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SYNTHESIS OF INSTRUMENTS FOR CYLINDRICAL GEAR WHEELS ROLLING

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Summary. Instrument for spur and helical gears rolling has been proposed. Methods of its design have been presented. Major geometric and kinetic parameters of gear rolling process using developed instrument have been determined.

Key words: Hyperbola, syntheses, relative speed, knurling, teeth wheel, spur teeth, helical teeth, involute profile.

INTRODUCTION

Rolling of cylindrical gear wheels is one of the most widely used processes of finishing and reinforcing teeth treatment. Knurling tools existing in industry has a number of drawbacks causing deformation of rolled tooth profile. The given investigation synthesizes hyperbola rollers for knurling spur and helical cylindrical teeth wheels having an involute profile obtained in space machine-tool engagement on work-pieces of 'one cavity hyperbola' type.

RESEARCH OBJECT

Increase of spur and helical cylindrical teeth wheels having an involute profile loading capacity is an actual task because they allow to design space-saving structures which find wide application in production of reduction units [Kudryavzev 1971], automobile and aviation engines [Davydov 1950], metal cutting machine-tools [Korostelev 1964] etc.

Teeth wheels loading capacity may be increased by using teeth rolling and teeth finishing tools, obtained by the authors in a space machine-tool engagement. Hyperbola rollers, rollers produced according to this technology, may be used at any machine-building works.

At present teeth knurling is performed with the help of cylindrical rollers. In the result of mutual relative sliding of work-piece teeth profiles and instrument at the opposite sides of rolled wheel tooth, excess material moves in different directions (fig.1). On driven and driving sides of a wheel tooth profile an excess metal moves unequally. On the driving side of tooth profile metal moves from the tooth head and flank to the indexing circle where metal heaping takes place resulting in formation of ridge or so called hill.

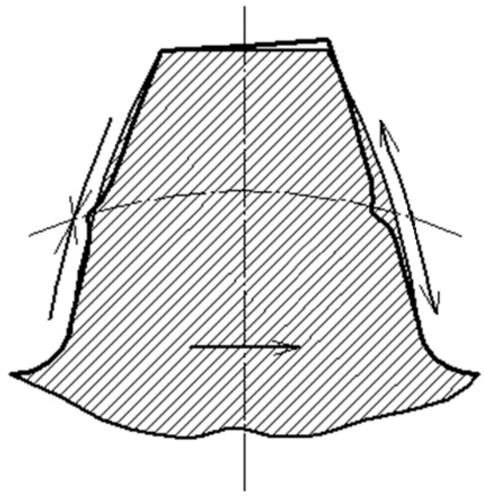

Fig. 1. Teeth profile deformation in the process of its rolling

On the opposite side of tooth profile, on the other hand, metal flows to the tooth head and flank , as a result a cavity appears in the zone of indexing circle. Subsequently, a hill and a cavity should be removed using additional technological operations such as grinding, shaving, honing, which increase the cost of wheels production and, which is more important, at this the most strong layer is removed which reduces load-carrying capability of rolled teeth wheels.

As it is impossible to eliminate teeth sliding in the process of rolling, one should aim at obtaining sliding along indexing diameter as well, than at adjusting the sliding along the whole tooth height. This can be obtained crossing the treated teeth wheel and roller shafts. At this we have the task to determine geometryof rolling tool and geometrical and kinematic indices arising in the processes of teeth gear-wheels rolling.

RESULTS OF EXPERIMENTAL RESEARCH

Relative speed (sliding speed); specific sliding; total speed of rolled teeth surfaces movement in direction perpendicular to characteristics (contact lines), angle between relative speed of sliding vector and characteristics direction refer to kinematic indices influencing on the process of rolling.

