SOME CHARACTERISTICS ASPECTS REGARDING THE PRECISION MANUFACTURING OF WORM GEARS

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Abstract: *One of the important problems for manufacturing the worm gears is the adequate realization of the worm hobs. The paper presents a method for the accurate definition of the geometrical parameters of the worm hob and the selection of the cutting tool with alternative cutting.*
Key words: *gears tools for gear manufacturing, worm hob, CNC.*

1. INTRODUCTION

Functional requirements for different increasingly complex mechanical transmissions, led to the introduction of various modifications of front and axial profile of gears.
On the other hand, cutting phenomena, especially in the case of manufacturing by meshing the special worm gears, require some new technological solutions, which determine the modification of the basic rack geometry of different types of tools.
Practical achievement of the functional and technological gear with different profile modifications required the development of special technologies.
Our research team from the Department of Manufacturing Engineering - Technical University of Cluj-Napoca, approached these issues for over 20 years; they have developed a range of technological and geometrically new solutions that have been tested experimentally on specialized companies in the Romania and even abroad. In this paper, we intend to present the main methods developed by us and the results of experimental tests.

2. DEFINING THE VIRTUAL WORM GEAR MANUFACTURING SYSTEM

In real gear manufacturing (RGM) the generation of gear tooth is a continuous process in which both the cutting tool and the worm piece rotates in a constant relationship with the hob that is being fat into the gear blanc.
But in virtual manufacturing system –VGM- (Song & Su, 2000) the worm gear is static and the hob rotate in two directions (Fig.1), one around its own axis and the other - around the gear axis.
However, the relative movements of the gear and the hob in VGM and RGM are the same.
By imagining that the observer sits on the work in RGM process, the movement of the hob the observer sees that is exactly the same as the virtual hob movements in VGM.
So when the hob process is finished, the gear process in VGM and RGM are identical (Song & Su, 2000).

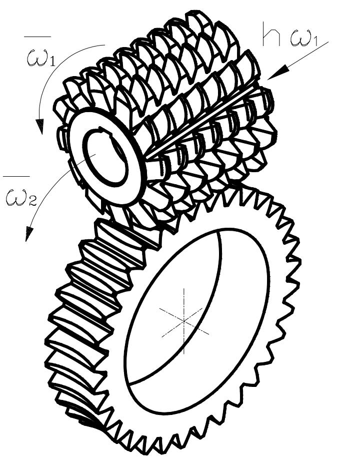

Fig.1. The position and relative movements within virtual gear manufacturing

3. ACCURATE CALCULATION OF WORM HOBS FUNCTIONAL GEOMETRY AND NEW METHOD FOR OPTIMIZATION OF LATERAL ACTIVE CLEARANCE ANGLES

It is well known that in the case of the worm hob, one of the difficult problems is the wear of cutting edges, which are mainly due to the inappropriate lateral clearance angle. In order to accurate calculation of this angle we developed a new methodology based on accurate theoretically and practical study.

