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Epicycloidal Gear Shaping Machine

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Abstract: In order to manufacture epicycloidal gears used in cycloidal drives, a machine was designed to generate the epicycloidal and equidistant profiles of the shortened epicycloid. The designed machine mainly consists of two interchangeable gears, whose division diameters are equal to the diameters of the epicycloid generators. The shortened epicycloid generator point is materialized by the shaft of the shaft mill, while the circle whose center is the generating point and materializes the equidistant to the shortened epicycloid is represented by either the shaft mill or the mill. The piece execution required movements are the cutting motion (shaft mill spin), non-slip rolling motion, and circular feed motion. These motions are accomplished through a kinematic chain composed from a feeder box, a gearbox, and an eccentricity adjustment mechanism.. The adjustment of the feed gain, of the generating gear radius ratios, and of the eccentricity of the generator point are accomplished manually with the aid of sliding sled devices equipped with graded drums. The feeder box and the gearbox are driven by two DC motors, their required power alongside the cutting parameters being determined according to the included formulae.

Keywords: epicycloidal gear, equidistant profile, design, manufacture machine, materialization

1. General information

The current solution of epicycloidal gear design represents the materialization of the theoretical definition of the epicycloid.

The epicycloid is a planar curve [1, 2, 4, 5] generated in the plane of a base circle C_b by a point G attached to the generating circle C_g which is rotating without slipping on the exterior circumference of the fixed base circle C_b (*Fig. 1*).

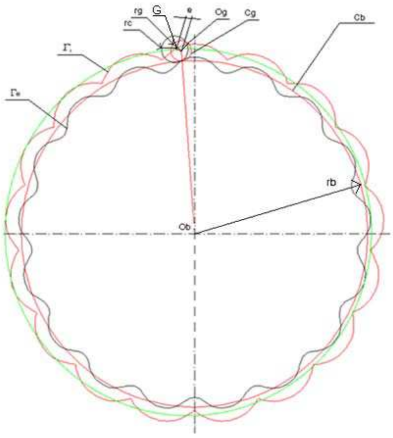

Figure 1: Generating the shortened epicycloid and the equidistant profiles

Gears with an epicycloidal profile are employed in bolt cycloidal speed reducers [3, 4, 5] (also called cycloidal drives) in which the satellite gear with a number of z teeth with an epicycloidal profile engages with $z+1$ bolts. This way, the generator point G that is attached to the generating circle C_g, situated inside it at a distance of e from its center O_g will produce z branches of the shortened epicycloid Γ_t. If in point G we fasten a bolt of radius r_c, this will envelop an equidistant to the shortened epicycloid Γ_e, which, if materialized (*Fig.2*), represents the satellite gear of the speed reducer.

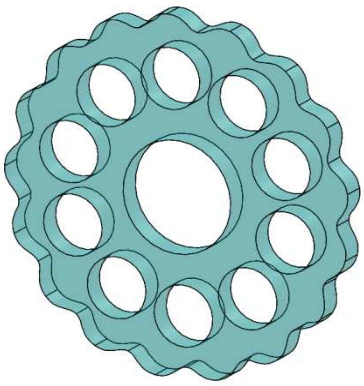

Figure 2: Epicycloid gear (isometric view)

