BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 4, 2013
Secţia
CONSTRUCŢII DE MAŞINI

STUDY OF STAGGERED-TOOTH MILLING CUTTER AND DESIGN OF MILLING CUTTERS WITH INCREASED DURABILITY FOR PROCESSING SCREW COMPRESSORS

BY

GHEORGHE PLESU[1*] and FLORIN CHIFAN[2]

[1]“Gheorghe Asachi” Technical University of Iaşi,
Department of Machine tools and cutting tools
[2]GL Project, Iaşi

Received: September 27, 2013
Accepted for publication: October 5, 2013

Abstract The design of staggered-tooth milling cutter is an important consideration for manufacturing helically surfaces. These surfaces are produced mostly by milling processes. The methodology proposed in the paper addresses the problem of the design of staggered-tooth milling cutter for the machining of helically surfaces. At the first point of this problem, there is presented the analytical method of obtaining cutter profile. At the second point, there is presented the graphic method of obtaining cutter profile. The main objective of this paper is to compare these two methods and to provide and analyze the final results.

Key words: staggered-tooth milling cutter, screw compressor, blade' profile.

1. Introduction

Screw compressor is a common type of machine used to compress gases. It consists of a pair of meshing rotors with helical grooves machined in

*Corresponding author; *e-mail:* gplesu@tgh.ro

them contained in a housing, which fits closely around them. The rotors and housing are separated by very small clearances. The rotors mesh like gears in such a manner that as they rotate the space formed between them and the housing is reduced progressively. Thus any gas trapped in this space is compressed. From then on, as a result of their ever improving efficiencies, high reliability, and compact form, screw compressors have taken an increasing share of the compressor market, especially in the fields of compressed air production, and refrigeration and air conditioning, and today, a good proportion of compressors manufactured for industry are of this type. For processing of rotor surface, with precision and efficiency, was imposed the using of staggered-tooth milling cutter, which is the most used method in the recent times

2. Brief Presentation of Milling Cutters

Analysis of disc cutters sharp solutions used in processing of complex helical surfaces can form an insight (Pleşu, 1999) (Fig.1), which makes a classification according to the cutters material used, construction of the milling cutters body, arrangement of the cutting part, the possibilities of repositioning of the cutting part at sharpening. For helical surfaces, the main criterion for designing profile cutters is the precision profile after regrinding. Small tolerances of helical tooth cutter surfaces require very high precision of the tool and the need of maintaining this accuracy over the whole period of the tool usage. So as to achieve these, there have been developed two directions of research:

- achieving constructive solutions to allow keeping the cutter’s diameter at regrinding;
- achieving machines systems run by computer to allow the calculation in the process of the milling cutter’s profile according to the new milling cutter diameter.

The precision requirements have also influenced the construction of shaped milling cutters by finding solutions to ensure similar conditions of cutting for every point on the tool’s profile and thereby considerably reducing cutting forces. Finding the optimal solution involves a study of existing solutions. In order to systematize these constructions a classification of them can be made by using the Table 1 (Kudevițkii, 1979). In this table an appeal has been made to a previous classification of existing shaped milling cutters solutions, using as criteria:

- the shape of profile;
- tooth shape and face of settlement shape;
- form generator and the radial rake angle;
- form and layout of the face of settlement;
- the shape of the bottom channel of chips.