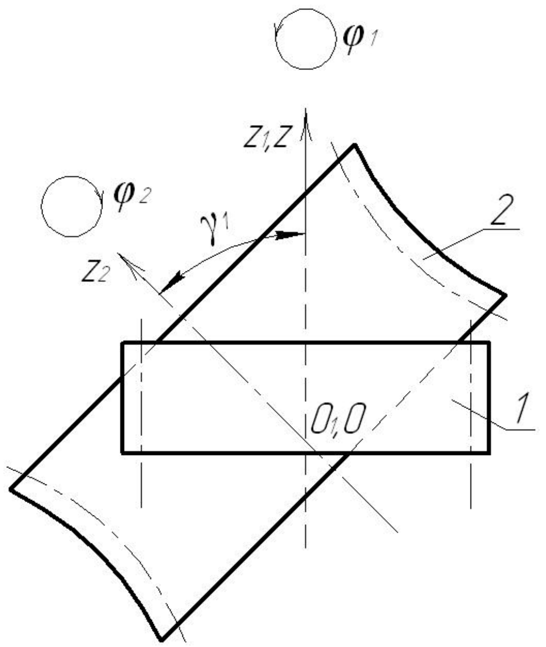

Fig. 2. Teeth wheel knurling by means of hyperbola roller

Figure 2 shows cylindrical teeth wheel 1, knurled by hyperbola roller 2. Rotating coordinate systems $S_1(x_1 y_1 z_1)$ and $S_2\,(x_2\,y_2\,z_2\,)$ are connected with the wheel and the roller respectfully. Counting of movable systems if performed from stationary system $S(xyz)$, where γ - an angle of shaft axes crossing; a_w - beeline between shafts. Let us make a transfer from coordinate system S_1 to S_2 in several steps [Litvin 1968]:

1.) $S_1 \rightarrow S$ Pivot turn z to the angle φ_1. In matrix form this transfer is presented as: $r = M_{01} r_1$, where r and r_1 - are radius-vectors matrices of one and the same spot of tooth wheel in the system S and S_1, M_{01} - matrix of transfer from coordinate system S_1 to S:

$$M_{01} = \begin{Vmatrix} \cos\varphi_1 & -\sin\varphi_1 & 0 & 0 \\ \sin\varphi_1 & \cos\varphi_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{Vmatrix},$$

2.) $S \to S_p$ Let us transfer the origin of coordinate system S to the origin of coordinate system S_2 and turn this system by angle γ of shaft axes crossing. As the result we shall have :

$$M_{po} = \begin{Vmatrix} 1 & 0 & 0 & a_w \\ 0 & \cos\gamma & -\sin\gamma & 0 \\ 0 & \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 0 & 1 \end{Vmatrix},$$

3.) Continuing in the same way, we shall determine the final matrix M_{21} of transference from S_1 to S_2:

$$M_{21} = \begin{Vmatrix} \begin{matrix}\cos\varphi_1\cos\varphi_2 + \\ +\cos\gamma\sin\varphi_1\sin\varphi_2\end{matrix} & \begin{matrix}-\sin\varphi_1\cos\varphi_2 + \\ +\cos\gamma\cos\varphi_1\sin\varphi_2\end{matrix} & -\sin\gamma\sin\varphi_2 & a_w\cos\varphi_2 \\ \begin{matrix}-\cos\varphi_1\sin\varphi_2 + \\ +\cos\gamma\sin\varphi_1\cos\varphi_2\end{matrix} & \begin{matrix}\sin\varphi_1\cos\varphi_2 + \\ +\cos\gamma\cos\varphi_1\cos\varphi_2\end{matrix} & -\sin\gamma\cos\varphi_2 & -a_w\sin\varphi_2 \\ \sin\gamma\sin\varphi_2 & \sin\gamma\cos\varphi_1 & \cos\gamma & 0 \\ 0 & 0 & 0 & 1 \end{Vmatrix}.$$

Using matrix of transfer from treated cylindrical teeth wheel coordinate system $S_1(x_1 y_1 z_1)$ to rolling tool coordinate system $S_2(x_2 y_2 z_2)$, that is M_{21}, we shall obtain the following expressions to determine equations of range of surfaces describing hyperbola rolling tool in question :

$$x_2 = f_1(x)(\cos\varphi_1\cos\varphi_2 + \cos\gamma\sin\varphi_1\sin\varphi_2) + f_2(\lambda)(\cos\gamma\cos\varphi_1\sin\varphi_2 - \\ -\sin\varphi_1\cos\varphi_2) - z\sin\gamma\sin\varphi_2 + a_w\cos\varphi_2)$$

$$y_2 = f_1(\lambda)(\cos\gamma\sin\varphi_1\cos\varphi_2 - \cos\varphi_1\sin\varphi_2) + f_2(\lambda)(\sin\varphi_1\sin\varphi_2 + \\ +\cos\gamma\cos\varphi_1\cos\varphi_2) - z\sin\gamma\cos\varphi_2 - a_w\sin\varphi_2) \tag{1}$$

$$z_2 = f_1(x)\sin\gamma\sin\varphi_1 + f_2(\lambda)\sin\gamma\cos\varphi_1 + z_2\cos\gamma,$$

where: $f_1(x), f(x)$ -are functions describing roller tooth depending on parameter λ.

