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Rotational Stability of Blank in Centerless Grinding with Longitudinal Supply

O. V. Zakharov

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In centerless grinding with longitudinal supply, the relation between the blank and the basing elements of the machine tool is not mutual: in the contact of the blank and the basing elements, forces are exerted only by the blank (the cutting forces and the weight).

Therefore, the stability of the blank's rotation is determined by the frictional conditions at the points of contact with the basing elements. These conditions depend on the grinding forces. The stability of rotation may be regulated by changing the inclination of the supporting blade, the positional angles of the driving wheel and grinding wheel, the binder in the driving wheel, and the grinding conditions.

Centerless grinding with longitudinal supply was investigated in terms of the stability of the contact forces in [1–3]. In the present work, we use calculation schemes largely corresponding to the setup of industrial machine tools. The conclusions permit expansion and refinement of the results in [1, 3].

Consider the forces in the cross section of the blank during centerless grinding with longitudinal supply (Fig. 1). Suppose that the weight of the blank is negligible in comparison with the cutting force. The frictional forces at the ends of the blank will also be neglected.

The blank is in equilibrium if the sums Σ_x and Σ_y of the projection of the forces onto coordinate axes OX and OY are zero, and the sum Σ_M of the torques relative to the instantaneous center of revolution is also zero. Accordingly, the equilibrium equations may be written in the form

$$\left.\begin{aligned}
\Sigma_x &= P_y\cos\alpha_3 + P_z\sin\alpha_3 + N_1\sin\alpha_1 - R_1\cos\alpha_1\\
&- N_2\cos\alpha_2 - R_2\sin\alpha_2 = 0;\\
\Sigma_y &= P_y\sin\alpha_3 - P_z\cos\alpha_3 + N_1\cos\alpha_1 + R_1\sin\alpha_1\\
&+ N_2\sin\alpha_2 - R_2\cos\alpha_2 = 0;\\
\Sigma_M &= (P_z - R_1 - R_2)r = 0,
\end{aligned}\right\} \quad (1)$$

where P_y and P_z are the radial and tangential components of the cutting force; N_1 and N_2 are the normal components of the reaction forces at the contact points of the blank with the supporting blade and the driving wheel; R_1 and R_2 are the corresponding tangential components (frictional forces); α_1 is the skew angle of the supporting blade; α_2 and α_3 are adjustable angles specifying the position of the center of the blank relative to the driving wheel and grinding wheel r is the radius of the blank (Fig. 1).

Equation (1) applies in the case of constant speed of the blank, when it leads the driving wheel. When the blank lags the driving wheel, the direction of reaction R_2 is reversed.

The independent setup parameters of the machine tool are the angles α_1 and α_2, whose choice helps determine the profile of the driving wheel [4, 5]. In addition, α_1 and α_2 vary independently over the grinding length. The setup angle α_3 of the grinding wheel may be determined on the basis of the ratio of the driving-wheel radius r_{dw} and the grinding-wheel radius r_{gw} (in the relative positions in Fig. 1): $\alpha_3 = \tan^{-1}\{[(r_{\text{dw}} + r)/(r_{\text{gw}} + r)]\sin\alpha_2\}$.

The component P_y of the cutting force in grinding depends on the cutting depth. The components P_z may be determined as $P_z = kP_y$, where $k = 0.3$–1 is the cutting coefficient [1]. Sharp grinding wheels are characterized by large k, and blunt wheels by small k.

The tangential forces R_1 and R_2 are expressed in terms of the normal reaction forces N_1 and N_2 and the frictional coefficients f_1 and f_2 of the blank with respect to the supporting blade and driving wheel, respectively;

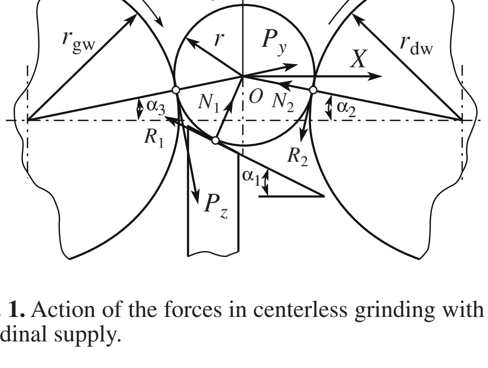

Fig. 1. Action of the forces in centerless grinding with longitudinal supply.

this is acceptable for steady motion or for transition from rest to rotation: $R_1 = f_1N_1$; $R_2 = f_2N_2$.

