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Internal gear cutting generation with toroidal hob

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Hobbing is a productive procedure for external gear processing, but is not commonly used with internal gears This is mainly because there is no hob able of internal gear cutting by generation. The paper advances a construction principle of the toroidal hob intended for internal gear cutting by generation (not by copying), similarly with the external gears. The profile of toroidal hob teeth is an involute and materializes the profile of a virtual spur gear. The paper presents the construction of a relieving machine intended for the preparation of the toroidal hob. This achieves the profiling of the toroidal hob teeth by means of an imaginary reference rack, which flank are processed by means of an abrasive tool. Thus a hob is obtained which, by repeated sharpenings, don't alters its profile so as to materialize, without approximations, the flanks of an external virtual gear. In order to validate the construction principle of the toriodal hob and the generating principle of the hob using the relieving machine (also presented in the paper) virtual machining is resorted to. The profile of the internal gear, virtually machined in compliance with the principles advanced in the paper, is compared with its theoretical profile. The differences between the two profiles were small and well within the calculation range implying that the generation principles are correct.

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1. Introduction

A cylindrical hob is commonly used for cutting involute, and other gears. However a cylindrical hob can be used only for cutting external gears, not internal ones. Internal gears are generally cut by means of a pinion-type cutter. In a very few cases, internal gears are cut by means of a single position hob or a single point tool. Gear cutting using a pinion-type cutter is inferior to hobbing in cutting efficiency and cutting accuracy. When single position hobs or single point tools are used for cutting, the precision is poorer and the tool life is shorter than the life of a cylindrical hob. The profile of the middle tooth of the single position hob takes the shape of the gap of the gears being machined, which further depends on the reference rack parameters, the number of teeth, the displacement of the reference profile and the gear inclination angle. The other teeth have a different profile and contribute to the gear rough cutting [2].

It has been found that the disadvantages of the prior art can be overcome by providing a spherical hob for cutting an involute gear [4]. But (*i*) the diameter of the spherical hob is imposed by the size of the virtual pinion being materialized, (*ii*) alters its profile due to resharpening, (*iii*) and provides distorsion of the processed gear as a result of the hob inclination axis with respect to the generation plane.

The paper advances a toroidal hob which removes the disadvantage of a   spherical hob, while allowing for the processing of the internal or external helical and spur gears having various addendum modification factors. In order to check the accuracy according to which the toroidal hob generates the piece gear, a soft in Visual Basic for Application in Autodesk Autocad was designed. This was further used to provide the solid model of the toroidal hob by means of the conceptual scheme of the reliving machine as described in this paper. The solid model of the toroidal hob was subsequently used for the virtual machining of an internal spur gear. By comparing the profile achieved by virtual machining with the theoretical profile very small differences were found due to the virtual machining process.

The remainder of this paper is organized as in the following sections. Section 2 describes the internal involute gear cutting by generation with the toriodal hob. Section 3 shows the construction of a relieving machine by means of which involute profile can be achieved using a tool or a grinding wheel with rectilinear profiles. Section 4 provides the results obtained by (*i*) virtual machining of the toroidal hob by the relieving machine, and (*ii*) virtual machining of the internal gear with a 3D model of the toroidal hob. Finally, in section 5 a conclusion is given.

2. Generation principle by hobbing involute internal gears

Let us consider an internal spur gear, made up of an internal spur gear and an external virtual spur gear. Virtual spur gear is the generating element, while the internal spur gear is the gear to be generated. Virtual spur gear should meet the restrictions of the situation when an internal gear is machined by a pinion-type cutter [1]. The generating principle advanced in this paper consists in materializing a virtual spur gear by means of a toroidal hob.

In the generation plane, which is perpendicular to the axis of the internal spur gear, the hob profile is identical with the profile of the virtual spur gear (see Fig.1).