Presented system is a range of rolling surfaces.

To obtain knurling teeth of rolling tools it is necessary to add a well-known from the engagement theory bridging equation to the obtained system of equations

$\vec{N} \cdot \vec{V}^{12} = 0$ [Tepinkichnev 1973], where $\vec{N}$ - is a vector of normal to roller mating surfaces and rolled wheel; $\vec{V}^{12}$ - is a vector of relative speed (sliding speed).

Then:

$$\vec{N} \cdot \vec{V}^{12} = -(1 - u_{21} \cos\gamma)(f_1' E + f_2 f_2') - z u_{21} \sin\gamma (f_2' \cos\varphi_1 + f_1' \sin\varphi_1) -$$
$$- a_w u_{21} \cos\gamma (f_2' \sin\varphi_1 - f_1' \cos\varphi_1) = 0$$

Taking into consideration the results of investigations and others, we shall find dependences, estimating a character of cylindrical gear wheels teeth rolling. These dependences are obtained for the case when rolled wheels profiles are outlined by random curve. Relative sliding speed projections in coordinate system $S_1(x_1 y_1 z_1)$:

$$\left.\begin{aligned} V_x^{(12)} &= -[f_1 \sin\varphi_1 + f_2 \cos\varphi_1](1 - u_{21} \cos\gamma) + \\ &+ \frac{a_w \cos\gamma (f_2' \sin\varphi_1 - f_1' \cos\varphi_1) - (1 - u_{21} \cos\gamma)(f_2 f_2' - f_1 f_1')}{f_2' \cos\varphi_1 - f' \sin\varphi_1} \\ V_y^{(12)} &= (f_1 \cos\varphi_1 - f_2 \sin\varphi_1)(1 - u_{21} \cos\gamma) - a_w u_{21} \cos\gamma \\ V_z^{(12)} &= (f_1 \cos\varphi_1 - f_2 \sin\varphi_1 + a_w) u_{21} \sin\gamma \end{aligned}\right\} \quad (2)$$

Specific sliding for rolled teeth wheel and a roller have the following levels:

$$\eta_1 = -\frac{(\vec{V}^{(12)} \vec{r}_1^{\,\mu})[(f_1')^2 - (f_2')^2] F^{\mu} (f_2 f_2' - f_1 f_1')}{f_2' \cos\varphi_1 - f' \sin\varphi_1}, \quad (3)$$

$$\eta_2 = (f_1 \cos\varphi_1 - f_2 \sin\varphi_1)(1 - u_{21} \cos\gamma) - a_w u_{21} \cos\gamma.$$

Total speed of teeth surfaces transfer in direction perpendicular to the contact line

$$u_\tau = \frac{2F^{\varphi_1}[(f_1')^2 + (f_2')^2] - F^{\lambda}(\vec{r}_1^{\,\lambda} \vec{V}^{(12)}) - [(f_1')^2 + (f_2')^2] F^{\mu} (\vec{r}_1^{\,\mu} \vec{V}^{(12)})}{\vec{V}^{(12)}[(f_1')^2 + (f_2')^2]\{[(f_1')^2 + (f_2')^2] F^{\mu} + (F^{\lambda})^2\}} \quad (4)$$

The angle between relative sliding speed vector and direction of contact line:

$$tgV_\tau = \frac{-F^{\mu}[(f_1')^2 + (f_2')^2](\vec{r}_1^{\,\mu} \vec{V}^{(12)}) - F^{\lambda}(\vec{r}_1^{\,\lambda} \vec{V}^{(12)})}{[(\vec{r}_1^{\,\mu} \vec{V}^{(12)}) F^{\lambda} - (\vec{r}_1^{\,\lambda} \vec{V}^{(12)}) F^{\mu}]\sqrt{(f_1')^2 + (f_2')^2}} \quad (5)$$

