ANNALS OF THE ORADEA UNIVERSITY
Fascicle of Management and Technological Engineering
ISSUE #1, MAY 2013, http://www.imtuoradea.ro/auo.fmte/

EXPERIMENTAL RESEARCH REGARDING CURVED BEVEL GEAR TOOTHING

Ioan PANTEA
University of Oradea, e-mail: ipantea@uoradea.ro

Abstract**—** This paper highlights the experimental research of the author regarding the implementation of spiral bevel gears with curved teeth, teeth which have a decreasing depth of the tooth. The subject of this paper is the process of toothing a gear with the use of cutting tools designed and made by the author. The knives have the side and peak edges generated according to an involute spiral. The proposed solution for the side and peak surface coincidental grinding is based on a key property of cylindrical helicoids of constant pace which states that the common screw axis is affine-invariant to the rototranslation of either helicoid. The exploitation of this property for achieving active helical edges ensures the conservation of the shape of the cutting tool's edges, and consequently of its profile. The results obtained with these cutting tools in the processing of the gear are being presented.

Keywords**—** gears, gear cutting tools, relieving head

I. INTRODUCTION

THE paper presents the experimental research obtained in the realization of a spiral bevel gear with curved teeth, processed with experimental cutting tools. The profile of these knives is formed by complex surfaces that are part of helicoids. In this case the side edge of the knives has a directrix curve made according to an involute spiral. The study is based on the spatial meshing method. An important issue is that of identifying an experimental model for the rectification of the cutter profile so that the deviations of the cutting edges from the sharpening field do not exceed the allowed values. When profiling the cutting tools the following problems have to be solved:

1) Determining the abrasive wheel contour (theoretic profile);
2) Determining the relieved surface equations.

Solving these problems is done simultaneously in a computing section by using the spatial meshing laws and coordinate system transformations [1].

The study method used in this paper is the simultaneous calculation of the knife's profile and that of the disc to be grinded in a computing section through the use of the laws of spatial meshing and through the coordinate system transformation. This study is based on an algorithm published by the author [2], which determines the following:

1) the generating curve;
2) the cutting edge in the computing section;
3) the rectified edge;
4) the cutting tool's theoretical edge;
5) the actual rectified edge;
6) the contour of the profile.

From a geometrical perspective, the profile of the knives corresponds to conjugated surfaces defined according to meshing theory [3]. From a kinematic standpoint, the issue at stake is that of determining the profile's dimensions and the limits within which it is possible to generate the conjugated surfaces of teeth. Meshing theory, developed for meshing in the plane, cannot be applied since the cutting edges of the knives are part of Archimedean helicoids, surfaces that cannot be wrapped by cone or by cylinder at the rectification stage [4], [5].

A complete theoretical study of the gear cutting tool profile to be toothed is possible only by using differential geometry and vector algebra. These complicated computational relationships can be fully exploited with the aid of computer programs. The mathematical model takes advantage of the possibilities offered by computer software and allows for a detailed study of the kinematic geometry, as well as that of the generation and control of the studied profiles [6]. Using the model provided, it is possible to simulate and study the execution errors and assess their influence on the process' precision.

II. TOOTHING KNIVES

Computer programs are used for simulating outer gear cutting tools which have a straight cutting edge. We have chosen the module m = 5mm knives which equip the 6" Hardac – Gleason gear cutting heads which are situated in the middle range of sizes and are more frequently used.

The clearence finishing is done through rectification with a grinding abrasive disc cutter on a Niles type worm milling machine or on thread grinding machines.

In order to attain the coordinate display functions of the cutting edge, of the abrasive tool coordinates, and of the real cutting edge deviations from a straight line passing through its extreme points, a software program was developed by the author. Based on the algorithm described above, the software program computes the following:

1) the p independent parameter according to the blade module;
2) the generating surface coordinates;
3) the abrasive tool surface coordinates;
4) the actual seating surface coordinates;
5) the deviation of the cutting edge from a straight line passing through its extreme points;
6) the maximum deviation Δ.

The simulation results were obtained by taking into consideration the following parameters:
1) the number of the actual seating surface sections: 6;
2) the number of points on the profile: 7;
3) maximum allowed tolerance: 0.08mm.

The data obtained was processed and verified using a software program written in MathCAD. Fig. 1. shows the deviations of the cutting edges.