The experimental maximum values of f_2 for different materials, binder, and straightening rate of the driving wheel are given in [2]. In particular, for a driving wheel with vulcanite binder, at a longitudinal straightening rate of 300 mm/min, $f_2 = 0.34$; for steel driving wheels, $f_2 = 0.17$.

Taking account of the notation adopted, Eq. (1) may be written in the form

$$\left.\begin{aligned}&P_y(\cos\alpha_3 + k\sin\alpha_3) + N_1(\sin\alpha_1 - f_1\cos\alpha_1)\\&-N_2(\cos\alpha_2 + f_2\sin\alpha_2) = 0;\\&P_y(\sin\alpha_3 - k\cos\alpha_3) + N_1(\cos\alpha_1 + f_1\sin\alpha_1)\\&+N_2(\sin\alpha_2 - f_2\cos\alpha_2) = 0;\\&kP_y - f_1N_1 - f_2N_2 = 0.\end{aligned}\right\} \quad (2)$$

Using Eq. (2), we find the boundary condition of stable blank rotation, without twisting or stopping. To this end, we derive an expression for P_y from the last relation in Eq. (2) and substitute it into the first two relations. As a result, we may write the condition of stable rotation of the blank, for any cutting force, in the form

$$\begin{aligned}&\sin(\alpha_1 - \alpha_2)(f_2 - f_1) - \cos(\alpha_1 - \alpha_2)(1 + f_1f_2)\\&+ f_1(b\cos\alpha_1 + c\sin\alpha_1) + f_2(a\cos\alpha_2 - d\sin\alpha_2)\\&- a\sin\alpha_2 - b\sin\alpha_1 + c\cos\alpha_1 - d\cos\alpha_2\\&- ab + cd = 0,\end{aligned} \quad (3)$$

where

$$a = f_1(k\cos\alpha_3 + \sin\alpha_3); \quad b = f_2(k\sin\alpha_3 - \cos\alpha_3);$$

$$c = f_2(k\cos\alpha_3 + \sin\alpha_3); \quad d = f_1(k\sin\alpha_3 - \cos\alpha_3).$$

On the basis of the last relation in Eq. (2), we may write a condition for twisting of the blank by the grinding wheel, when it leads the driving wheel, and a condition for stopping of the blank, when it lags the driving wheel

$$kP_y - f_1N_1 \mp f_2N_2 \gtrless 0, \quad (4)$$

where the upper signs correspond to twisting, and the lower signs to stopping.

These conditions may be rewritten in the form

$$\begin{aligned}&(kn - f_1l)[n(\sin\alpha_2 - f_2\cos\alpha_2)\\&+ m(\cos\alpha_2 + f_2\sin\alpha_2)]\\&\mp f_2n[ml - n(\sin\alpha_3 - k\cos\alpha_3)] \gtrless 0,\end{aligned} \quad (5)$$

where $n = \sin\alpha_1 - f_1\cos\alpha_1$; $l = \cos\alpha_3 + k\sin\alpha_3$; $m = \cos\alpha_1 + f_1\sin\alpha_1$; the upper signs again correspond to twisting, and the lower signs to stopping.