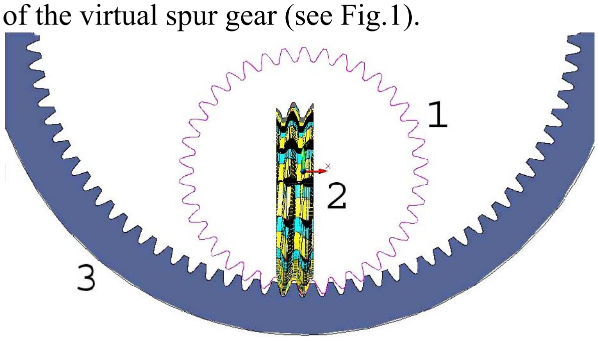

Fig.1 The hob profile is identical with the profile of the virtual spur gear. (1) Virtual external spur gear profile. (2) Hob. (3) Gear blank.

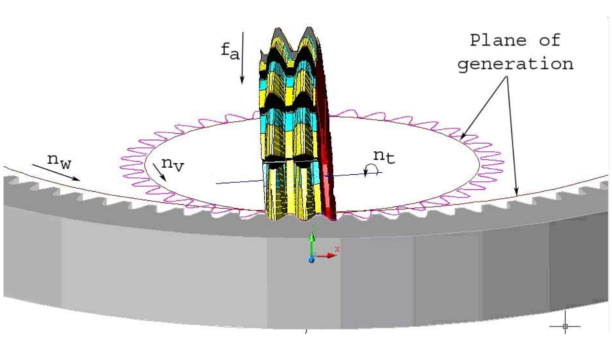

Fig.2 Hob position with respect to the generation plane. (n_t-rotation movement of the hob; n_v-rotation movement of the virtual spur gear; n_w-rotation movement of the gear blank; f_a-hob displacement to the gear blank)

The hob axis is inclined with respect to the generation plane by an angle which value is equal to the average value of the hob thread inclination angle (see Fig.2).

The rotation n_t of the hob determines the rotation of the virtual spur gear around its axis, at a speed $n_v = \frac{n_t}{k}$, where k is the number of starts of the hob. The internal spur gear to be generated gears with the virtual spur gear. The speed of the internal spur gear is given by the relation: $n_w = n_v \cdot \frac{z_i}{z_w}$, where z_i is the number of teeth of the virtual spur gear, and z_w is the number of teeth of the internal spur gear. The teeth of the gear blank is generated by the hob edges due to the fact that the edges of the toroidal hob materialize the teeth profile of the virtual gear.

In order that the gear blank be machined along the entire width the toroidal hob has a feed motion f_a, along the axis of the virtual spur gear (see Fig.2).

Masato Ainoura [3, 4] presents a hob which materializes the profile of the virtual gear in a plane containing the machine axis and generates the profile of an internal gear as shown above. This hob is spherical, featuring a diameter equal to that of the virtual gear. The thread of this spherical hob is generated by a cutting tool of a profile identical to that of the virtual gear. The hob spherical shape is imposed by the need that, as a result of the hob inclination with respect to the generation plane by an angle equal to the average angle hob spiral, the intersection of the generation plane with the hob be a circle arc as well featuring a radius equal to the radius of the virtual spur gear. Spherical hob has the following disadvantages:

(a) the diameter of the spherical hob cannot be set to the desired value, as this should be equal to the diameter of the virtual gear;

(b) because, during machining, the axis of the spherical hob is inclined to the plane of generation, the profile of its teeth no longer corresponds to that of the virtual gear teeth;

(c) after resharpening the spherical hob, its diameter gets smaller.

(d) since the profile of the spherical hob teeth does not change by resharpening, this no longer corresponds to the teeth profile of the virtual gear.

