide wheel is found as the geometric locus of the contact lines with the blank, by means of vector-matrix transformations of the coordinate systems and the kinematic conditions of contact.

Finally, the surface equations of the guide wheel for machining cylindrical surfaces take the form

$$\left.\begin{aligned} X_2 &= -r(\sin\vartheta\cos\alpha + \cos\vartheta\sin\alpha\sin\beta) \\ &+ z\sin\alpha\cos\beta + a; \\ Y_2 &= r\cos\vartheta\cos\beta + z\sin\beta + b; \\ Z_2 &= r(\sin\vartheta\sin\alpha - \cos\vartheta\cos\alpha\sin\beta) \\ &+ z\cos\alpha\cos\beta; \\ \tan\vartheta &= \frac{z\tan\alpha\sec\beta + a}{-b - z\sec\alpha\tan\beta}, \end{aligned}\right\} \quad (1)$$

where r is the radius of the blank; ϑ, z are the curvilinear coordinates of the blank's surface; b is the shortest distance between the axes of the blank and the guide wheel; α, β are the projections of the angle of rotation of the guide wheel onto the horizontal and vertical planes, respectively.

The profile of the guide wheel, which is a solid of rotation, may expediently be specified in the cylindrical coordinate system (Z_2, R_2), where $R_2 = \sqrt{X_2^2 + Y_2^2}$. The coordinate $Z_2 \in [-L/2; L/2]$ is regarded a fixed parameter.

EXAMPLE

We will calculate the profile of a guide wheel (Table 1) for machining blanks (diameter 10 mm) with the following parameters: $L = 400$ mm; $a = 26$ mm; $b = 200$ mm; $\alpha = 2°$; $\beta = 30'$.

The guide-wheel surface calculated from Eq. (1) is a quasi–hyperboloid. If the distance a is increased and the angle α is reduced, a more rational guide wheel is formed, with smaller curvature of the profile. The straightening of such wheels was considered in [6].

In grinding the conical surfaces (Fig. 2a), the basing and motion of blank *1* must be such that its generatrix is parallel to the axis of cylindrical grinding wheel *2*. Such continuous motion demands screw motion of the blank relative to the grinding wheel. The basic element creating the circular and longitudinal supply is guide wheel *3* with a helical channel. Blade *4* serves as a support; it does not determine the blank's trajectory. For shaping by means of a cylindrical grinding wheel, the supporting blade has a complex curvilinear surface.

The conical surfaces are analyzed on special machine tools (VSh-818 machines; Vistan plant, Belarus) or on modernized centerless grinding machines with a broad grinding wheel (SASL-5/2 machine; Mikrosa, Germany). In the latter case, the machines are equipped with a guide wheel that has a helical channel [7].

We now introduce the following coordinate systems (Fig. 2b): $S_0(X_0 0_0 Y_0 Z_0)$, the blank's system; $S_1(X_1 0_1 Y_1 Z_1)$, the conditionally motionless system associated with the machine tool; $S_2(X_2 0_2 Y_2 Z_2)$, the guide wheel's system. Relative to system S_0, coordinate system S_1 is turned by an angle β counterclockwise around the X axis and shifted a distance a along the X axis. The

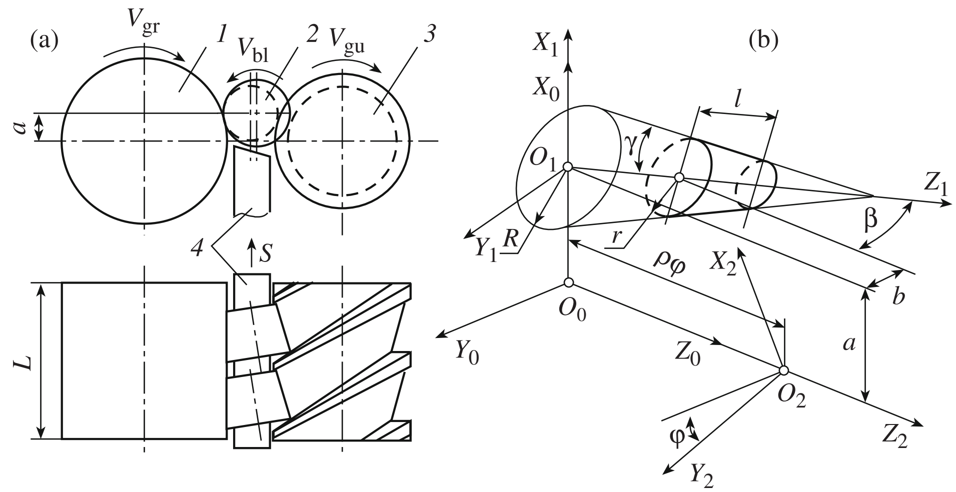

Fig. 2. Centerless grinding (a) and guide-wheel configuration in machining conical surfaces (b).