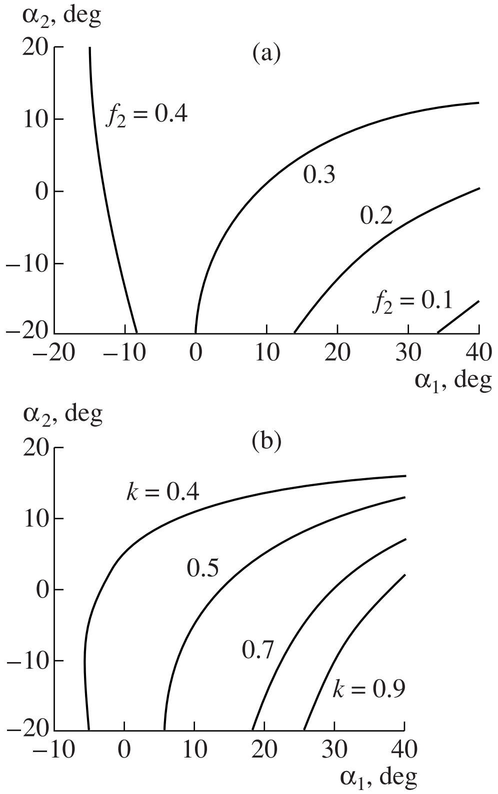

Fig. 2. Stability curves for blank rotation as a function of the frictional coefficient f_2 when $f_1 = 0.15$ and $k = 0.4$ (a) and as a function of the cutting coefficient k when $f_1 = 0.17$ and $f_2 = 0.34$ (b).

Using Eqs. (3)–(5), we investigate the contact closure in centerless grinding, in the case of stable blank rotation. Stability curves are plotted in Fig. 2a as a function of the frictional coefficient f_2 at the driving wheels in angular coordinates α_1 and α_2, when $f_1 = 0.15$ and $k = 0.4$. (These values of f_1 and k correspond to preliminary grinding of the bearing wheels by means of hard-alloy cutters.) If we assume $r_{dw} = r_{gw}$, then $\alpha_2 = \alpha_3$.

The region of stable rotation of the blank by the driving wheel in Fig. 2a is to the right of the curves corresponding to $f_2 = 0.1$, 0.2, and 0.3 (and conversely for $f_2 = 0.4$). The region of twisting of the blank lies to the left of these curves. No region of stopping of the blank according to Eq. (5) is seen over the whole range of α_1 and α_2 when $f_2 = 0.1$–0.4.

For rotation of the blank, stability curves in terms of α_1 and α_2 are shown in Fig. 2b as a function of the cutting coefficient k, when $f_1 = 0.17$ and $f_2 = 0.34$. These data correspond to the machining of bearing wheels by means of a driving wheel with vulcanite binder and a hard-alloy blade.

Analysis of Fig. 2 shows that increasing the frictional coefficient of the driving wheel expands the permissible ranges of α_1, α_2, and α_3. When $f_2 < 0.2$, only

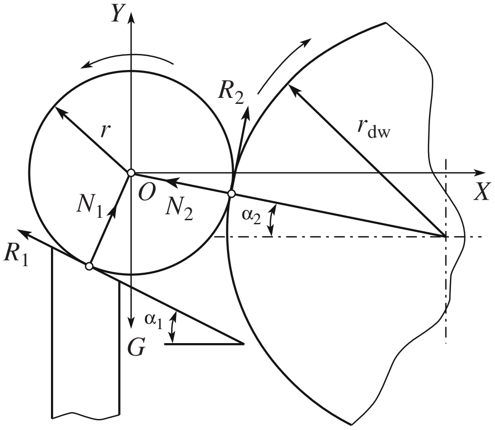

Fig. 3. Action of forces in centerless basing.

negative α_2 may be used. This case corresponds to grinding with a metallic driving wheel when the axis of the blank is below the line connecting the axes of the two wheels. The correctness of this recommendation is confirmed by the data of foreign firms (for example, Modler, Germany [2]).

When $f_2 > 0.4$, practically all the angles used in practice are permissible ($-10° \le \alpha_1 \le 40°$; $-20° \le \alpha_{2,3} \le 20°$). With increase in k, the permissible angles are shifted to the region $\alpha_1 > 0$, $\alpha_2 < 0$.

