MANUFACTURE OF GEARS WITH ASYMMETRIC TEETH ON CNC MACHINE TOOLS

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Abstarct: This paper presents issues on the possibility of machining gears with asymmetric teeth on CNC machine tools, with simple cutting tools (end mill) and our own results, obtained in this direction. Gears with asymmetric teeth are of involute flanks with different base circles, which confer gear the specific character to have two different pressure angles, depending on the direction of rotation. The obtained accuracy of gears with asymmetric teeth, manufactured on CNC machine tools, can be compared with the manufacturing precision of gears by cutting methods, with gear tooth side milling cutter or gear tooth end mill.

1. INTRODUCTION

Kapelevich, DiFrancesco, Karpat, Yang and others developed the problem of gears with asymmetric teeth. [1], [3], [4], [7], [6], [13], [14]. In these works a series of theoretical and practical studies are presented, highlighting the potential of this kind of gears.

In the present study aspects are described on the possibility of processing gears with asymmetric teeth on CNC controlled machine tools, with simple cutting tools (end mill) and our own results, obtained in this direction.

To increase the performance of gears, the use of gears with asymmetric teeth, with different features on each flank, dependent on the direction of rotation, is tested out, with results.

The improvement of gearing conditions of one of the flanks is made against the opposite flank, which can be achieved for the majority of gears, because, in general, in industrial equipments the gears rotate in one direction only, and to reverse the direction of rotation, reverser gears are foreseen.

For example, the gears in gear boxes of road equipments, internal combustion engines, water or gas turbines, reduction gears of wind turbines, etc., have one active direction of rotation only. In this respect, one wheel flank is active and just this flank has to have optimized qualities in terms of gearing. A particularly important aspect is the fact, that the result is a tooth with high mechanical resistance to be able to transmit larger moments.

Gears with asymmetric teeth are of involute flanks with different base circles, which confer gear the specific character to have two different pressure angles, depending on the direction of rotation.

2. TECHNOLOGICAL POSSIBILITIES OF MANUFACTURING GEARS WITH ASYMMETRIC TEETH

Gears with asymmetrical teeth in terms of geometric dimensioning and their analysis with finite element methods [2], [5], [8], [9], [10], [11], [15] are discussed and studied in several papers.

The manufacturing technology of these wheels is presented in several papers [12], but only briefly, and the manufacturing technology of these gears is based on gear cutting machine tools with specially designed cutting tools for these asymmetric teeth.

The manufacture of gears with asymmetric teeth can be made on tooth construction machine tools, by rolling or by copying, followed by a finishing process by grinding, shaving or lapping with cutting tools, specially designed for these kinds of gears.

The following idea is developed: special tools with asymmetric teeth (worm cutters, gear cutters) would raise some complex and complementary issues for manufacturing prototype for gears with asymmetrical teeth, which are necessary for tests and experiments.
In addition to the conventional gear manufacturing technologies, the tooth constructions with asymmetric teeth with some conditioning can be manufactured by specific methods of manufacture on CNC controlled machine tools, also.
To process the gears with asymmetric teeth on CNC machine tools, we start from a solid model (3D), or a closed 2D outline, outline which is printed on a simple cutting tool with 2-4 cutting edges, of end mill type.

3. MAKING THE PROFILE FOR GEARS WITH ASYMMETRIC TEETH

Because gears with asymmetric teeth are wheels and gears in research stage, there is no exclusively accepted and standardized notation. From the point of view of gear flank notation, Kapelevich uses the terms: *coast involute profile* respectively *drive involute profile*, but it is not known which flank will the active one, which is the optimal direction of rotation, the mashing should be made on „*coast involute profile*” or on „*drive involute profile*”.
Depending on the reference gear rack angle, we distinguish following flanks:

- The normal flank, without indicative, is the specific flank for conventional gears with symmetric teeth, where the reference gear rack angle and the generator gear rack angle are equal for the two flanks, usually in correlation with the standardized values.
- The modified flank, with indicative m, is the specific flank for a gear with asymmetrical teeth, where the reference gear rack pressure angle and the generator gear rack meshing angle are different values in relation to the standardized values, specific for the normal flank. The modified flank, with indicative m+, is a flank, where the reference gear rack angle of one flank is larger than the one of the normal flank, and the flank with the indicative m- is a flank, where the reference gear rack angle is smaller, than the one of the normal flank. It is recommended, that the indicatives m+ and m- should be accompanied by the reference gear rack’s real value.