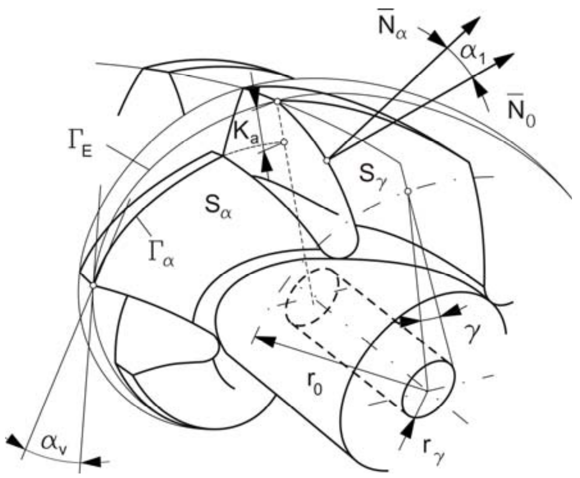

Fig.2. The constructive geometry of worm-hob

In this goal we considered that from the point of view of gear-cutting by generating kinematics, the cutting edges of the hob must be on a helical surface, which is in relative motion with basic rack flanks (or if the case of worm gear manufacturing, on an imaginary helical surfaces - modeled on ensuring adequate contact patch*). In this way, we consider the constructive lateral clearance angel α_l on connection with these surfaces (Fig.2).
Based on the figure, we define the constructive lateral clearance angle α_l as the angle between the normal $\overline{N_0}$ at the spatial imaginary envelope surface and normal $\overline{N_\alpha}$ to the lateral surface of the tool, in any point of the cutting edge.
The functional lateral clearance angle, was defined like the complement of the spatial angle between the normal $\overline{N_\alpha}$ and relative speed, from the cutting process (fig. 3).
In order to accurate determination of the constructive lateral clearance angle, we use the cutting triangular planes in order to generate the cutting process with worm-hob (Fig. 4).

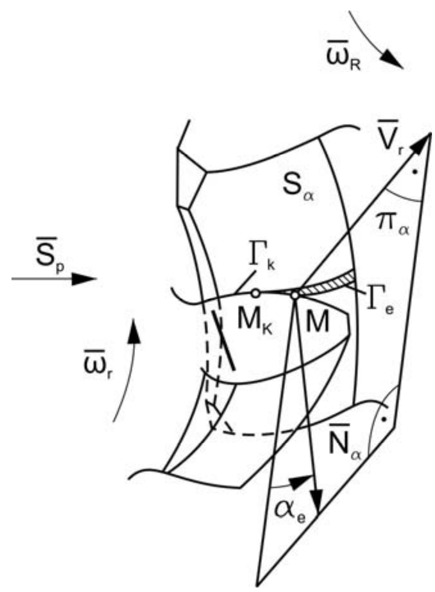

Fig.3. The active lateral clearance angle

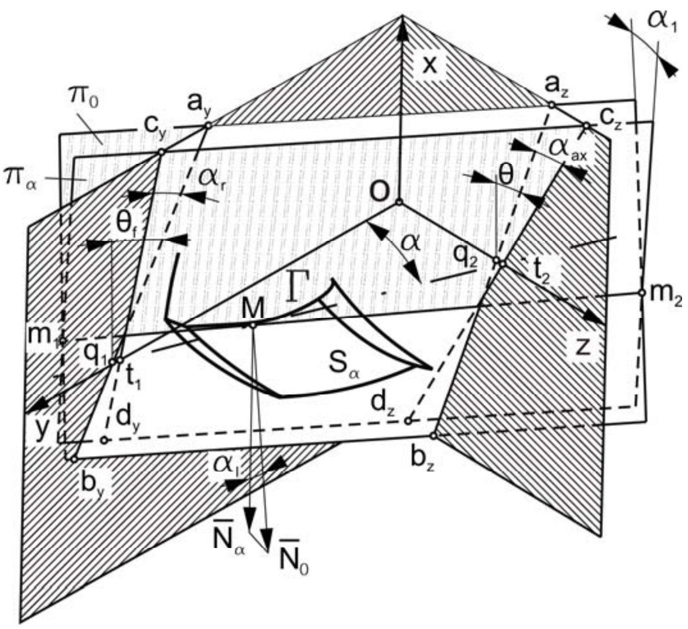

Fig.4. The characteristic triangular planes of generating cutting processes

The normal $\overline{N_0}$ at tangent plane to lateral relieved surface, can be calculate with the following equation:

$$\overline{N_\alpha} = \bar{\tau} \times \overline{\tau_e} \tag{1}$$

where: $\bar{\tau}$ - is the tangent vector at cutting edge on point M (their direction is identically with intersection line $m_1 m_2$ between planes Π_0 and Π_α, τ_e - is the tangent vector at helicoidally line across this point. Using the previsions definition:

$$\alpha_l = \arccos \frac{\overline{N_0}.\overline{N_\alpha}}{\left|\overline{N_0}\right|.\left|\overline{N_\alpha}\right|} \qquad (2)$$

in order to accurate determination of *functional (active) lateral clearance angle*, we must analyze the relative motions of gear cutting processes by generation (Fig.5)

