DETERMINATION OF THE MOLD HOLLOW DIMENSIONS FOR OBTAINING THE CORRECT MEASURES OF THERMOPLASTIC INJECTION MOLDED GEARS

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ABSTRACT

This paper presents methods for determining dimensions of the mold hollow in order to obtain the most accurate thermoplastic gear by injection. The software Lama 16C allows slightly fluctuate certain gear parameters, their drawing, comparison and tracing of the parameters change affecting the geometry and gear parameters. After changing replaceable mold inserts in experimental tools and after applying corresponding procedures of measurement and control of the obtained thermoplastic gears, their dimensions have been checked in order to determine the optimal dimensions of the mold hollow as the most prominent factor of the desired shape.

KEYWORDS: thermoplastic gear, mold hollow, injection process

1. INTRODUCTION

The process of thermoplastic injection implies that a thermoplastic granule is heated up until it is molten, which is followed up by its sufficiently fast injection into the mold hollow at a given temperature. The heat is then led away from the mold hollow thus enabling one part of the thermoplastic to cool and harden enough to be taken out of the mold hollow. During the process of the thermoplastic part’s cooling a volume contraction is taking place. Both its contraction and the contraction dispersal affect accuracy and precision of the thermoplastic part dimensions. However, a great deal of research is needed to predict contraction. Thus, this paper examines the possibility of obtaining accurate dimensions as well as the required precise profile of an involute thermoplastic gear.

2. MOLD HOLLOW DIMENSIONS

Regarding the data about thermoplastic as well as on the basis of the precisely determined behavior of the thermoplastic during its injection, and by using general properties of involute gearing, there are different ways of determining the mold hollow dimensions. The following ways are proposed in this paper in order to obtain proper gear dimensions [1, 2], where m represents the gear module and S the shrinkage coefficient in percentage:

a) As the basis for determining the mold hollow dimensions a corrected module *m* is taken, whose value is changed as much as the amount of contraction with respect to the given value:

$$m' = m \cdot \left(1 \pm \frac{S}{100}\right) \tag{1}$$

All the mold hollow dimensions are calculated according to the module *m* as well as the contact line angle α_o=**20°**. Regarding this module, the mold hollow dimensions for x=0 are:

- pitch circle: $D' = m' \cdot z$
- root circle:

$$D_i' = D' - 2 \cdot 1,25 \cdot m' \tag{2}$$

- addendum circle: $D_s' = D' + 2 \cdot m'$
- fixed circle: $D_0' = D' \cdot \cos\alpha_0$

The tooth thickness at an arbitrarily chosen place:

$$b_y' = 2 \cdot R_y \cdot \left(\frac{\pi}{2 \cdot z} + inv\alpha_0 - inv\alpha_y\right) \tag{3}$$

where $\cos\alpha_y = \dfrac{D_0'}{D_y}$

b) The mold hollow dimensions are determined on the basis of the corrected module $m'=m\cdot(1+S/100)$ and the contact line angle:

$$\alpha_0' = \alpha_0 \cdot \left(1 \pm \frac{S}{100}\right) = 20^0 \cdot \left(1 \pm \frac{S}{100}\right) \quad (4)$$

The mold hollow dimensions are:

- pitch circle: $D' = m' \cdot z$
- root circle: $D_i' = D' - 2 \cdot 1{,}25 \cdot m'$
- addendum circle: $D_s' = D' + 2 \cdot m'$
- fixed circle: $D_0' = D' \cdot \cos\alpha_0'$

The tooth thickness at an arbitrary diameter:

$$b_y' = 2 \cdot R_y \cdot \left(\frac{\pi}{2 \cdot z} + inv\alpha_0' - inv\alpha_y'\right) \quad (5)$$

where $\cos\alpha_y' = \dfrac{D_0'}{D_y}$.

c) In the case of thermoplastics with a higher contraction coefficient, the mold hollow dimensions are calculated by the module along with a respective teeth correction by applying the involute function (Figure l).