The gear’s asymmetric teeth are defined by two involutes, generated on two different basis circles. The pitch circle, circle, which, in case of gear pairs without addendum modification coincides with the reference circle, is the same for both flanks. Therefore, the pressure angles on the two flanks of the tooth will be different. The ratio between the base circle, the reference circle and the pressure angle, in case of gear without addendum modification, has the following form:

$$d_d = \frac{d_b}{\cos\alpha} \quad \text{or} \qquad d_b = d_d \cdot \cos\alpha \qquad (1.)$$

d_d - reference diameter

d_b - base diameter

α - pressure angle

Because the reference diameter is equal for the two involutes, we can write:

$$\begin{aligned} d_{b\_m+} &= d_d \cdot \cos\alpha_{m+} \\ d_{b\_m-} &= d_d \cdot \cos\alpha_{m-} \end{aligned} \qquad (2.1.)$$

$$d_d = \frac{d_{b\_m+}}{\cos\alpha_{m+}} = \frac{d_{b\_m-}}{\cos\alpha_{m-}} \qquad (2.2.)$$

d_d - reference diameter

d_{b_m+} - base circle diameter for the flank with pressure angle m+

d_{b_m-} - base circle diameter for the flank with pressure angle m-

α_{m+} - pressure angle m+

α_{m-} - pressure angle m-

The asymmetry coefficient k is introduced, as the gear's invariant:

$$k_{\frac{m-}{m+}} = \frac{\cos\alpha_{m-}}{\cos\alpha_{m+}} = \frac{d_{b\_m-}}{d_{b\_m+}} \quad \text{or} \quad k_{\frac{m+}{m-}} = \frac{\cos\alpha_{m+}}{\cos\alpha_{m-}} = \frac{d_{b\_m+}}{d_{b\_m-}} \qquad (3.)$$

For profile generation, AutoCAD's AutoLisp program will be used, taking into account, that the involute is the curve, described by the C point, belonging to the TC right, which rolls without slipping over a fix circle of radius r_b, called the base circle.
Hereinafter the profile and the gear, with asymmetric teeth, generation processes are presented.

1 – The base circle diameter is determined by means of reference diameter and of pressure angle by formulas (2.1.).

2 – By means of AutoLISP program sequence, presented below, on the basis of base circle, the defining involute is generated for one of the flanks, as a poly line (fig.2.), after which, taking into account the tooth thickness on the reference diameter, the other tooth flank is generated, also, defined by the other base circle.