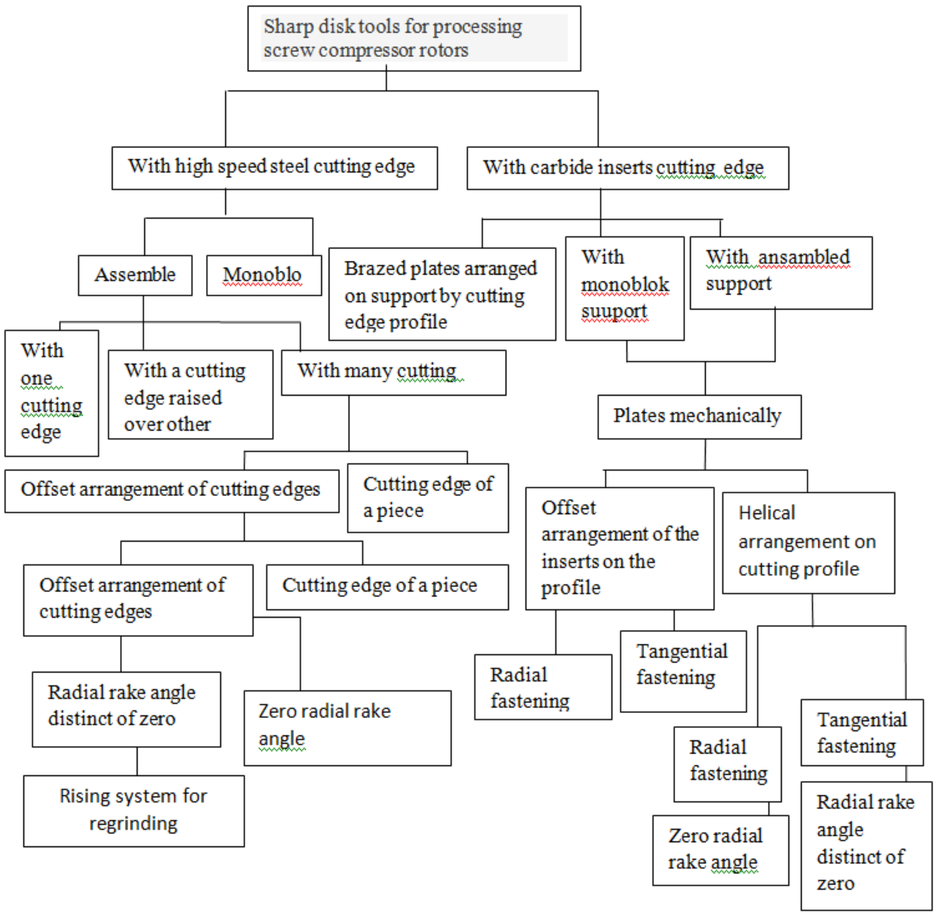


Fig.1 − Disc cutters solutions.

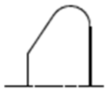
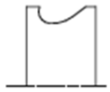
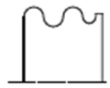
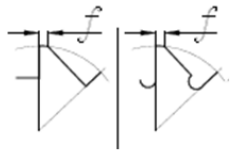
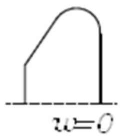
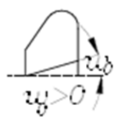
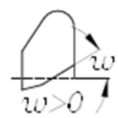
Among the already known solutions, the one with staggered-tooth has several advantages, which led to its use mainly to the processing screw compressors

In Fig. 2 it is shown the construction of this type of milling cutter for a screw compressor. It can be seen staggered arrangement, both axial and radial of the cutting blade. The arrangement of the cutting edges requires the determination of its position, in order to ensure obtaining favorable cutting angle on the entire length of its profile.

The channels for attaching the teeth on the body of milling cutter have different tilt direction and the value of axial rake angle may differ for each of successive teeth, which is about half of the width of the profile generator tool disk.

Table 1

The classification of profiling cutters by the shape of the profile and constructive parameters

By the shape of the profile	Convex 	Concave 	Complex 	Variable 
By the shape of the tooth	Relieved 	Sharpened 		Sharpened relieved 
By the shape of generator and radial rake angle value	Straight  $\gamma = o$ $\gamma > o$ $\gamma < o$			Curved  $\gamma > o$
By the shape and direction of the tooth surface clearance	straight 	bend 	Helical 	Duble bend 

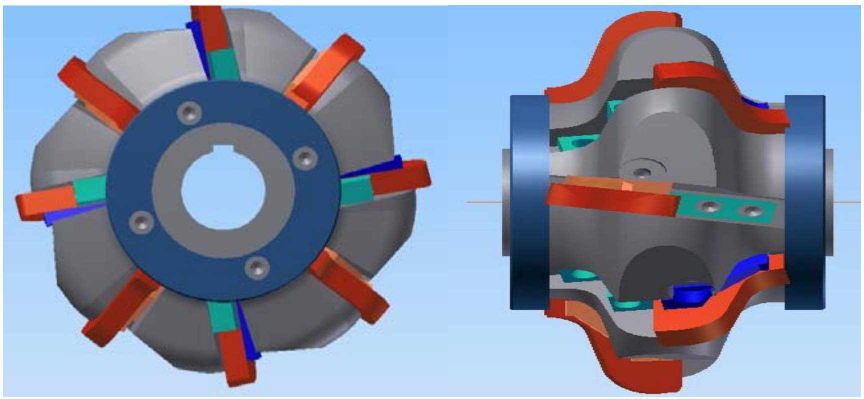


Fig. 2 – Milling cutter with staggered-tooth.

To the top of the cutter, which is the most used part in the cutting process, two successive teeth overlap. To ensure a rigid clamping of the two teeth, the body of milling cutter is designed to provide only a small part of the tooth outside it. Tools made by foreign companies have both the fastening hole diameter and external diameter large, thus ensuring a high resistance body. In our country there are no specialized machines for processing rotors and achieving tools, ensuring of enough strength of the tool is related to obtain sufficiently large dimensions for the body of milling cutter deck.

Staggered-tooth side milling cutter has established itself as the solution used recently. According to the method of disposal of teeth, their favorable profiling and cutting angles across the tooth, means that in the computer aided design system disk tool to be introduced specific modules of this solution, modules that can also be used for simple solutions.

The design of such tools requires solving several problems concerning establishing of inter conditioning between its parameters in order to achieve the functional characteristics when there are restrictions concerning characteristics of machine tools for tool implementation and those for helical surface processing.

However, considering the complexity of tool design, a methodology has been developed to allow:

• calculation of cutting edge profile;
• obtaining cutting angles at each point of the cutting edges;
• achieve continuous cutting;
• providing non- interference of the channels for disposal cutting teeth.