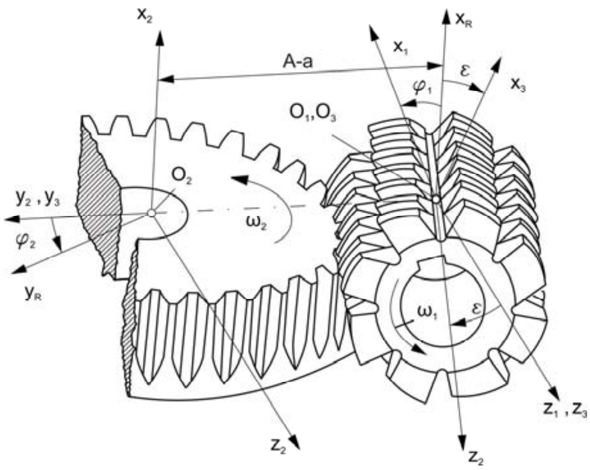

Fig.5. Relative position and movement between worm-hob gear in the cutting processes

Using the matrix methodology (after Litvin), the relative speed can be calculated by using the following equation:

$$\overline{v_r} = \begin{Bmatrix} (A-a-y_1)\sin\varepsilon + e_{ax}.n_p \\ x_1 \sin\varepsilon + (z_1 - h\varphi_1)\cos\varepsilon \\ (A-a-y_1)\cos\varepsilon + h.i_{12} \\ 0 \end{Bmatrix} \qquad (3)$$

where: with x_1, y_1, z_1, there are marked the coordinates of the certain *M* point, from the enveloping helicoidally surfaces;

- e_{ax} – axial feed , mm/rev;
- *h* – helical motion parameter, mm/rad;
- *a* – cutting depth, mm;
- ε - angle of worm-hob axis inclination.

In this way, the active lateral clearance angle can be determined with expression:

$$\alpha_{le} = \arcsin \frac{\overline{N_\alpha}.\overline{v_r}}{\left|\overline{N_\alpha}\right|.\left|\overline{v_r}\right|} \qquad (4)$$

Certainly in order to accurately do analytical and numerical calculations, these parameters were necessary to elaborate some complex mathematical algorithms. Limited space of this paper does not allow their detailing, but those interested can find in (Gyenge & Bob, 2007). On the basis of mathematical algorithms, computer programs have been built to precisely determine these angles, as well as their modifications.

Figure 5 shows the variation of the active clearance lateral angle for a real production case. The effective parameters of analyzed technological gear are:

- transmission ratio: $i = \frac{z_2}{z_1} = 70$;
- lead angle of reference helicoidally line of hob: $\varepsilon = 0{,}2835$;
- axial feed: $e_{ax} = 2mm / wrew$;
- radial relieving parameter of hob: $P_A = 10mm$;
- distance between axes: $A = 200mm$;
- initial point parameters: $p_0 = 0; v_0 = 0$.

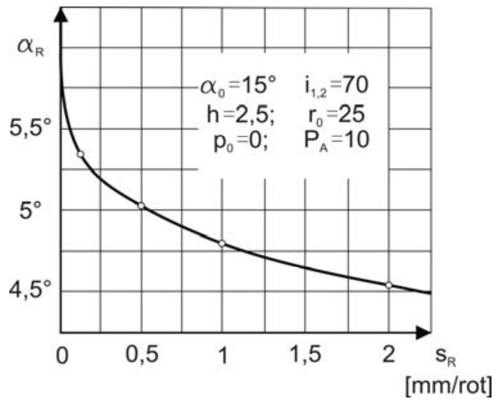

Fig.6. The variation of the functional lateral clearance angle

From the diagram it can be seen that such a relatively common gear drive, with pressure angle $\alpha = 20^0$ already at a depth of cutting $a = 2mm$, the active lateral clearance angle is less than about 2^0 as compared to the constructive angle.

It is well known that in case of small pressure angle (special worm gears, gears with profile modification, etc.), the lateral clearance angle is decreasing dangerously and leads to a pronounced increase of friction from the cutting process and increased of the profile size. For decreasing these negative effects, based on the intensive researches, we developed one advantageous method that has been succesfully applied in the industry, as worm hob.