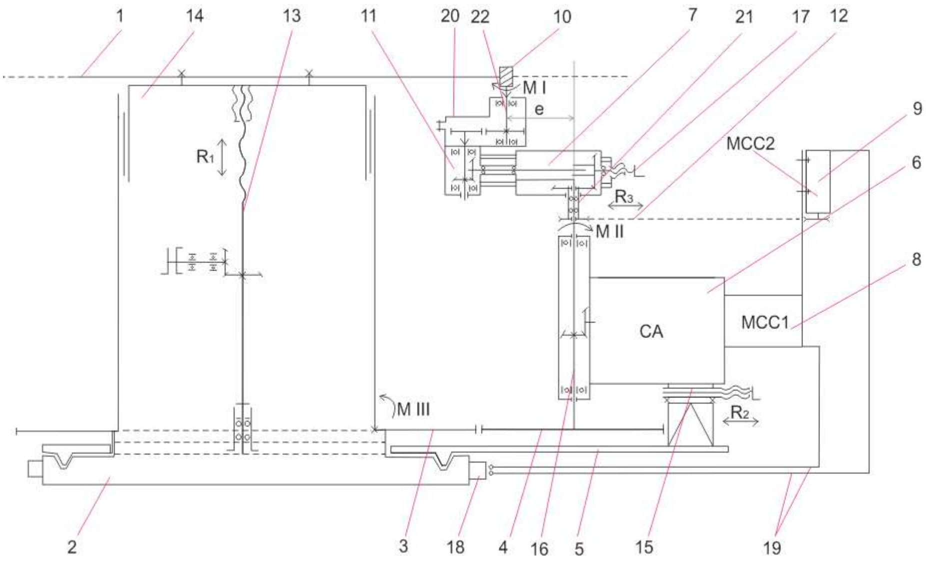

Figure 3: Machine that performs the toothed planetary gear

The machine that can manufacture the epicycloidal gear is described below (*Fig.3*) and has the following components:

1 - Workpiece blank;
2 - Circular guide frame;
3 - Fixed gear (rack), materializing circle $C_{b;}$
4 - Rolling gear, materializing circle C_g;
5 – Sledge with Circular guide;
6 - Cutting box advance (milling or grinding);
7 - Cutting box gearbox;
8 - DC motor for advance (MCC1);
9 - DC motor for cutting (MCC2);
10 - Grinding bit or abrasive disc;
11 - Shaft mill spindle;
12 -Transmission belt;
13 - Workpiece raising-lowering mechanism (R_1);
14 - Plate;
15 - Slide adjustment mechanism (R_2);
16 - Vertical spindle for rolling movement (MII);
17 - Slide adjustment mechanism for eccentricity **e** (R_3);
18 - Ring rail for DC power supply;

19 - Power cable with collector brushes;
20 - Shaft mill spindle adapter for small eccentricities;
21 - Belt wheel bloc – conical gear;
22 - Shaft mill spindle for small dimensions.

Certain elements of this machine are able to perform the technological motions as follows:

- M_I - shaft mill rotation (cutting);
- M_{II} - no-slip rotation;
- M_{III} - circular feed;
- R_1 - manual adjustment for penetration feed;
- R_2 - manual adjustment of radius of generating circles radius ratio;
- R_3 - manual adjustment of eccentricity **e.**

Frame 2 supports all the other mechanisms which compose the gear-making machine, has around it a V-shaped guide and a central round guide in which plate 14 slides, on which the workpiece blank is fastened.

Gear 4 is the one doing the rolling motion (MII) and drives sled 5 through its circular advance motion (MIII), which supports other mechanisms.

The motion of the rolling gear 4 is provided by the MCC1 DC motor through the feed box 6, a conical gear with output on shaft 16, held by two radial thrust bearings. The exchangeable rolling gear 4 is fastened at the extremity of this spindle. The other extremity contains a flange that supports gearbox 7, spindle 16, gear 4, feedbox 6 and the DC motors 8 and 9.

The sliding of the plate is performed with mechanism 13, composed of a nut fastened to the plate, a trapezoidal thread screw supported by a spherical thrust bearing, with radial and axial ball bearings. The rotation of the screw is accomplished by an assembly of bevel gears driven from outside the bearing pedestal through a crank wheel with a graded drum to measure the penetration feed.

On the outside of the frame is fastened gear 3. It materializes through its nominal diameter the base circle C_b given by the epicycloid definition. Control sled 15 is guided by the circular guide 5.

Gearbox 7 receives motion from DC motor 9 through the bloc 21 consisting of transmission belt 12 and a conical gear. This bloc 21 is attached to shaft 16 via two radial thrust bearings but rotates independently from it. The conical pinion gear from bloc 21 engages with the conical gear in gearbox 7 fitted with a grooved sleeve through which a grooved shaft slides (when adjusting R_3), transmitting motion to the conical gear on the shaft of shaft mill 11.

The adjustment control R_3 ensures the realization of dimension $\boldsymbol{e}$. In order to allow small values, we can mount of the shaft of shaft mill 11 a housing, 20, which supports a spur gear drive of the same diameter, the shaft of shaft mill 10 becoming in this case spindle 22. In such a way we can manufacture epicycloids with a generating circle C_g of radius r_g < 15mm. The shaft mill's center represents the generator point *G* from the epicycloid definition, whereas dimension ***e*** represents the eccentricity of the generating point *G*, and the exterior diameter of the shaft mill is equal to the diameter of the circle that generates the equidistant to the shortened epicycloid.