helical motion in system S_2 is specified by parameters p and φ. A right helical line is shown in Fig. 2b. (The vectors $\bar{\omega}$ and $\bar{q}$ are in the same direction.) The blank takes the form of a truncated cone of length l, at a distance b along the Y_0 axis in the system S_0.

The axial cross section of the guide wheel's helical surface for machining conical surfaces is described by the equations

$$\left.\begin{aligned}
X_2 &= (u\sin\gamma\cos\vartheta + a)\cos\varphi + E\sin\varphi;\\
Z_2 &= u\sin\gamma\sin\vartheta\sin\beta + (R\cot\gamma - u\cos\gamma)\cos\beta\\
&- b/\tan\beta - p\varphi;\\
\tan\varphi &= \frac{E}{u\sin\gamma\sin\vartheta + a};\\
(C-D)&\tan^2\frac{\vartheta}{2} + 2\cos\gamma(a\cos\beta + p\sin\beta)\tan\frac{\vartheta}{2}\\
&+ C + D = 0,
\end{aligned}\right\} \quad (2)$$

where u, ϑ are the curvilinear coordinates of the blank's surface; γ is the angle of the generatrix of the blank's cone; R is the base radius of the extended cone; r is the base radius of the blank; β is the skew angle; a is the shortest distance between the axes of the blank and the guide wheel; b is the fitting parameter of the machine tool; p, φ are the pitch and angular parameter of helical motion; finally

$$C = (p\cos\beta - a\sin\beta)\sin\gamma;\quad E = u(\sin\vartheta\sin\gamma\cos\beta - \cos\gamma\sin\beta) - R\cot\gamma\sin\beta;\quad D = (R\cot\gamma\cos\gamma - u)\sin\beta.$$

In Eq. (2), there are three independent variables: u, ϑ, φ. However, the penultimate equation of the system establishes the relation between parameters ϑ and φ. Therefore, in the solution, u is the only independent parameter. The range of u corresponding to the blank's length l is found from the second relation in Eq. (2).

In contrast to a and b, the angle β is not established directly in the machine tool, but is calculated. (As a rule, $\beta = \gamma$.) The shortest interaxial distance a may be positive or negative. It is selected so as to assure a stable interaction in grinding [1, 5]. When using a metal guide wheel, with a frictional coefficient less than 0.2, it is expedient to place the blank below the line connecting the axes of the grinding and guide wheels.

EXAMPLE

We will calculate the axial cross section of the guide wheel for machining a conical blank with $r = 10$ mm; $\gamma = 10°$; $l = 20$ mm. The setup parameters are $p = 25$ mm; $a = 10$ mm; $b = 100$ mm; $\beta = 10°$ (Table 2).

The surface of the guide wheel for machining conical blanks is a nonlinear helical surface. Analysis shows that the characteristic axial profile is curvilinear and concave, with a flexure limit of 0.01 mm. The profile of the circle depends on the dimensions of the blank and also on the selection of the setup parameters for the centerless grinding machine.

The equations for the transition surfaces of the guide wheel formed by the common circles of the conical surface and the base planes of the blank are obtained by means of a numerical algorithm. The width of the transition curves in the axial cross section is taken into account in selecting the pitch p.

