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Equations of Rounded-Edge Profile for a Ring Gear in a Wave Reducer with Intermediate Rolling Elements

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Abstract

The paper considers geometrical parameters of a ring gear for a wave gear with rolling elements. A coordinate system is selected. Parametric equations for the ring gear profile are deduced. An equation for rounded edges of the ring gear is developed to increase the transmission efficiency and shorten the ring gear's running-in period. An epicycloidal ring gear profile is plotted in AutoCad. A sample model produced from these calculations is shown. The product is intended for use in the design of a hand-held electric drill on the base of a commutator motor with useful capacity of 1 kW.

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Keywords: electric drill; commutator motor; wave reducer; intermediate rolling elements; ring gear profile; wear debris; epicycloid; rounding radius; parametric equations.

1. Introduction

An electric drill power tool based on a commutator motor with a wave reducer with intermediate rolling elements was previously described in [1]. Features of this machine include compactness and small weight (Fig.1). It was achieved by using a commutator motor whose mass-to-power ratio is small compared to other types, together with a wave gearing with intermediate rolling elements which outperforms other existing mechanical types of transmission [2]. The profile of the ring gear of the wave gearing with intermediate rolling bodies is an epicycloid [3, 4] with a number of valleys exceeding the number of rolling elements by one. Such ring gear profile has sharp

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edges in points where one valley meets the other. At the first stage of the running-in period these edges undergo intensive wear and wear particles find their way into the contact zone between the rolling elements and the ring gear thus decreasing the transmission efficiency. Equations for rounded ring gear were developed to rectify this drawback.

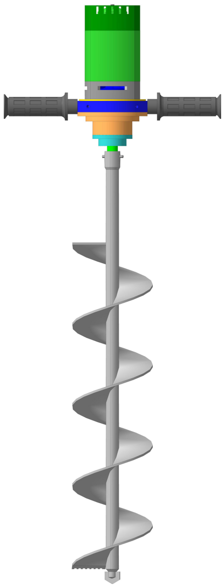

Fig. 1. Hand-held electric drill.

The hand-held electric drill is able to drill holes with a diameter of 100 mm to a depth of 1m in soils of any category.

2. Equations of rounded-edge profile

To obtain a set of parametric equations for the rounded edge of the ring gear let us introduce a new coordinate system and several notations while keeping the kinematic scheme of the mechanism unchanged (Fig.2).

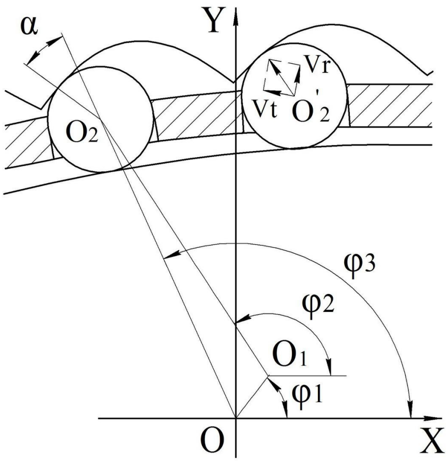

Fig.2. A new coordinate system

OO_1 is the generator's eccentricity; OO_2 is a distance between the centres of the crown and the roller; O_1O_2 is a distance between the centers of the generator and the roller; φ_1, φ_3 are the current angles of the generator and the separator respectively; φ_2 is a rotational angle of an imaginary rod (O_1O_2); α is the movement transmission angle.

Let us designate:

$$OO_1=\vec{L_1};\ O_1O_2=\vec{L_2};\ OO_2=\vec{L_3},\ \text{then:}\ \vec{L_1}+\vec{L_2}=\vec{L_3} \quad (1)$$

Applying Euler transformation we may write the parametric equations for the ring gear profile in the following form:

$$\begin{cases} x = L3\cdot\cos(\varphi_3) + 0{,}5\cdot D_r\cdot\cos(\varphi_3-\alpha); \\ y = L3\cdot\sin(\varphi_3) + 0{,}5\cdot D_r\cdot\sin(\varphi_3-\alpha). \end{cases} \quad (2)$$

Dr is the rolling element diameter (the element can be a ball or a roller).

$$L3=\sqrt{L_1^2\cdot\cos^2\left[(U-1)\cdot\frac{\pi}{2}-U\cdot\varphi_3\right]-L_1^2+L_2^2}+L1\cdot\cos\left[(U-1)\cdot\frac{\pi}{2}-U\cdot\varphi_3\right] \quad (3)$$

where U is number of valleys of the epicycloids.

Transmission angle is found from the function:

$$\tan(\alpha)=\frac{V_r}{V_t} \quad (4)$$

Vr is the radial component of the O'_2 centre movement speed,

Vt is the tangential component of the O'_2 centre movement speed.

Let us deduce the equation to obtain rounded edges on the ring gear. For that end we create an analytic model (Fig.3).