Adjustment of the eccentricity *e* of the generating point *G* is accomplished through the sled mechanism 17 fastened to the side of gearbox 7, which engages only shaft 11, respectively housing 20 in its manual adjustment of R_3.

In order to manufacture different epicycloid profile gears, gears 3 and 4 will be exchanged with others of different dimensions, materializing the generating circles C_b and C_g of the proposed epicycloid.

Power supply of the DC motors 8 and 9 is realized using the ring rail 18 through the collector brushes and cable 19.

The adjustment of the cutting parameters (cutting speed and feed) is achieved by modifying the speed of the DC motors, parameters which will be selected after the optimal cutting regime is computed. For the same purpose we also draw the plot of the speed for the gearbox.

2. Theoretical setting technological parameters milling machine with toothed planetary gears

The M_I motion is the shaft mill rotation which executes a slot in the workpiece which is identical to the profile of the shortened epicycloid's equidistant.

The M_{II} movement is the feed.

Cutting speed *v* is calculated by equation (1)

$$v = \frac{c_v d_f^q}{T^m t_l^x s_d^y t^n z^p} k_v \quad \text{[m/min], where} \qquad (1)$$

- c_v – a constant characterizing the milling conditions;
- T – economic sustainability of the shaft mill bit [min];
- t_l – contact length [mm];
- t – cutting depth [mm];
- k_v – speed correction coefficient;
- d_f – shaft mill diameter [mm];
- s_d – feed per tooth [mm];
- *q, m, x, y, n, p* – exponents.

The feed per minute s_m is determined by equation (2)

$$s_m = s_d \, z \, n \quad \text{[mm/min], where} \qquad (2)$$

- s_d – advance per tooth [mm];
- z – number of teeth on the shaft mill;
- n – shaft mill's rotation speed determined by relation (3) based on cutting speed v and the shaft mill diameter d_f.

$$n = \frac{1000\,v}{\pi\, d_f} \quad \text{[rot/min]}\ . \tag{3}$$

Substituting equation (3) into equation (2) we get:

$$s_m = \frac{1000\,v\,s_d\,z}{\pi\, d_f} \quad \text{[mm/min]}\ . \tag{4}$$

Calculating transmission ratio of the feedbox i_{CA}:

$$i_{CA} = \frac{n_1}{n_{Cg}}\text{, where} \tag{5}$$

- n_1 – average speed of DC motor M_{CC1};
- n_{Cg} – speed of the generating gear C_g calculated with formula (6).

$$n_{Cg} = \frac{s_m}{2\,\pi\, r_g} \quad \text{[rot/min]}\ . \tag{6}$$

Calculation of the transmission ratio i from the engine MMC to milling:

$$i = \frac{n_2}{n} = i_{CV}\, i_c\text{, where} \tag{7}$$

- n_2 – average speed of DC motor M_{CC2} [rot/min];
- n – shaft mill speed [rot/min];
- i_{CV} – transmission ratio CV;
- i_c – belt transmission ratio.

The required power P_e [kW] must be at least:

$$P_e \geq P_n\,\eta\text{, where} \tag{8}$$

P_n- nominal power [kW], η - device efficiency coefficient.
Depending on the cuting parameters the expression of the cutting power is [6]

$$P_e = k\, d_f^x\, t_l^n\, s_m\, s_d^y\, t^w \quad \text{[kW], where} \tag{9}$$

- d_f – shaft mill diameter [mm],
- t_1 – contact length [mm],
- s_m – advances per minute [mm/min],
- t – cutting depth [mm],
- s_d – advance per tooth [mm],
- x, n, y, w – exponents.

3. Conclusions

Gears with epicycloidal tooth profiles are components of bolt cycloidal speed reducers.

Their implementation can be accomplished through shaping with an adequate cutting blade, milling with a worm hob of appropriate profile, or milling on a CNC machine.

Using the presented gear shaping machine, we can create epicycloidal tooth profile gears according to the generating scheme of the equidistant to the shortened epicycloid in a wide range of products. This is ensured by the possibility of modifying the generating gears, the equidistant *e*, and the shaft mill's diameter.

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