In grinding a cambered surface (Fig. 3a), the trajectory of the initial cylindrical blank is the arc of a circle of radius R_1, with its center at the point 0_0. The axis of the blank at any moment is the tangent to a circle of radius R_1; its angular position is specified by δ. The longitudinal supply is created by the frictional force on account of rotation of the guide wheel by α relative to the plane of the blank's trajectory. The shortest distance between the axes of the blank and the guide wheel is specified by means of b. The supporting blade is curvi-

Table 2

Z_2, mm	40.623	42.531	44.439	46.347	48.255	50.163	52.072	53.980	55.889
X_2, mm	91.376	92.067	92.759	93.450	94.142	94.833	95.525	96.216	96.908
u, mm	55.557	53.526	51.495	49.464	47.433	45.403	43.372	41.341	39.310
ϑ, deg	100.360	100.324	100.288	100.252	100.216	100.181	100.146	100.111	100.076
φ, deg	–84.810	–84.806	–84.802	–84.799	–84.796	–84.793	–84.791	–84.788	–84.787

Table 3

Z_2, mm	–200	–150	–100	–50	0	50	100	150	200
R_2, mm	70.473	79.152	85.313	88.966	90.125	88.788	84.942	78.557	69.598
l, mm	4.16	1.42	0.88	0.08	0.02	–0.05	–0.02	–1.38	–4.12
ψ, deg	11.90	8.80	5.85	2.90	0	–2.90	–5.80	–8.80	–11.90
ϑ, deg	5.79	5.39	4.75	3.92	2.93	1.87	0.81	–0.19	–1.05

linear. In the specified configuration, the initially cylindrical blanks are characterized by point contact with the guide wheel.

We now introduce the following coordinate systems (Fig. 3b): $S_0(X_0 0_0 Y_0 Z_0)$, the conditionally motionless machine-tool system; $S_1(X_1 0_1 Y_1 Z_1)$, the blank's system; $S_2(X_2 0_2 Y_2 Z_2)$, the guide-wheel's system. Relative to system S_0, coordinate system S_1 is turned by an angle δ around the X_0 axis and shifted a distance R_1 along the Y_0 axis. Relative to system S_0, coordinate system S_2 is turned by an angle α around the Y_0 axis and shifted a distance a along the X_0 axis and also a distance $(R_1 - b)$ along the Y_0 axis.

The equations of the guide wheel's surface when machining cambered surfaces takes the form

$$\left.\begin{aligned} X_2 &= -r\sin\vartheta\cos\alpha - Q\sin\alpha + a;\\ Y_2 &= -r\cos\vartheta\cos\rho + l\sin\delta + R_1(\cos\delta - 1) + b;\\ Z_2 &= -r\sin\vartheta\sin\alpha + Q\cos\alpha;\\ l &= \frac{\cos\delta(R\tan\vartheta + a) - \tan\vartheta(\cos2\alpha + b) + \tan\alpha\sin\delta}{\tan\alpha + \tan\vartheta s\sin\delta}, \end{aligned}\right\} \quad (3)$$

where l, ϑ are curvilinear coordinates of the blank's surface; α is the guide wheel's angle of rotation; a, b are setup parameters of the machine tool; $Q = (r\cos\vartheta - R_1)\sin\rho + l\cos\delta$.

To calculate the guide wheel's profile, which is specified by cylindrical coordinates (Z_2, R_2), a numerical method is employed: two nested cycles are organized to find the minimum wheel radius R_2 in the specified end plane $Z_2 = Z_i$. The fixed parameter in the external cycle is Z_2; that in the internal cycle is δ. Research shows that, when R_2 is determined to within 0.1 μm, it is sufficient to specify δ to within 0.05°.