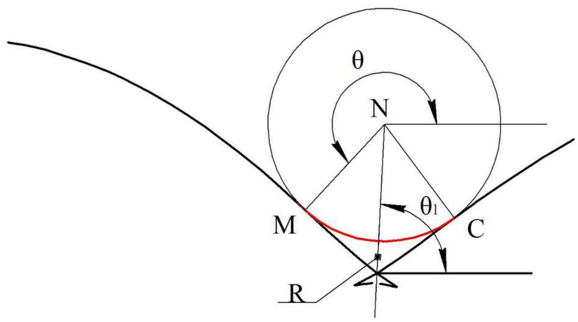

Fig.3. Analytic model

MC is the edge rounding arc; $N(x_0,y_0)$ are the coordinates of the rounding circle centre; R is the distance between the centres of the ring gear and rounding circle; NC is the radius of the rounding circle (*r*); θ is the angle between the normal to the tangent line raised from point M and the X axis; θ_1 is the angle between interval R and the X axis.

The rounding circle radius is chosen dependently on the rolling element diameter in the range: *r*=0.05…0.055 *Dr*.

Then we may write the equation for the rounding arc in the following form:

$$\begin{cases} x = R \cdot \cos(\theta_1) + r \cdot \cos(\theta + \Delta\theta); \\ y = R \cdot \sin(\theta_1) + r \cdot \sin(\theta + \Delta\theta). \end{cases} \tag{5}$$

Angles θ and θ_1 are calculated from the functions:

$$\theta = \varphi_3 - \alpha + \pi \tag{6}$$

$$\theta_1 = \pi/2 - \pi/U \tag{7}$$

The coordinates of the point $M(x_n,y_n)$. The coordinates of the centre of the rounding circle $N(x_0,y_0)$ in at the crossing point of the intervals R and MN, defined by the functions:

$$\begin{cases} y_0 = k_1 x_0; \\ y_0 = k_2 (x_0 - x_n) + y_n. \end{cases} \tag{8}$$

Where: for the straight line R:

$$k_1 = \tan(\pi/2 - \pi/U); \tag{9}$$

for the straight line MN:

$$k_2 = \tan(\varphi_3 - \alpha). \tag{10}$$

Thus, all the necessary equations are deduced allowing us to plot the rounded-edge profile of the ring gear of the wave gear with intermediate rolling elements.

3. Results and discussion

The formulas (1, 2) were used to calculate the coordinates of the ring gear for the wave gear with intermediate rolling elements in MathCad 15 software package [5]. From these coordinates an epicycloid with sharp edges was plotted (Fig.4, a) with characteristic loops in locations where valleys meet protrusions (Fig.4, b).

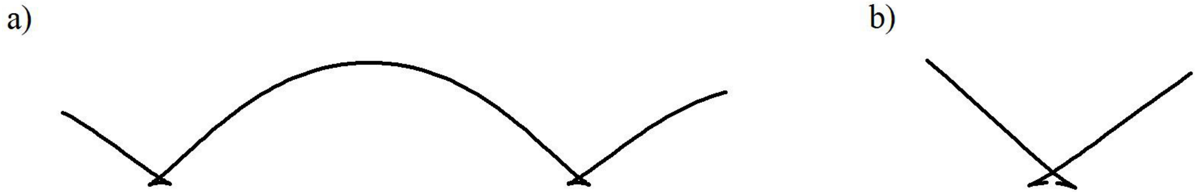

Fig.4. (a) fragment of the epicycloids; (b) loop at the sharp.

Then the coordinates were calculated for the epicycloid with rounded edges in accordance with the equations (2-10). The results of the calculation are given in table 1.

Table 1. Coordinates of a part of the epicycloid.

№	1	2	3	4	5	6	…	264	265	266	267	268	269
X(mm)	0	0.018	0.036	0.054	0.072	0.090	…	2.293	2.294	2.296	2.297	2.298	2.300
Y(mm)	45.125	45.124	45.124	45.124	45.123	45.123	…	43.900	43.900	43.900	43.900	43.900	43.900

After that the AutoCad software package [6] was used to plot the ring gear profile curve (Fig.5).

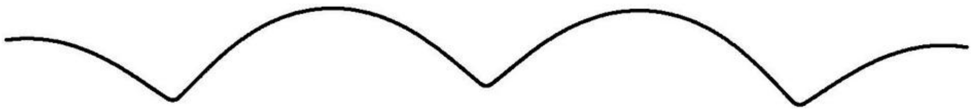

Fig.5. A fragment of a rounded-edge epicycloid.

A file containing the ring gear profile curve was loaded into ADEM software [7], which was used to create machine-specific instructions for Emco Concept Mill 155 NC control block.

4. Conclusion

Thus, all the necessary equations were derived allowing us to plot the rounded-edge ring gear of the wave drive with intermediate rolling elements. From the coordinates calculated a set of machine-specific instructions was created for the NC control block and a sample model was produced. The ring gear profile with rounded edges will shorten the burn-in time of the gear, eliminate large part of wear products coming into the contact zone between the intermediate rolling elements and the ring gear, thus increasing efficiency, reliability and lifetime of the transmission.

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