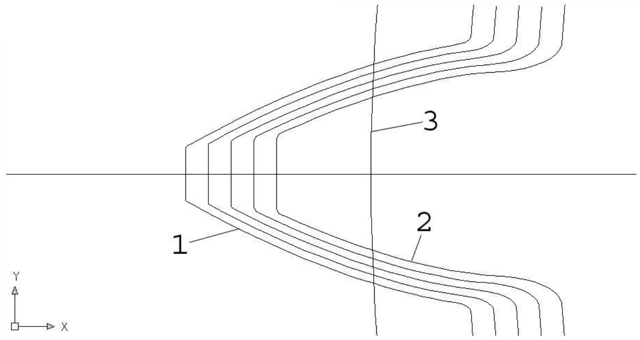

Fig. 3. Modification of the toroidal hob gear profile after resharpening. (1) Profile of the toroidal hob tooth machining the virtual gear; (2) Profile of the toroidal hob tooth after four resharpenings materializing another virtual gear; (3) The dividing circle (which is the same for all teeth profiles materialized by the virtual gear namely dividing circle of the virtual gear).

Unlike the spherical hob, the hob proposed in this paper has a toroidal shape, so that its diameter can be established independently of the diameter of the virtual gear. Secondly, with the toroidal hob the tooth hob profile, in a plane perpendicular to the spiral direction (i. e. in the plane of generation), is identical to the profile of the virtual gear. Thirdly, the profile of the toroidal hob tooth, inside the generation plane, is achieved by meshing the virtual gear with an imaginary rack which flanks are materialized by a rectilinear profile cutting tool identical with the basic rack profile. Fourthly as a result of resharpening, the diameter of the toroidal hob decreases, and their profile keeps on changing until the involute but materializing the profile of a new virtual gear (see Fig.3). This new virtual gear has the same module, number of teeth and meshing angle as the initial virtual gear, but has a smaller diameter corresponding to the decreased diameter of the hob.

In this way the materializing of a virtual gear by means of a hob is theoretically perfect.

3. Construction of the relieving machine intended for the preparation of the toroidal hob

In order to prepare the toroidal hob a relieving machine can be used as illustrated in Fig. 4.

The movements performed by the relieving machine are the following:

(a) *Basic movement n_w of the toroidal hob body (1)*. This movement is induced by the motor (M), and transmitted to the toroidal hob.

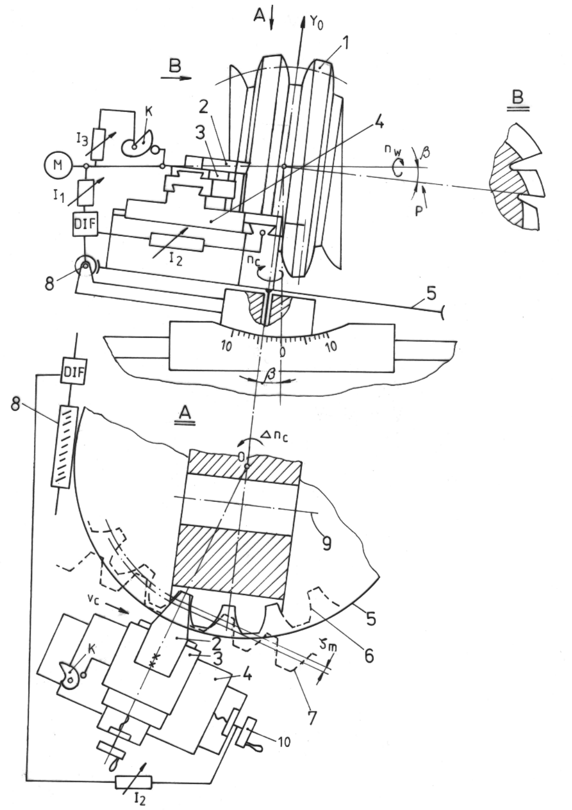

Fig.4 Kinematic scheme of the hob relieving machine for hobbing the internal gear [5]. (1) Toroidal hob. (2) Linear profile cutting tool. (3) Cutter holder. (4) The slide which moves with speed v_c. (5) Worm gear. (6) Profile of virtual gear. (7) Virtual basic rack profile. (8) Worm screw. (9) Rotation axis of toroidal hob. (O) Center of virtual gear. (DIF) Differential drive. (M) motor. (I_1, I_2, I_3) Elements correlating the movements. (β) Inclination angle of the generation plane with respect to the toroidal hob rotation axis. (P) Generation plane. (Y_0) Direction of the toroidal hob spirals. (n_w, n_c) Correlation rotations that make threading possible. (Δn_c, v_c) are rotation and translation movements performed by the cutting tool so that the basic rack 7 rolls over the virtual gear. (ξ) addendum modification factor.