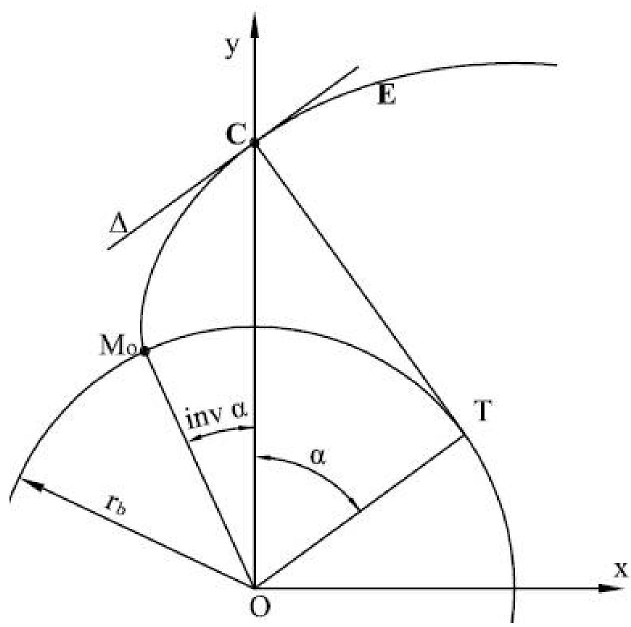


Fig. 1. Determination of the involute

To the „r_b" value, the radius of the base circle, the appropriate value of the base circle for the m+ flank with meshing angle will be assigned, then assign the value of the base circle for the m- flank with meshing angle, and change the progress of course.
The AutoLisp program sequence is the following:

```
(setq fiGri 0)
        (setq M1ii P2)
        (while (< fiGri fiGr)
                (setq fiRadi (/ (* fiGri pi) 180))
```

```
                    (setq Mx1i (+ (* rb (sin (- pi fiRadi))) (* rb1
                              fiRadi (cos (- pi  fiRadi)))))
                    (setq My1i (- (* rb (* fiRadi (sin (- pi
                              fiRadi)))) (* rb1 (cos (- pi fiRadi))) ))
                    (setq M1i (list Mx1i My1i))
          (command "pline" M1ii M1i "")
          (setq M1ii (list Mx1i My1i))
          (setq fiGri (+ fiGri 1))
           )
(command "pedit" "last" "j" "all" "" "")
```

3 – Knowing the gear's root circle "d_f", the fillet profile is made by means of some fillet radius "$\rho_{f\ m+}$" and "$\rho_{f\ m-}$", in correlation with the „d_f" end mill diameter, use for in manufacturing process (fig.3.).

$$\rho_{f\_m+} = \frac{d_f}{2}$$

respectively

$$\rho_{f\_m-} = \frac{d_f}{2} \qquad (4)$$

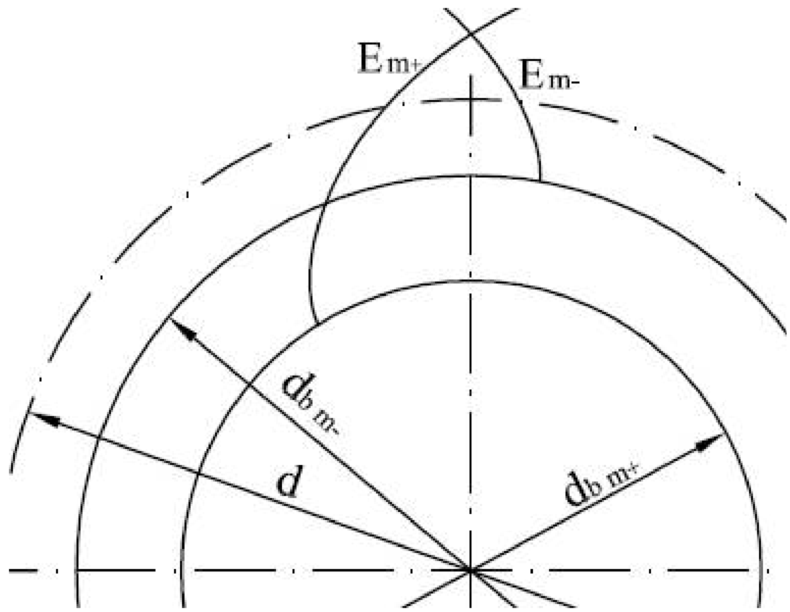


Fig. 2. Asymmetric gear tooth generated by two different involute

4 – With the gear's tip diameter "d_a", known size, the involutes' end will be defined (fig.3.) and a tooth will be obtained (fig.4.a.), which will be multiplied circularly by the gear's axis, with the equal number of the wheel's teeth, so obtaining the gear's outline (fig.4.b.).