4. THE WORM AND WORM WHEEL CNC TESTING

The complex control of manufacturing worm gear is (Gyenge et al., 2008) made with a measuring control machine Brown&Sharpe ghibli-trax (Fig.7).

Fig.7. Measurement of worm wheels for cylindrical worms on Brown&Sharpe ghibli-trax

The worm wheel is considered as conjugate gearing of the cylindrical worm i.e. the surface points of the worm wheel including normal direction are calculated by using only the geometrical parameters of worm and worm wheel. Included are (Gyenge et al., 2008) the worm types ZI, ZA, ZN, ZK and ZC (see e.g. DIN 3975).The measurement of worm wheels will be executed with a regular probe star which in general consists in 8 probing pins (fig.8).

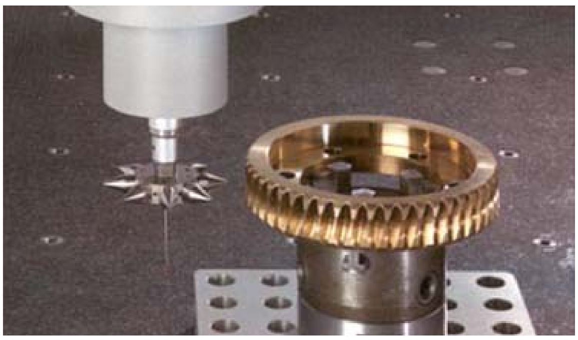

Fig.8. Mask for worm wheel parameters machine

Once the coordinate system of the worm wheel is established the complete measurement and evaluation of the worm wheel is processed by the command WWHEEL.

The different measuring tasks can be executed altogether or individually by several calls of the command.

Executing the WWHEEL command invokes automatically other masks where the user can enter the geometrical parameters and details for the selected measurement tasks.

The geometrical parameters includes both wheel and worm parameters, introduced in separate mask

After the last input mask the probing mask appears with the advice to probe both flanks of a gap or a tooth.

These probing are used for the rotational orientation of the worm wheel, defining the reference tooth or gap.

After probing the automatic measurement starts immediately. After every single task e.g. measurement of a profile the plot evaluation is executed.

The evaluation charts from figure 9 can be obtained:

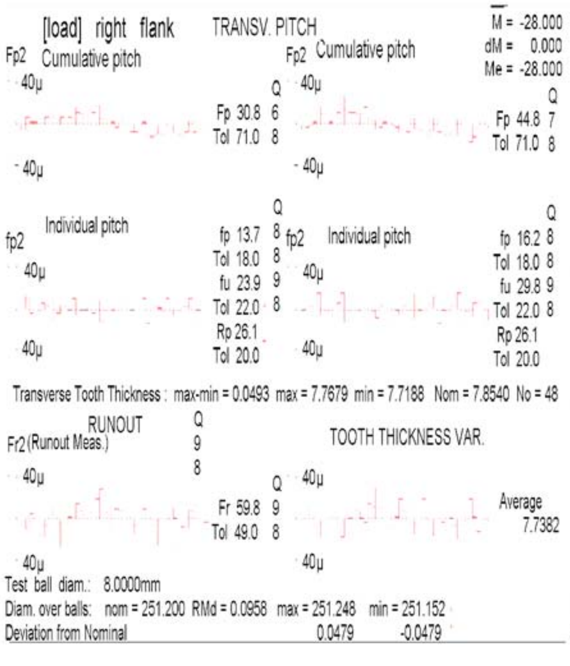

Fig.9. Run out and pitch evaluation chart

During the experimental research were manufactured by our CNC grinding method different gears with profile modifications and normal module m = 12, number of teeth z=14…60 (Table 1).