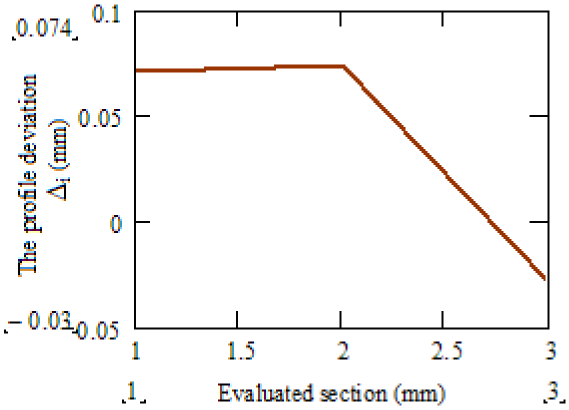

Fig. 1. The deviation of the profile

III. EXPERIMENTAL RESEARCH

The construction and technological constraints posed by the bevel gears are quite different than those of spur gears. Achieving and maintaining the angle between the axes during use for bevel gears is more difficult than achieving and maintaining the parallelism of the axes, in the case of spur gears.

The fact that most bevel gears have cantilever axes leads to the elastic deformation of these during operation and increases the risk of edge contacts, as well as high and uncontrolled stress concentrations appearing in and around the contact areas [7].

This is one of the reasons why bevel gears with curved and spur teeth are used less frequently, especially in demanding gears, in favor of curvilinear toothed gears. Moreover, the issue of crowning the side edges of the teeth of spiral bevel gears becomes an important necessity due to its ubiquity in bevel gears toothing systems. It is to this effect that a diverse range of bevel gears have been designed and manufactured over time, using various execution technologies to obtain the crowning, which has led to the creation of a large number of gear cutting tools and machinery. Spur gears have a low degree of coverage while gears with inclined teeth are very sensitive to the variation of the angle between the axes [8].

Bevel gears with curved teeth ensure a high degree of uniformity for transmitting motion, their coverage through flank advancement is increased, and the total coverage is improved significantly. The functional qualities of bevel gears with curved teeth are superior with respect to other types of spur or inclined teeth. This superiority becomes even more apparent if we take into account the other advantages offered by these gears, such as the avoidance of total load-bearing through the local optimization of the contact spot due to the crowning, which makes that the convex side of the tooth come in contact with the concave part of a tooth, as well as the decrease in the position vector of the force application point [9].

The kinematic accuracy is the main requirement for these gears [10]. The structural type and the technological execution process type is determined according to the destination of each gear. If the structural type choice is between straight and curved teeth, the selection criteria being structural but equally determined by the existing equipment of the gear cutting machinery, we have the possibility of substituting these gears, a fact which simplifies the equipping of these machines [11]. Experimental research were carried out with these knives with regards to the execution of a spiral bevel gear with a decreasing depth of the tooth. The research was aimed at determining the variations of the flanks of the teeth that were processed with these involute knives, in the case of sharpening the knife within the entire available work field [12].

The processing of the gear was done on the Gleason 528 curved teeth bevel gear cutting machine. A software program was developed, using Visual C++, in order to calibrate the machine head. It has been named “Software for computing the tool’s parameters in the process of cutting gears with decreasing tooth depth”. Four groups of knives were mounted on the 6” cutting head, each group consisting of an outer and inner knife, rectified on a technological device designed and made by the author. The outer knives were fixed at the outer diameter D_e, while the inner knives were mounted at the inner diameter D_i [2]. The blades were adjusted using the set of jigs that are part of the machine’s standard equipment. The semi-finished wheel was mounted on the gear cutting machine which was previously adjusted according to the Gleason adjustment chart. The gear cutting head was first fitted with the Gleason knives. Three of empty spaces between the teeth were done using this setup, after which the same head was equipped with the experimental knives adjusted to the same diameter.

After making the first measurements, during the head adjustment phase, we found that the inner and outer diameters of the head, which had been equipped with the outer and inner experimental knives, were kept constant for any diametrical pair of points located on the side seating edge surfaces of the knives. The grinding program was ran after this phase and the obtained data was then used in developing the adjustment chart for the Gleason 13A gear cutting machine. The grinding depth of the gear cutting machine was adjusted the experimental knives. Three empty tooth spaces were done, pictured in Fig. 2.

These were followed by five other knife sharpenings, each time at a depth of 3mm so that the maximum blade sharpening width (two-thirds of the height) would not be exceeded. The knives were sharpened a total of six times. After each sharpening, three more empty tooth spaces were made, each one being separated on the gear by an empty space processed at a smaller depth. Neither signs of wearing on the knife profiles, nor their warming have been observed.