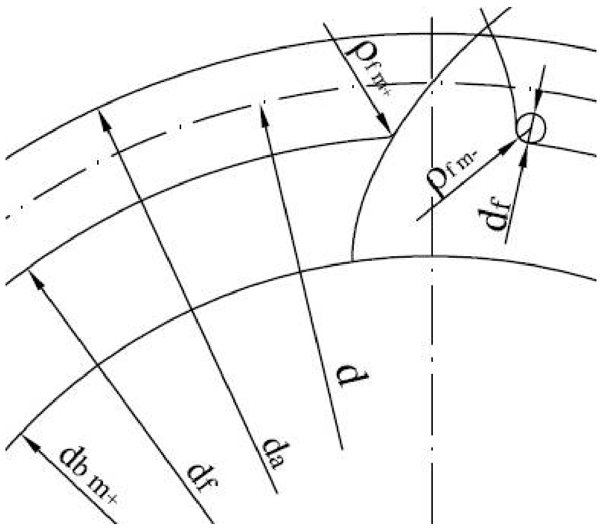


Fig. 3. Correlation between end mill diameter and the fillet radius

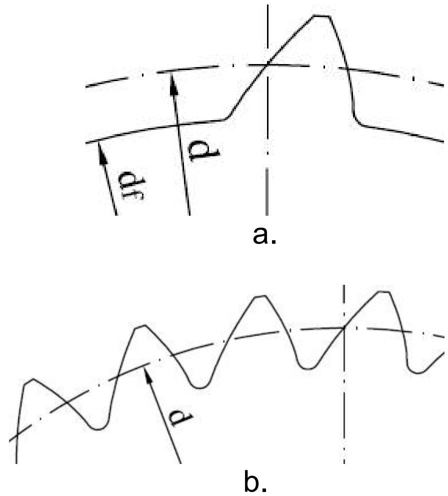
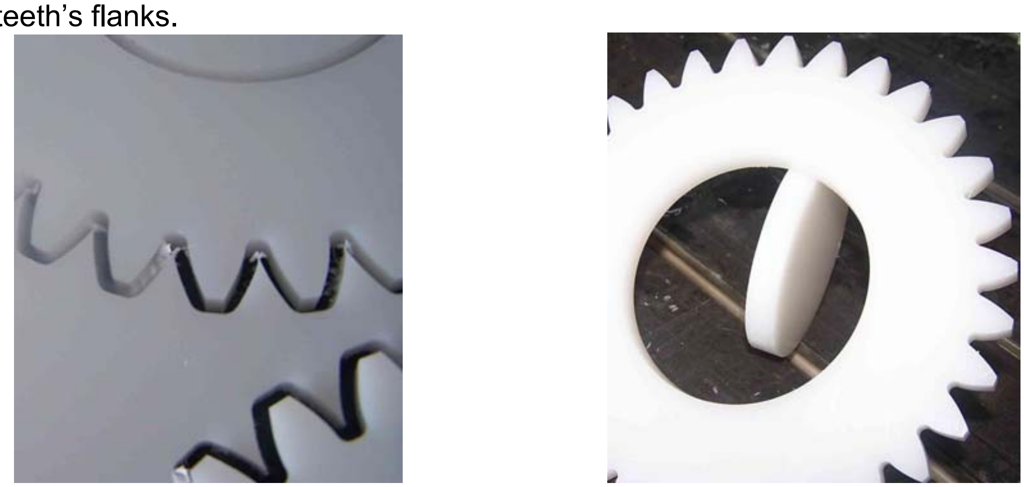


Fig. 4. Gears profile with asymmetric teeth

4. MANUFACTURE OF GEARS WITH ASYMMETRIC TEETH ON CNC CONTROLLED MACHINE TOOLS

Having the gear's profile electronically, it is introduced in the CNC machine tool's program, together with the parameters of cutting conditions, accepted for the tool.
With the end mill the gear with asymmetric teeth will be machining, by its outlines, with a technologically rated cutting depth, after which, using the depth feed, a final passage will be made, through which the gear is defined. Depending on the cutting conditions and the quality requirements, this final passage can be of finishing, with specific technological procedure. In case the surface quality is not sufficient, grinding processing will be used, in the flooring of metallic materials. From the same application the wheel's boring will be processed, too. The wheel's boring can be processed on lathe too, but with centering on the teeth's flanks.



a. ***b.***

Fig. 5. Gears with asymmetric teeth made on CNC controlled machine tool

In figure 5.a-b., the processing of gears with asymmetrical teeth is presented, in workshop conditions. The processed gear with asymmetrical teeth has 31 teeth; the meshing angle on the m+ flank with meshing angle is of 40 degrees, respectively of 20 degrees, on the m- flank with meshing angle, having a width of 10 mm, made of industrial plastics (HD500). It is machined using an end mill cutting tool with 3 mm diameter and 1 cutting edge. The machining was made on a FlexiCAM machine.