Table 1. The main date of tested gears

N°	norm	m_n	z	α	β	Addendum modification	Profile modification
Wheel 1	DIN	12	18	20^0	0	0	-
Wheel 2	AGMA	10,808511	30	28^0	0	0	$\Delta\alpha_f = 0{,}027$ $\Delta\alpha_a = 0{,}033$
Wheel 3	DIN	8	70	20^0	10^0 (left)	x = -0,411	-
Wheel 4	DIN	8	16	20^0	10^0 (right)	x = 0,411	-
Wheel 5	DIN	12	14	20	0	0	-
Wheel 6	AGMA	10,948275 (DP-2,32)	18	25^0	0	0	$\Delta\alpha_f = \Delta\alpha_a$ $= 0{,}038$

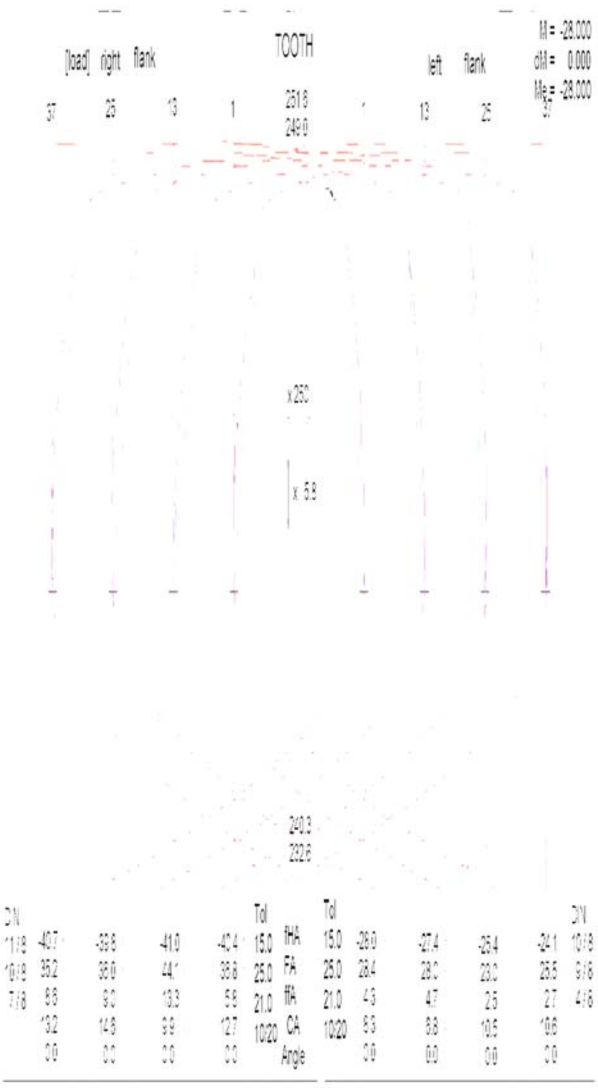

Fig.10. Profile evaluation chart

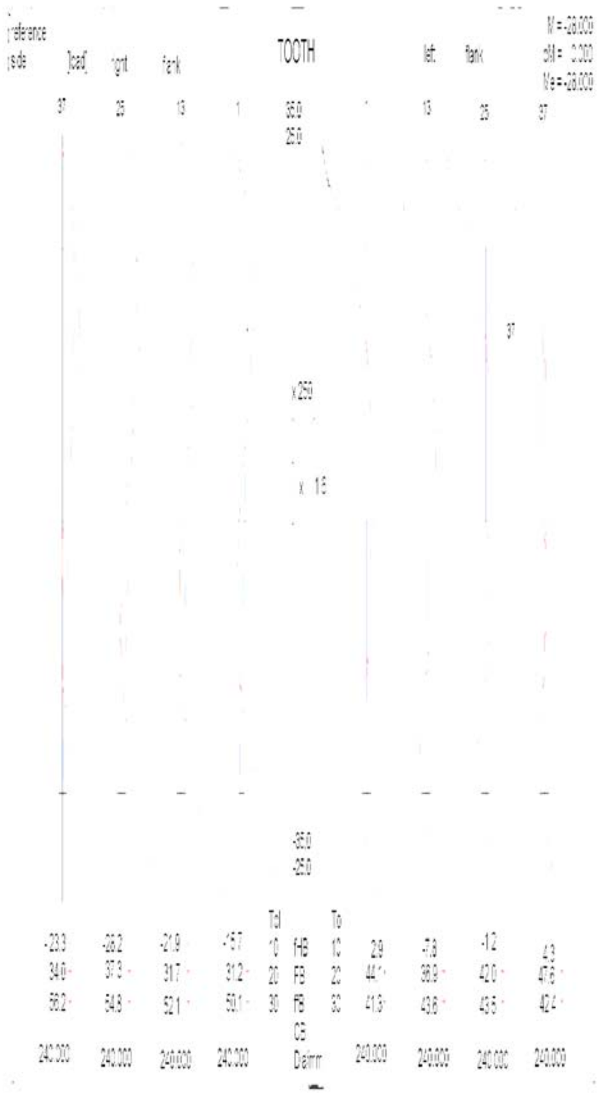

Fig.11. Flank traces evaluation

The profile measurement can be executed at right, left or both flanks (fig.10).
Default is the complete measurement. If no tooth numbers are entered, 4 equally distributed numbers are determined by the program.
For the topography evaluation, the deviations of the tooth flank at grid points perpendicular to the surface are displayed.
The deviations are shown at a symbolic tooth with their true value without prospectively shortage.
The large deviations which would make the plot unreadable are cut off by the amount given in the input mask.
The points concerned are marked with a small circle in the base grid.
The limiting value is notified at the lower left corner of the plot.
The measurements showed that the different parameters of the gears manufactured with developed CNC method are appropriate to a precision class of 5-after DIN 3962.

5. CONCLUSIONS

The accurate determination of worm hob geometry leads to an increased durability and also to a significant improvement of the accuracy parameters and surface quality of the manufactured gears.
Our researches made with modern equipment have highlighted the methodology and technology advantages.
Our technical and experimental research in this area may contribute to the development of high quality and maintenance transmission in the case of different industrial applications.