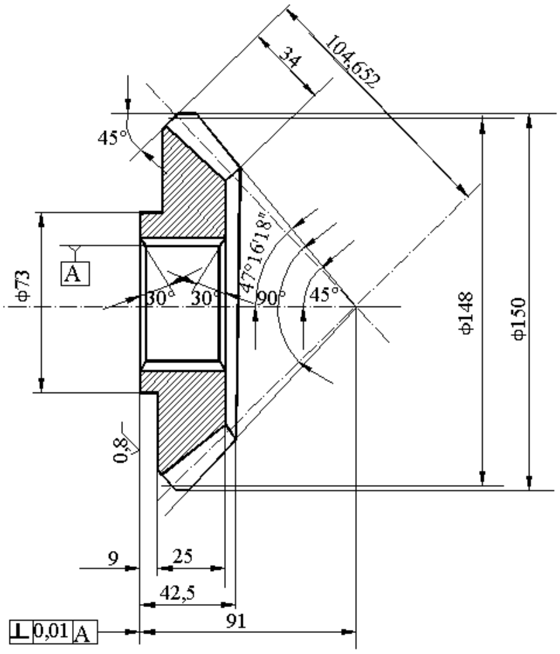

Fig. 2. The toothed wheel used for testing

The measurements were done on a JCS-CLY 1086, coordinate measuring machine, pictured in Fig. 3.


Fig. 3. Experimental measurements

4. THE RESULTS OF MEASUREMENTS

Fig. 4. and Fig. 5. show the topographical comparison of the wheel teeth flanks, and these were generated by inputting the coordinates of the measured points into the Mathcad 10 Professional software program.

The data obtained from the measurements was further processed before being used for parameter assessment and comparison.

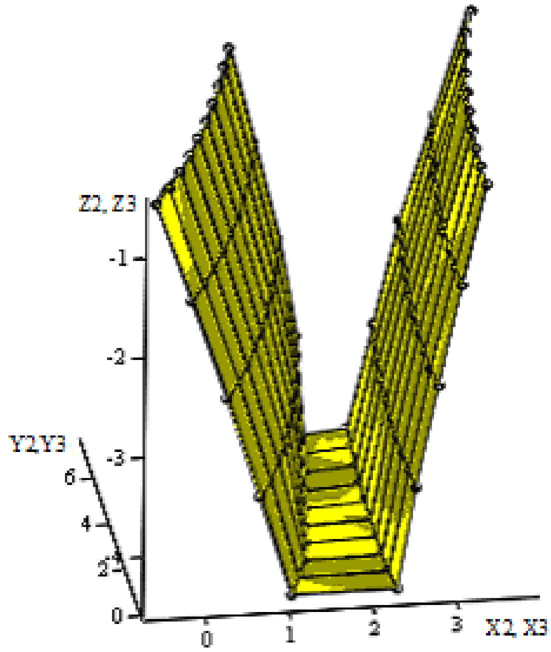

Fig. 4. The topography of the gap between the teeth done with the experimental knives

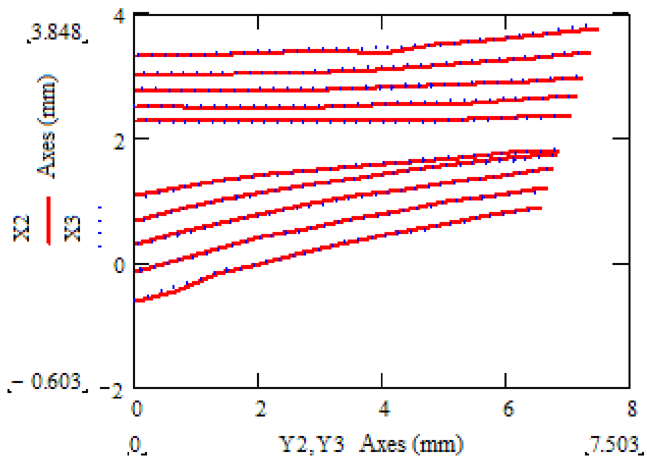

Fig. 5. A comparison of the gaps between the teeth's topography made with the experimental knives after the second and third sharpening

Differences between the measuring points from flanks on the Y axis when processed with the experimental knives at the second and third re-sharpening are shown in Fig. 6.

Y2 – Y3 =

Axes (mm)

	0	1	2	3	4	5
0	0	0	0	0	0	0
1	$-3.01\cdot10^{-3}$	$8.4\cdot10^{-4}$	$9.45\cdot10^{-4}$	$1.295\cdot10^{-3}$	$6.65\cdot10^{-4}$	$4.9\cdot10^{-4}$
2	$9.1\cdot10^{-4}$	$1.68\cdot10^{-3}$	$2.1\cdot10^{-3}$	$2.45\cdot10^{-3}$	$1.68\cdot10^{-3}$	$6.3\cdot10^{-4}$
3	$1.68\cdot10^{-3}$	$3.15\cdot10^{-3}$	$3.15\cdot10^{-3}$	$3.255\cdot10^{-3}$	$9.45\cdot10^{-4}$	$7.35\cdot10^{-4}$
4	$3.384\cdot10^{-3}$	$5.076\cdot10^{-3}$	$4.653\cdot10^{-3}$	$3.807\cdot10^{-3}$	$2.397\cdot10^{-3}$	$8.46\cdot10^{-4}$
5	$3.168\cdot10^{-3}$	$5.808\cdot10^{-3}$	$5.808\cdot10^{-3}$	$6.864\cdot10^{-3}$	$8.8\cdot10^{-4}$	$3.872\cdot10^{-3}$
6	$5.112\cdot10^{-3}$	$6.39\cdot10^{-3}$	$6.816\cdot10^{-3}$	$7.242\cdot10^{-3}$	$2.13\cdot10^{-3}$	$4.047\cdot10^{-3}$
7	$6.972\cdot10^{-3}$	$8.217\cdot10^{-3}$	$8.466\cdot10^{-3}$	$9.462\cdot10^{-3}$	$1.494\cdot10^{-3}$	$2.739\cdot10^{-3}$
8	$7.175\cdot10^{-3}$	0.01	$9.184\cdot10^{-3}$	$8.036\cdot10^{-3}$	$7.175\cdot10^{-3}$	$5.453\cdot10^{-3}$
9	$8.125\cdot10^{-3}$	0.011	0.012	$9.75\cdot10^{-3}$	$6.825\cdot10^{-3}$	$8.775\cdot10^{-3}$