Stable rotation of the blank is required not only in the working zone of the machine tool but also on entering and leaving this zone, i.e., at points with no cutting force. Here, the blank may be set in rotation by means of additional devices, such as sprung levers or rotating rollers (without a built-in drive). However, a better approach is rational selection of the machine-tool's adjustable parameters, as well as the materials of the supporting blade and the driving wheel.

Consider the forces acting in the cross section of the blank, in the absence of cutting forces, i.e., in the absence of the grinding wheel (Fig. 3). The equilibrium equations of the blank then take the form

$$\left.\begin{aligned}\Sigma_x &= N_1\sin\alpha_1 - R_1\cos\alpha_1 - N_2\cos\alpha_2\\ &\quad + R_2\sin\alpha_2 = 0;\\ \Sigma_y &= N_1\cos\alpha_1 + R_1\sin\alpha_1 + N_2\sin\alpha_2\\ &\quad + R_2\cos\alpha_2 - G = 0;\\ \Sigma_M &= (R_2 - R_1)r = 0,\end{aligned}\right\}\qquad(6)$$

where G is the weight of the blank.

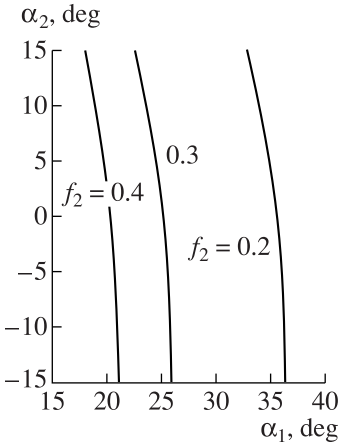

Fig. 4. Curves corresponding to the boundary condition of contact closure as a function of the frictional coefficient f_2 when $f_1 = 0.1$.

On the basis of the notation adopted, we may write Eq. (6) in the form

$$\left.\begin{aligned}&N_1(\sin\alpha_1 - f_1\cos\alpha_1)\\ &+ N_2(f_2\sin\alpha_2 - \cos\alpha_2) = 0;\\ &N_1(\cos\alpha_1 + f_1\sin\alpha_1)\\ &+ N_2(\sin\alpha_2 + f_2\cos\alpha_2) - G = 0;\\ &f_2N_2 - f_1N_1 = 0.\end{aligned}\right\}\qquad(7)$$

The condition for stable rotation of the blank takes the form

$$f_2\sin\alpha_1 - f_1\cos\alpha_2 + f_1f_2(\sin\alpha_2 - \cos\alpha_2) > 0.$$

The boundary condition for stable rotation of the blank may be explained in explicit form by solving Eq. (7) for α_1

$$\alpha_1 = 2\arctan\frac{1 + \sqrt{1 - f_1^2(1 - \sin\alpha_2 + \cos\alpha_2/f_2)^2}}{1 + \sin\alpha_2 - \cos\alpha_2/f_2}.$$

The curves corresponding to the boundary condition of contact closure are plotted in Fig. 4 as a function of the frictional coefficient f_2, in terms of the coordinates α_1 and α_2, when $f_1 = 0.1$. The region of stable rotation of the blank lies to the right of the curves corresponding to $f_2 = 0.2$, 0.3, and 0.4.

Analysis of Fig. 4 shows that rotation of the blank is stable if $f_2 > 2f_1$. In the absence of the grinding wheel, α_1 must be larger than in grinding. With increase in f_2, the region of permissible α_1 expands. Both positive and negative α_2 values are possible.

Our research indicates that correct choice of the angles α_1, α_2, and α_3 and also the driving-wheel material and binder and the grinding conditions ensures stable rotation of the blank in machining and also on entering and leaving the machine tool's working zone.

Experiments in the machining of rollers and bearing rings on Mikrosa (Germany) SASL-200 × 500 and SASL-5AD machine tools confirm the validity of our recommendations for the adjustment of centerless grinding machines with longitudinal supply.

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