5. DIMENSIONAL ACCURACY OF MANUFACTURED GEARS WITH ASYMMETRIC TEETH

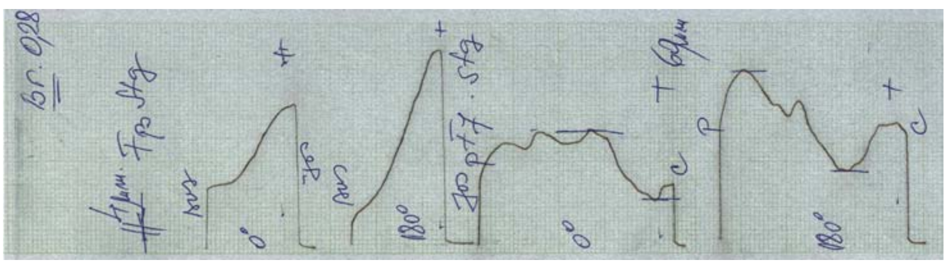
The gear accuracy control can be made, in general, with control equipment suitable for gears with symmetric teeth, except that by their adjustment, a particular tuning is required, specific for the pressure angle of the controlled flank.

In figure 6, we presented the deviations of the flank's course and form, in case of gears with asymmetric teeth, processed on CNC controlled machine tool, without finishing or fitting processing.

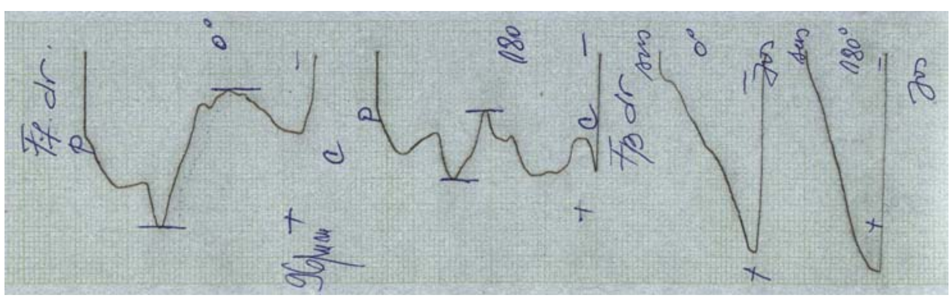
According to the Control Data Sheet, the teeth have:

- Radial run-out: 0,28 mm
- Longitudinal form error:
  - left: 68 μm
  - right: 56 μm
- Profile form error: 60 – 96 μm

In some situations, specific for agricultural machines, such properties of surface, flank forms and run-outs are sufficient.



a.



b.

Fig. 6. Longitudinal form error and profile form error

6. CONCLUSIONS

1 – Due to the deflection of the milling cutter and the fastening system, the processed teeth flank presents a relatively small tilt, which can be remedied at the gear drive's shaping, by manufacturing mirror wheel pairs.

2 – The obtained accuracy of gears with asymmetric teeth, manufactured on CNC machine tools, can be compared with the manufacturing precision of gears by cutting methods, with gear tooth side milling cutter or gear tooth end mill.

3 – The system can be extended on steels, too.

4 – Considering the potential of these gears, research is required in terms of moment transmission capacity and their manufacturing technology.

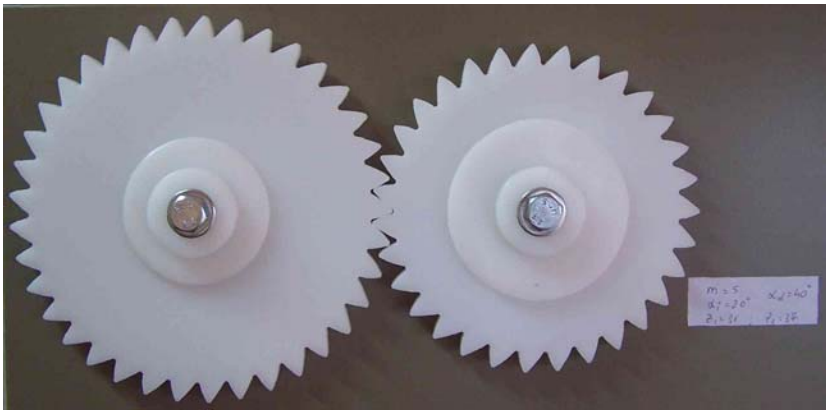


Fig. 7. Gear drive formed by gears with asymmetric teeth

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