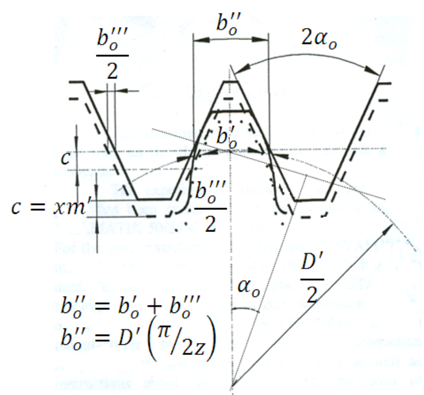

Fig. 1. *Tooth Thickness at Displacement*

The teeth thickness expressed by the involute function for the case when the basic profile is displaced for c=m· x, where x is the correction factor:

$$b_y' = 2R_y\left(\frac{\pi}{2 \cdot z} \pm \frac{2x}{z} tg\alpha_0 + inv\alpha_0 - inv\alpha_y\right) \quad (6)$$

where Dy=D′ the tooth thickness is:

$$b_0'' = D' \cdot \left(\frac{\pi}{2 \cdot z}\right) = b_0' + b_0''' \quad (7)$$

where D′=m′·z and b′0=b′y.

A subsequent increase of the tooth thickness in the mold hollow due to the contraction is:

$$b_0''' = b_0'' \cdot \frac{S}{100} \quad (8)$$

According to figure 1 b_0''', it is calculated:

$$b_0''' = 2 \cdot tg\alpha_0 \cdot x \cdot m' \quad (9)$$

On the basis of the equations (7), (8), (9), after its rearrangement, an expression is obtained for calculating the correction factor x by taking into consideration the contraction:

$$x = \frac{\pi \cdot S}{400 \cdot tg\alpha_0} \quad (10)$$

This correction factor is equivalent to an increase of the mold hollow dimensions for gear manufacture. The respective linear side clearance f_0 can be realized by taking into consideration the correction factor x_f as well:

$$x_f = \frac{f_0}{4 \cdot \sin\alpha_0 \cdot m'} \quad (11)$$

It is recommended that the side clearance has the value of f_0=m/12.5 or that it can be chosen depending on the module and the manufacture quality [1].

d) In order to determine the mold hollow dimensions for gear manufacture what can also be taken into consideration is the determination of all mold dimensions by the correction module and cos α′0=cos α0·(1±S/100).

3. EXPERIMENTAL REASEACH AND PROCEDURE

In order to carry out the experimental research presented in this paper a special tool set has been made for injecting thermoplastic gears (Figure 2). The tool set is conceived as the one with variable mold inserts that provide for the injection of the whole family of various gears (Figure 3) [3].

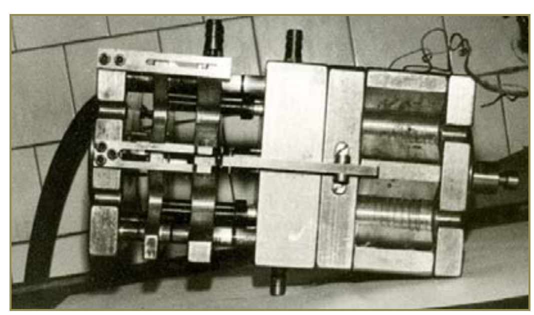

Fig. 2. *Experimental tools made for injecting thermoplastics*

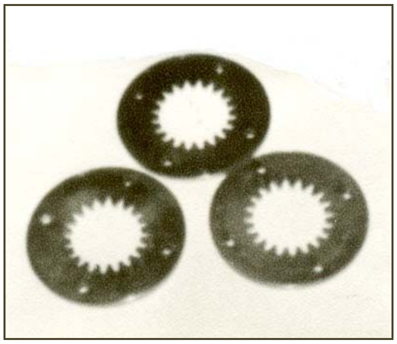

Fig. 3. *Variable mold inserts*

The structural tool performance implies an automatic removal of the injection system. The tool set has three planes of separation. The molten thermoplastic enters into the mold hollow form through three points (inlets) providing for an easy separation of the injection system from the finished gear (Figure 4).