(b) *Toroidal threading obtained by rotating the toroidal hob (1), associated with the rotation n_c of the cutting tool (2) around the axis Y_0*. Rotation of the cutting tool is given by the worm gear (5) that receives the movement from the motor (M) by means of the worm screw (8), the differential drive (DIF) and element I_1, which correlates rotations n_W and

n_c so that to meet the relation $\frac{n_w}{n_c} = \frac{1}{z_0}$, where z_0 is the number of teeth of a virtual spur gear.

(c) *The relieving movement* performed by the cutting tool is rectilinear and permanently oriented to the center O_0 of the virtual gear. This movement is given by the main shaft by means of cam (K) and element (I_3) which correlates the relieving movement with rotation n_w of the toroidal hob. The relieving movement ensures a continuous displacement (ξ) of the basic rack along the tooth of the toroidal hob. Consequently, after resharpening the hob tooth profile remains an involute, and will represent the profile of the virtual gear, having addendum modified by $\xi \cdot m$, where ξ is the addendum modification factor, and m is module.

(d) *Roling movement* consisting of the additional rotation movement Δn_c around the axis Y_0, and cutting tool translation movement v_c along the reference line . Movements Δn_c and v_c are so correlated as to represent the rolling of the basic rack onto the virtual gear. The additional rotation movement Δn_c is transmitted from the hand wheel (10), by means of differential drive (DIF), and worm (8) of the worm gear (5).The element I_2, correlates rotation Δn_c with translation v_c.

4. Verification of the generating principle of the toroidal hob and the internal gear cutting using virtual machining

To verify the generation principle advanced in this paper, a Visual Basic for Aplication soft was designed for work under Autodesk Autocad. The soft helped in virtually designing the toroidal hob in accordance with the generation principle showed in Fig.4, thus obtaining the solid model of the toroidal hob. The solid model of the toroidal hob was further used for the virtual machining of an internal gear to subsequently provide its solid model. In order to make a comparison between the internal gear profile, as generated by this toroidal hob, and the theoretical profile, these profiles have been intersected by concentric circles (see Fig.5).

Coordinates x, y of the intersection points between the two profiles and the intersecting circles have been carefully compared and the differences Δx and Δy were found. Results are given in Table 1. It can be noted that these differences are very small and within the error limits of the virtual machining.

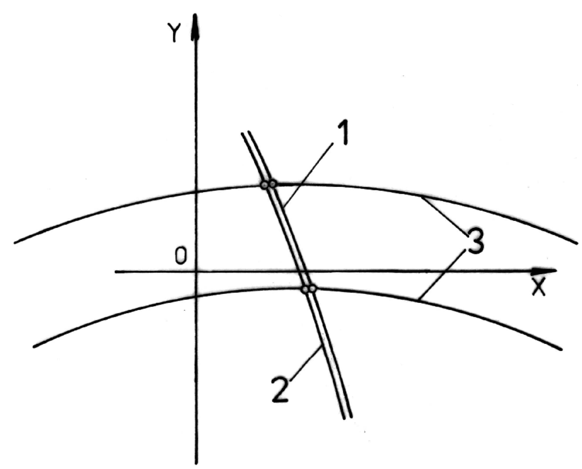

Fig. 5 Intersection of profiles with concentrical circles. (1) Generated profile. (2) Theoretical profile. (3) Concentrical circles. (4) XOY – Refference system of the profiles.