6. REFERENCES

► Gyenge Cs. & Boca V. (2007). Virtual technological system for worm manufacturing, *The 3rd international conference on manufacturing science and education – MSE*, ISSN 1843 – 2522, Sibiu.

► Gyenge Cs., Boca V., Bob M. & Mihai M.(2008). Some Characteristics Aspects Regarding The Modeling And Optimization Of Virtual Technological System In Gear Manufacturing. *12th International Research/Expert Conference - Trends in the Development of Machinery and Associated Technology – TMT,* August 26-30, 2008. Istambul, Turkey.

► Mihai M., Gyenge Cs. & Boca V. (2006). New technology for Manufacturing Globoid Worm Gears, *Proceedings International DAAAM Symposium*, ISSN 1726 – 9679.

► Gyenge. Cs , Kismihály. I. (2000). Minimising of profile errors of hobs for worm gear machining, *Proceedings of the 11th International DAAAM Symposium*, ISBN 3-901509-13-5, October, 2000, Opatija.

► Song Y. & Su D. (2000). Three–dimensional virtual manufacturing of worm gear, *The international Conference on Gearing, Transmissions, and Mechanical Systems*, ISBN 1 86058 260 5.

► Gyenge, Cs. (1991). Design and manufacturing the high precision worm hobs, In: *Gép Budapest*, pp. 385-394, October 11-12, 1991, Budapest.

► Gyenge, Cs. (1996). Exactly determination of lateral relief angel of hobs, In: *Gép Budapest*, pp. 38-42, October, Budapest, 1996.

► Gyenge, Cs. & Bob, M. (2007). Aspecte caracteristice ale controlului digital complex al rotilor dintate cilindrice cu modificari de profile, *12th International Conference on Tools ICT*, 2007, Miskolc.

► Litvin, F. & Fuente, A. (2009). *Geometria angrenajelor si teoria aplicat.* Second Edition, 2009, Cluj-Napoca.

► Rao, J.S., Puri, T. & John, J. (200). Computer-aided design of gears in transmissions of gears in transmission systems, *International Conference on Gearing, Transmissions and Mechanical Systems,* pp.213-222, 2000.