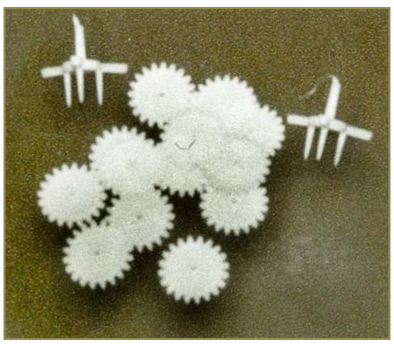

Fig. 4. *Gears after the separation of the injection system*

The manufacture of variable mold inserts has been done on the electro-erosion machine with a wire electrode. For the gear manufacture by injection the material Hostaform/ Celconacetal copolymer (POM) (produced by Ticona GmbH, as a member of Celanese Corporation) has been used. Comparing to other thermoplastics Hostaform has high hardness, rigidity and good dimension stability of finished parts and it is used for high performance applications. The Hostaform as a product is followed by the manufacturers' detailed list of its production range, physical and mechanical properties, as well as the instructions about the methods and conditions of processing. The shrinkage coefficient adopted for the calculations is 2%.

With the aid of the software application Lama 16C, it is possible to make slight variations of particular gear parameters, besides their drawing and comparison, as well as to follow the way in which changes of particular gear parameters affect the very geometry and gear dimensions. The use of this program provides for an early rejection of particular variants and thus unnecessary manufacture of particular variable mold hollows for the sake of experiments is also avoided [4,5].

On the basis of the above-mentioned considerations and for the sake of experimental procedure for determining the most optimal mold hollow dimensions for gear manufacture, the following variable mold inserts have been produced with the given dimensions:

-m=1,50 [mm]; α_o= 20°; z = 20 teeth; x=0
-m=1,53 [mm]; α_o =20,40°; z = 20 teeth; x=0
-m=1,53 [mm]; α_o = 20°; z = 20 teeth; x=0
-m=1,53 [mm]; α_o = 19,60°; z = 20 teeth; x=0

The experimental research presented in this paper has been carried out on the automatic injector Belmatik 50/28R, produced by Belišće.

4. ANALYSIS OF THE DIMENSIONS AND SHAPES OF THE THERMOPLASTIC GEARS

Respective check-up procedures of the obtained thermoplastic gears have been applied in order to test their dimensions and shapes for the sake of determining the most optimal dimensions of the mold hollow. Thus the most accurate gear is to be obtained. The gear testing machine Klingelnberghas made records of the involute profile testing (that is, check-up of the contact line angle and the fixed circle diameter) as well as of the involute and the gear side line testing [6,7].

The respective results obtained during the gear testing are given in the Table 1. (*D=30 [mm]; z=20* teeth*; x=0*).

Number 1 gives theoretical gear dimensions that should be realized. Numbers 2, 3, 4 and 5 give the dimensions of the obtained thermoplastic gears whose mold hollow dimensions are presented with respect to the values given in respective columns. In table 1, notations have the following meanings:

D - Pitch circle diameter
D_s - Addendum circle diameter
D_i - Root circle diameter
D_0 - Fixed circle diameter
W_k - Over tooth dimension (k=3)
$\overline{f_{D_0}}$ - Deflections fixed circle diameter
$\overline{f_\alpha}$ - Contacting line angle displacement
α - Contacting line angle
b_t - Flat tooth thickness
L - Tooth length
f_β - Side line angle displacement
A_β - Side line displacement
A_r - Eccentricity