Table 1. Difference between the profile generated by the proposed toroidal hob and the theoretical profile of the internal gear, having module 10 mm and 90 teeth

Coordinates of the generated profile		Coordinates of the theoretical profile		Difference between the theoretical and generated profiles	
x	y	x	y	Δx	Δy
11.0726	9.8337	11.0745	9.8306	0.0019	-0.0031
10.7858	8.8241	10.7779	8.8207	-0.0079	-0.0034
10.5002	7.815	10.5017	7.8121	0.0015	-0.0029
10.1937	6.8054	10.1872	6.8022	-0.0065	-0.0032
9.8877	5.79633	9.8875	5.79363	-0.0002	-0.0027
9.5579	4.7868	9.5506	4.7839	-0.0073	-0.0029
9.2348	3.7778	9.2366	3.7752	0.0018	-0.0026
8.8832	2.7685	8.8755	2.7658	-0.0077	-0.0027
8.5375	1.7598	8.5361	1.7574	-0.0014	-0.0024
8.169	0.7508	8.1608	0.7483	-0.0082	-0.0025
7.8045	-0.2574	7.8031	-0.2596	-0.0014	-0.0022
7.4158	-1.2659	7.4062	-1.2682	-0.0096	-0.0023
7.0295	-2.2738	7.0234	-2.2758	-0.0061	-0.002
6.6267	-3.2816	6.6189	-3.2836	-0.0078	-0.002
6.2215	-4.289	6.214	-4.2909	-0.0075	-0.0019
5.8068	-5.2959	5.8039	-5.2975	-0.0029	-0.0016
5.375	-6.3026	5.365	-6.3042	-0.01	-0.0016
4.9534	-7.3087	4.9557	-7.3101	0.0023	-0.0014
4.4984	-8.3146	4.4899	-8.316	-0.0085	-0.0014
4.0485	-9.3198	4.0406	-9.321	-0.0079	-0.0012
3.5938	-10.324	3.5913	-10.325	-0.0025	-0.001
3.0777	-11.329	3.1559	-11.329	0.0782	-1E-04

5. Conclusions

The advantage of a high productivity, specific to the hobbing of the external gears, can be achieved with internal gears too by using a toroidal hob which construction is described in this paper .

The toroidal hob materializes, both in the beginning and after repeated resharpenings, external gears of a given module which are able of meshing with any internal gear featuring the same module. Preparation of the toroidal hob is possible when using a relieving machine the particular construction of which is presented in this paper.

Verification of the construction principle for the toroidal hob and the operating diagram of the relieving machine, proposed in this paper, is achieved by virtual machining. The result of the verification confirms that gear cutting by generation with a toroidal hob as shown in the paper is theoretically correct.

Acknowledgements

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Figure 1

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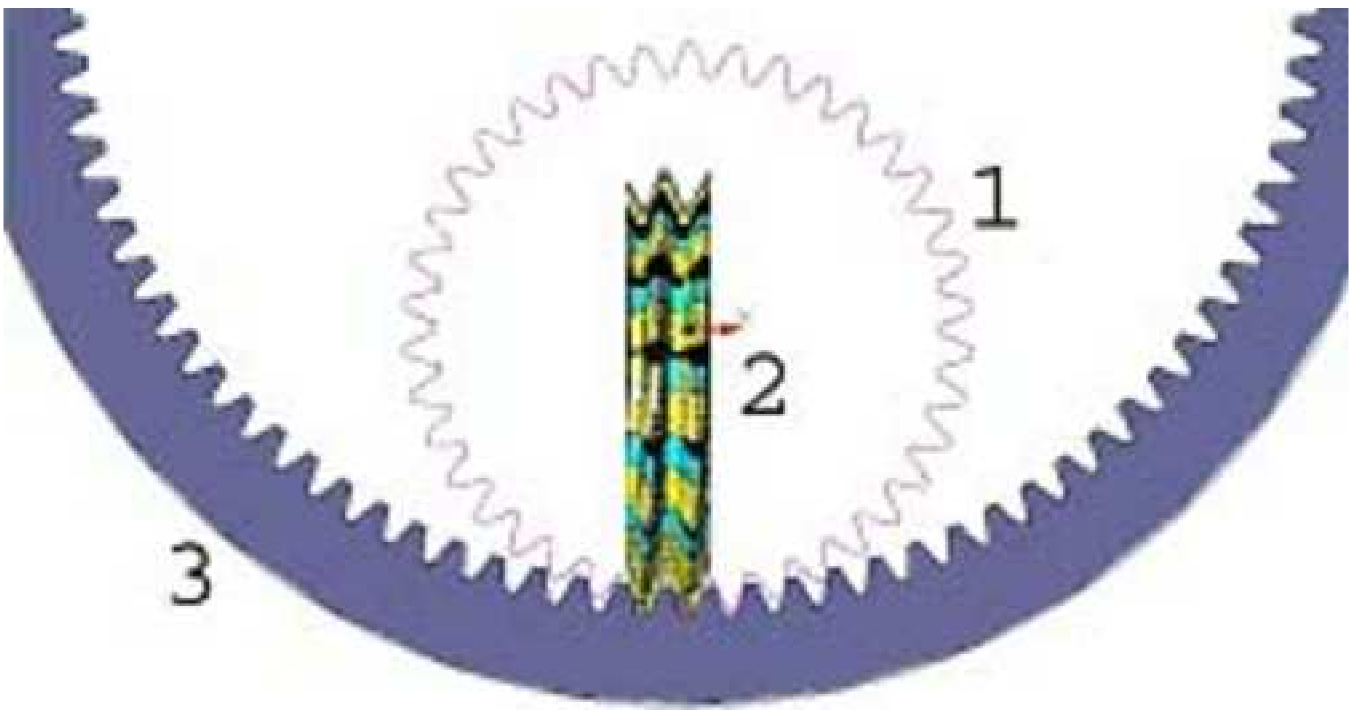