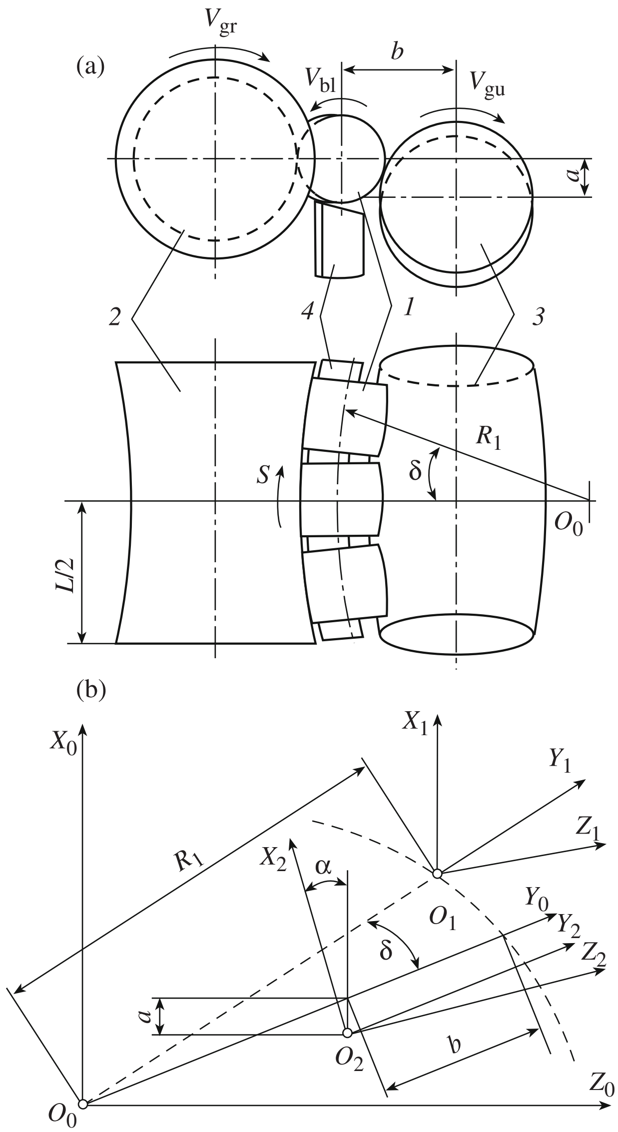

Fig. 3. Centerless grinding (a) and guide-wheel configuration in machining cambered surfaces (b).

EXAMPLE

We want to calculate the profile of a guide wheel (width $L = 400$ mm), for the setup parameters $r = 10$ mm; $R_1 = 1000$ mm; $a = 5$ mm; $b = 100$ mm; $\alpha = 2°$ (Table 3).

Analysis shows that the profile of the guide wheel is asymmetric relative to the plane $Z_2 = 0$ of the convex curve. The radius of the guide wheel is greater in the part of the profile below the center 0_2 of the wheel's axis, with positive *a* (Fig. 3b).

The guide wheel's profile depends on *a*: with increase in *a*, a more rational profile is formed, with smaller fluctuations of the contact angle ϑ over the machining distance. With increase in α, the profile changes so as to become less symmetric relative to the plane $Z_2 = 0$, other conditions being equal. When R_1 is equal to or less than *L*, trimming of the profile is observed: that is, the wheel's profile is theoretically formed at values of *l* exceeding the geometric dimensions of the blank. As a result, the wheel radius R_2 becomes less than it would be for a blank of the initially specified length.

Thus, the proposed methods and formulas permit more precise calculation of the guide-wheel profiles in centerless grinding machines for cylindrical, conical, and cambered surfaces. With constantly increasing requirements on the dimensional and shape precision of machine parts, their use ensures the manufacture of parts satisfying current and prospective requirements.

REFERENCES

1. Ashkinazii, Ya.M., *Bestsenstrovye krugoshlifoval'nye stanki. Konstruktsii, obrabotka i pravka* (Centerless Grinding Machines: Design, Operation, and Straightening), Moscow: Mashinostroenie, 2003.
2. Brzhozovskii, B.M. and Zakharov, O.V., Shaping Guide Wheels in Centerless Grinding of Cylindrical Parts, *Stanki Instrum.*, 2005, no. 4, pp. 12–14.
3. Zakharov, O.V., Centerless Grinding of Conical Surfaces on Machine Tools with Longitudinal Supply, *Avtomat. Sovremm. Tekhnol.*, 2006, no. 7, pp. 14–16.
4. Zakharov, O.V., Centerless Grinding of the Cambered Surfaces of Bearing Rollers, *Avtomat. Sovremm. Tekhnol.*, 2007, no. 1, pp. 3–7.
5. Zakharov, O.V., *Minimizatsiya pogreshnostei formoobravoniya pri bestsentrovoi abrazivnoi obrabotke* (Minimizing the Shaping Errors in Centerless Abrasive Machining), Saratov: SGTU, 2006.
6. Zakharov, O.V. and Brzhozovskii, B.M., Straightening the Guide Wheel in a Centerless Grinding Machine, *Avtomat. Sovremm. Tekhnol.*, 2006, no. 9, pp. 20–23.
7. Russian Patent 43209.