Respective measuring procedures have shown that a quality is obtained of the pitch circle diameter IT8 for the gear whose mold hollow dimensions are listed in the rows 3 and 4, IT6 for the gear whose mold hollow dimensions are in row 5 (Table 1). The field of toleration for over-teeth dimension for the working gear (row 1) is $T_W=20[\mu m]$ while the respective deflections are $A_{Wd}=56[\mu m]$ and $A_{Wg}=-36[\mu m]$ for the side clearance $J_{nmax}-J_{nmin}=t_{jn}=122-61=61[\mu m]$ (ISS-Institute for Standardization of Serbia: Gears - Cylindrical involute gear pairs - Base tangent length tolerances - SRPS M.C1.034). The centricity quality (A_r) of all the gears is presented in the row 2, 3, 4, and 5 and it is 5 or 6 (ISS-Institute for Standardization of Serbia: Gears - Cylindrical involute gear pairs - Profile, pitch and radial run-out tolerances - SRPS M.C1. 035).The toleration field size for the tooth thickness of the given gear $T_S=20[\mu m]$, while the respective deflections are $A_{Sg}=-36[\mu m]$ and $A_{Wd}=-56[\mu m]$.

Table 1. *Gear testing results*

No	Gear Dimensions	D_s	D_i	W_k	$\overline{f_{D_0}}$	$\overline{f_\alpha}$	D_0	α	b_t	L	f_β	A_β	A_r
		[mm]	[mm]	[mm]	[mm]	[°]	[mm]	[°]	[mm]	[mm]	[°]	[mm]	[mm]
1	$m = 1{,}50;\ \alpha = 20^0$	33,000	26,250	11,491	0	0	28,190	200	2,323	3,00	0	0	0
2	$m = 1{,}50;\ \alpha = 20^0$	32,131	25,725	11,242	-0,678	3°46'	27,512	16°14'	2,306	3,004	2°06'	0,046	0,020
3	$m = 1{,}53;\ \alpha = 20{,}4^0$	32,948	26,242	11,434	-0,204	1°08'	27,986	18°22'	2,328	3,019	1°24'	0,036	0,022
4	$m = 1{,}53;\ \alpha = 20^0$	32,944	26,240	11,488	-0,051	0°17'	28,139	19°43'	2,337	3,023	1°10'	0,028	0,018
5	$m = 1{,}53;\ \alpha = 19{,}6^0$	32,982	26,242	11,490	-0.030	0°10'	28,160	19°50'	2,343	3,010	1°12'	0,026	0,018

The side line deflections for the manufactured gears whose mold inserts are listed as 4 and 5 are A=28[μm] corresponding to the quality 9 (ISS-Institute for Standardization of Serbia: Gears - Cylindrical involute gear pairs - Radial tooth error and alignment tolerances - SRPS M.C1.033). The achieved involute quality of the manufactured gears with mold inserts listed as 4 and 5 is 7 and 6 (ISS-Institute for Standardization of Serbia: Gears - Cylindrical involute gear pairs - Profile, pitch and radial run-out tolerances -SRPS M. CI.035).

By comparing the results given in Table l it can be concluded that the acquired values for the fixed circles diameters (D0) as well as for the connecting line angles (α0) for gears listed as 4 and 5 are in good agreement with the mathematical values in row 1. By analyzing the obtained thermoplastic gear dimensions it can be concluded that: optimal gear dimensions (m=1,50 [mm]; αo= 20°; z = 20 teeth; x=0) are acquired by the mold hollows whose dimensions are listed as number 5 in the table, that is at m=1,53 [mm]; αo = 19,60°; z = 20 teeth; x=0.

5. CONCLUSIONS

This paper presents many ways of determining the mold hollow dimensions in order to obtain the most appropriate form of gear. The software application Lama 16C has provided the possibility of varying particular gear parameters in addition to their drawing and comparison. At the same time, it has provided for the possibility of following up the ways in which changes of particular gear parameters affect the very geometry and dimensions of gears. By changing their variable mold inserts and by applying particular procedures for measuring and testing the obtained thermoplastic gears, their dimensions have been checked up. It has been shown that the optimal thermoplastic gear dimensions (m; α0=20°; z; x=0) can be achieved by the mold hollows having the following dimensions: m′=m·(1+S/100); α′0=α0·(1-S/100); z=20 teeth and x=0.

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