Figure 2

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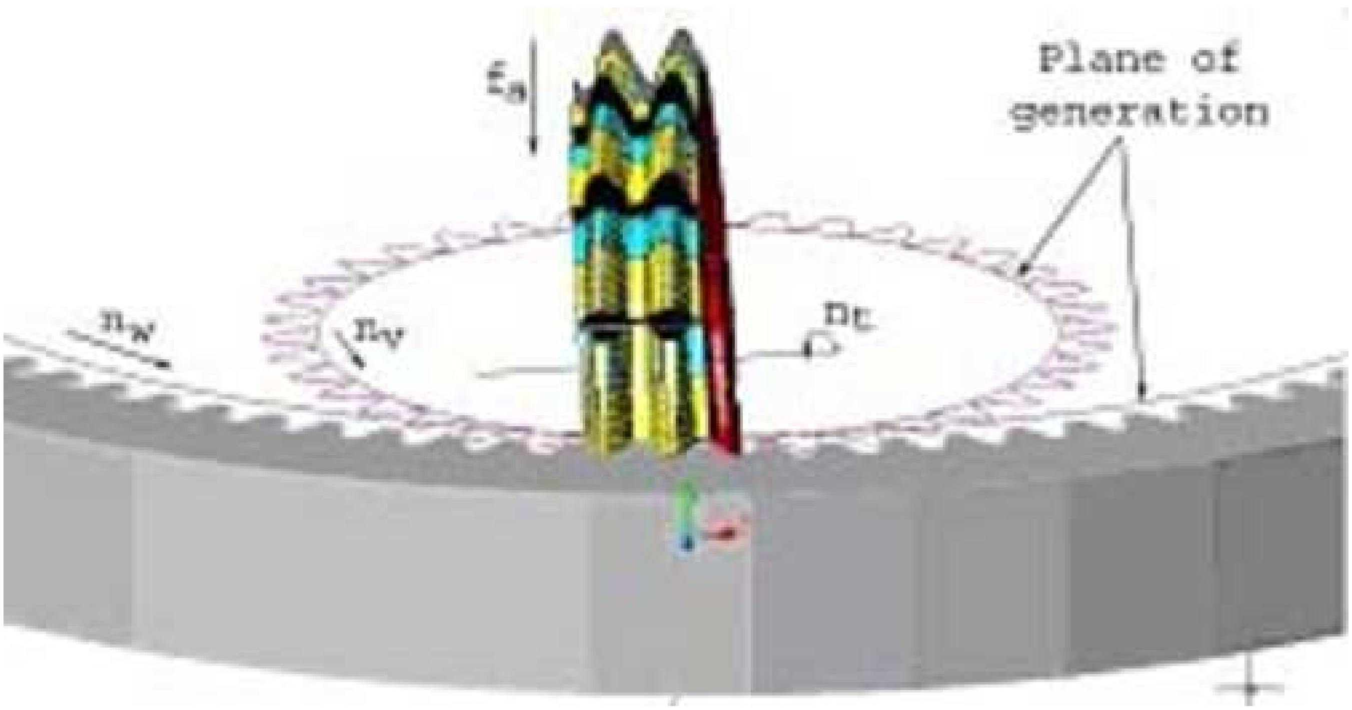