Evaluated section (mm)

Fig. 6. Differences between the measuring points from flanks on the Y axis when processed with the experimental knives at the second and third re-sharpening

V. CONCLUSIONS

Through the study of the empty spaces, the comparative analysis of the gear teeth flanks of the processed gear, given the same processing conditions (in terms of sharpened depth compensation through machine adjustment), allows for the formulating of the following findings:

1) The numerical results and measurements point out that the obtained knife profile (the cutting edge deviation after the re-sharpening) falls within the allowed tolerances and the tooth flank remains constant during processing;

2) We have confirmed that the theoretical and experimental computation methods are correct. Moreover they can be applied to any process variation. We feel that the experimental research, through computer simulation, and the direct research in exploitation systems, do clarify many of the technical aspects regarding the technology for the execution of gear cutting tools used on spiral bevel gears.

3) Measurements using an electronic pyrometer were done with regard to the heat transferred to the knives during the grinding process. We have found that the temperature of the knives was not raised by more than 1..2 degrees Celsius above the ambient temperature.

REFERENCES

[1] Litvin, F.L., *Gear Geometry and Applied Theory.* University of Illinois, Chicago. PTR Prentice Hall,1994.

[2] Pantea, I., *Contributions regarding the technology of the tools used for bent teeth bevel gears teething. (Contribuţii privind tehnologia sculelor de danturat roţi dinţate conice cu dinţi curbi.)*Doctorate Thesis, University of Oradea, 2004, p 48-52.

[3] Aron, I. s a., *Conical bevel gears with curved teeth.(Angrenaje conice cu dinţi curbi.)* Science Book House Publishing, Cluj-Napoca, 1999, p. 10–53.

[4] Şteţiu, G. ş.a., *Practice and theory of cutting tools, vol. I, II, III. (Teoria si practica sculelor aschietoare.)* University of Sibiu Publishing, ISBN 973-95604-3-1, Sibiu,1994.

[5] Lăzărescu, I. ş.a., "*Contributions regarding the geometry of knives used for the processing of circular arc teeth of conical bevel gears". (Contribuţii în legătură cu geometria cuţitelor pentru prelucrarea danturii roţilor dinţate conice în arc de cerc.)*Bucharest, The Institute of Applied Mechanics Magazine, no. 3/1959.

[6] Pantea, I, Stanasel, I. & Blaga, F., *The Simulation of the Profiling Technology of Toothing Knives*, Annals of DAAAM for 2008 & Proceedings of the 19th International DAAAM Symposium, Vienna, Austria, 2008, p1015-1016. http://www.conftool.com/daaam2008/

[7] Minciu, C., *Cutting tools.(Scule aşchietoare.)* Design guidebook. Bucharest, Technical Publishing, 1995.

[8] Sauer, L.ş.a.., *Tools for toothing.(Scule pentru danturare.)* Bucharest, Technical Publishing 1962.

[9] Guja, N., "*Trends and novelties in gearing".(Tendinţe şi noutăţi în domeniul angrenajelor.)* Machine-tool construction 1/1999, p. 3-4.

[10] Târziu, H., *Research regarding the relieving of milling heads used on conical bevel gears with curved teeth on universal rectification machines.(Cercetări teoretice şi experimentale privind detalonarea capetelor de frezat dantura roţilor conice cu dinţi curbi pe maşini de rectificat universale.)* Doctoral Thesis, Transilvania University of Brasov, 2001, p. 62 – 64.

[11] Maroş, D., *The kinematics of gear wheels.(Cinematica roţilor dinţate.)* Bucharest, Technical Publishing 1959 p. 12–24.

[12] Mihăilă, I., *Mechanical technologies.(Tehnologii mecanice.)* University of Oradea Publishing, 2004, p. 267-271.