In presented expressions derivatives $F^{\varphi_1}, F^{\lambda}, F^{\mu}$ are determined from equations (3), (4), (5), and expressions $\vec{r}_1^{\,\mu} \vec{V}^{(12)}$ and $\vec{r}_1^{\,\lambda} \vec{V}^{(12)}$ have the following view :

$$\begin{aligned} \vec{r}_1^{\,\lambda} \vec{V}^{(12)} = (-f_1' f_2 + f_2' f_1)(1 - u_{21} cos\gamma) - \mu i_{21} sin\gamma (f_1' cos\varphi_1 - f_2' sin\varphi_1) \\ - a_w u_{21} cos\gamma (f_1' sin\varphi_1 + f_2' cos\varphi_1) \end{aligned} \quad (6)$$

$$\vec{r}_1^{\,\mu} \vec{V}^{(12)} = f_1 cos\varphi_1 - f_2 sin\varphi_1 + a_w u_{21} sin\gamma$$

Numerical analysis of presented expressions determining geometric and kinematic parameters of rolling reveals that kinematic (2), (3), (4) and geometric (5) reading on roller which presents one-cavity hyperbola are changing depending on coordinate z_2, that is width of hyperbola roller. That is why, having calculated given indices, we shall find necessary cross section of a roller in question on axis z_2, where minimal coefficients of specific slid η_1 and η_2, influencing on the metal transfer as well as on sections with favorable total transfer speed and maximum angle between relative sliding speed vector and contact lines (characteristics) direction. Having found his cross section, it is easy to produce hyperbola roller, having a profile which can be determined if we have found coordinates x_2 and y_2 from the equation system (1) for the certain z_2. At this roller sizes can be easily determined from the known (6) parametric equations :

$$z_2 = -a_w \frac{cos^2\gamma}{sin\gamma} tg\psi - rsin\gamma sin\psi \tag{7}$$

$$\rho = a_w - rcos\psi\sqrt{1 + cos^2\gamma tg^2\psi}$$

where: a_w - axle base; r - cylinder radius, which is the size of rim clearance bigger than a rolled wheel cylinder cavity radius by the size of rim clearance; ψ - parameter.

At present experiments on spur wheels rolling have been carried out $m_n = 1{,}5; z = 50$. A number of hyperbola roller teeth $z = 10$; gradient angle $\beta = 63°$. Test rolling of cylinder helical wheel was performed with the same roller $z = 29$; $\beta = 27°$. Instrument profiling has been carried out at the gear hobbing machine-tool 5D32. Index change gear trains, differential mechanisms, vertical feed have been calculated traditionally according to the machine-tool passport. Process of abovementioned rollers production is shown on Figures 3 and 4.

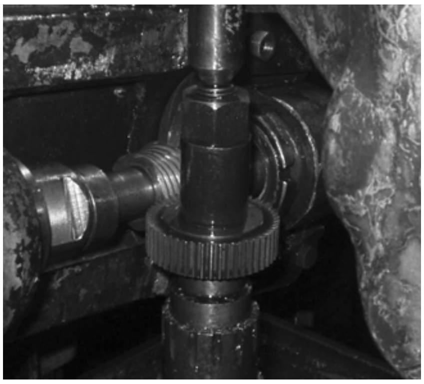

Fig.3 Spur roller knurling.

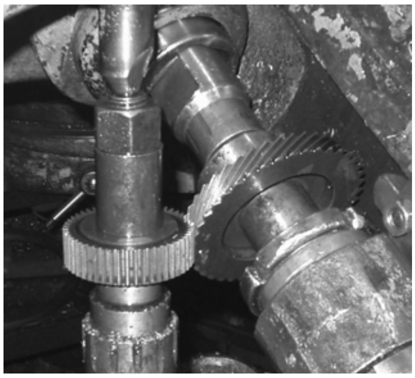

Fig.4 Helical roller knurling.

CONCLUSION

Principally new knurling instruments obtained in a space machine-tool engagement on work-pieces of 'one-cavity hyperbola' type have been developed. Hyperbola rollers which can be used in knurling of cylindrical wheels both with spur and helical teeth have been synthesized.

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СИНТЕЗ ИНСТРУМЕНТОВ ДЛЯ НАКАТЫВАНИЯ ЦИЛИНДРИЧЕСКИХ ЗУБЧАТЫХ КОЛЕС

Кашура А.Л., Кириченко И.А., Витренко В.А.

Аннотация. Синтезированы инструменты для накатки зубьев цилиндрических зубчатых колес с эвольвентным профилем, полученные в пространственном станочном зацеплении на заготовках вида «однополостной гиперболоид».

Ключевые слова: гиперболоид, синтез, относительная скорость, накатка, удельные скольжения, приведенная кривизна.