Figure 3
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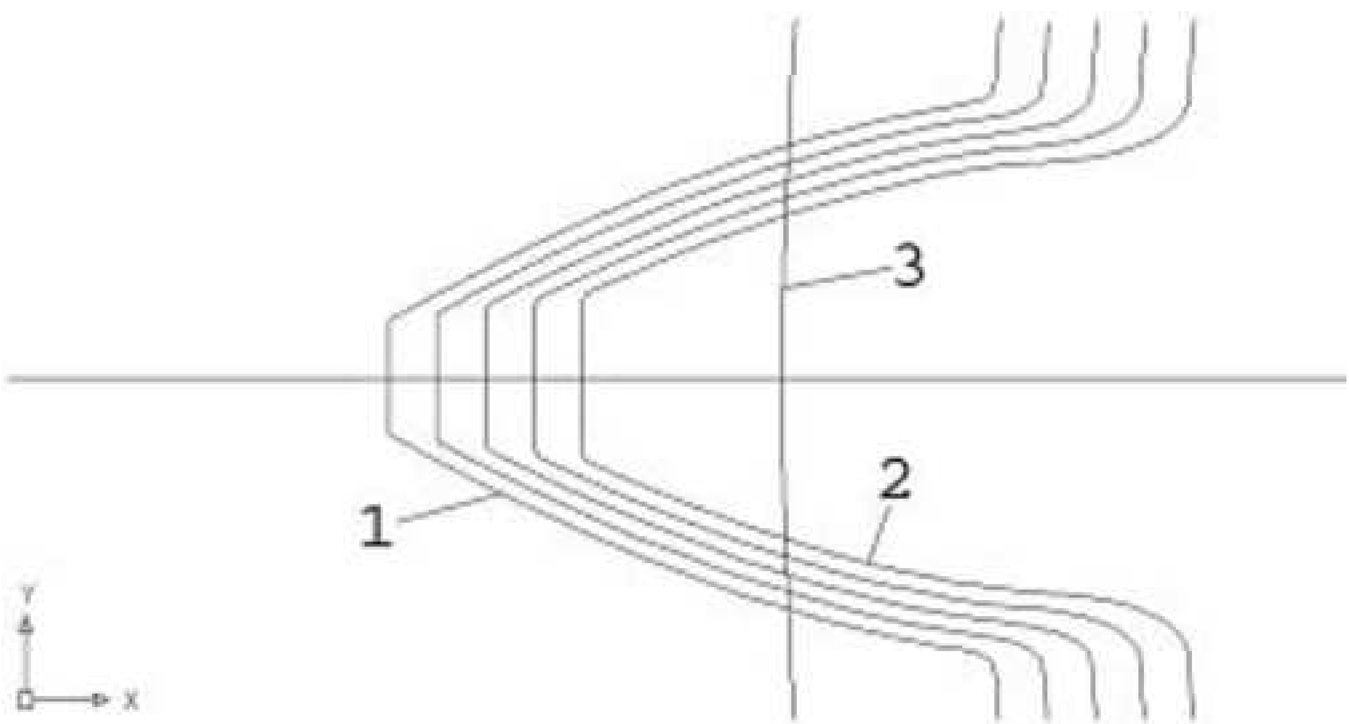

Figure 4

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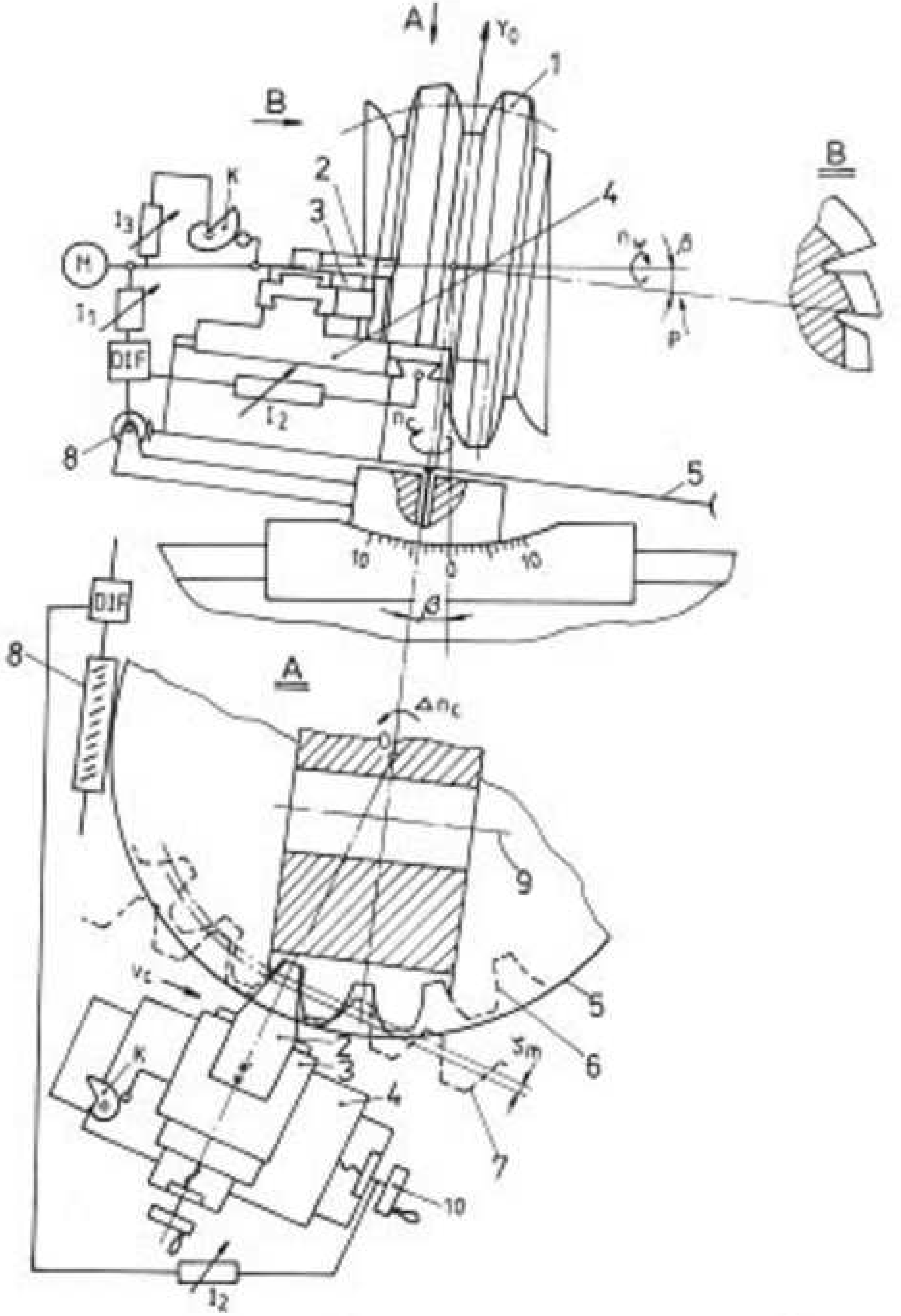

Figure 5
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