Since in the technical literature staggered-tooth side milling cutter's issue, used in processing of complex helical surfaces, was approached in (Csi, 1990) and (Kudevițkii, 1978), but not able to solve all the issues above, it was used in a more general approach of this type of tool which can be extracted as some particular cases the positive rank angle milling cutter and the plain milling cutter (slab mill).The advantage of staggered-tooth side milling cutter used at the processing of complex helical surfaces was previously pointed out.

Based on the analysis, there was made a picture of designing, proposed in Fig. 3 and the realization of mathematical models to define numerical profile blades and to determine functional parameters for these milling cutters (Fig. 4).

Making cutting angles at each point of the blade profile is a first issue of great importance for the construction of these milling cutters. Also, the condition of continuous non-interference in sharpening-cutting led to the establishment of formulas to determine the number of teeth of the tool.

The data concerning positioning of cutter teeth on the body of the milling cutter provide the minimum dimension between teeth (minimum width of the body between two teeth), important dimension in terms of resistance. The technical literature also shows formulas for calculating static and functional angles. In the following paragraph, there are presented only mathematical modules with nature of originality

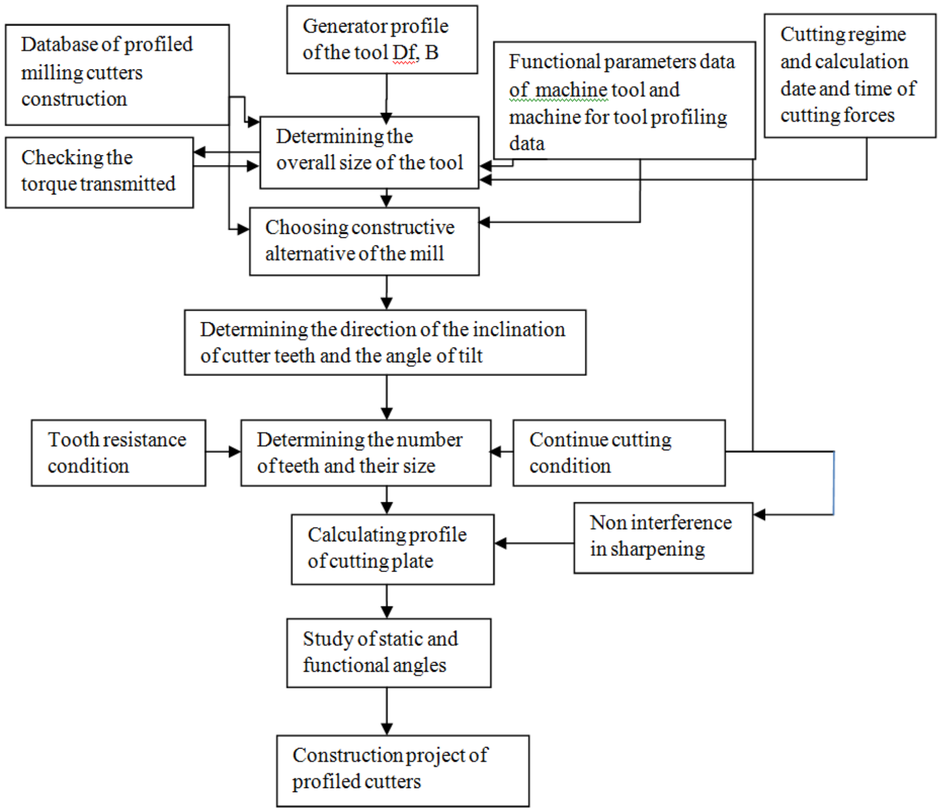


Fig. 3 – Picture of designing.

3. Determining the Angle of the Cutting Blade of Staggered-Tooth Milling Cutter

To ensure the making of positive cutting angle at any point of the blade, it is necessary to establish the position of tooth in the body of the milling cutter according to the general profile of the tool. Tooth position to the body is given by the following geometrical parameters:

-angle ω_0 between the axial plane and blade plane;

-distance from the origin of the tool reference system to the point to which it is being made the rotation of the blade $z\omega_0$.

The profile of the tool is given by the parameters R_s, z_s and σ_s. To achieve suitable cutting angle of the cutting process at any point of the blade it is necessary that the point K, around which is made tool's tooth rotation, to be located after the last point of intersection between the normal at profile generator and rotation axis of the tool. According to Fig.5 it is necessary to respect the following condition:

$$L_i/tg\omega_0 \geq R_{si}/tg\varphi_i, \tag{1}$$

where: R_{si} the radius of general profile of the tool in any point; L_i distance from the point considered on the edge of blade to the axis of rotation of the tool projected in $O_sy_sz_s$ plane; φ_i the angle between the tangent to the profile generator of the tool and axis of its rotation, L_i the distance from the axial plane to the current point of the blade; ω0 angle of rotation of the blade to the point K. Because at this stage of the milling cutter's design there is only known its general profile, the whole new parameters involved will be expressed on its coordinates. So, φ_i angle and can be expressed in the following form:

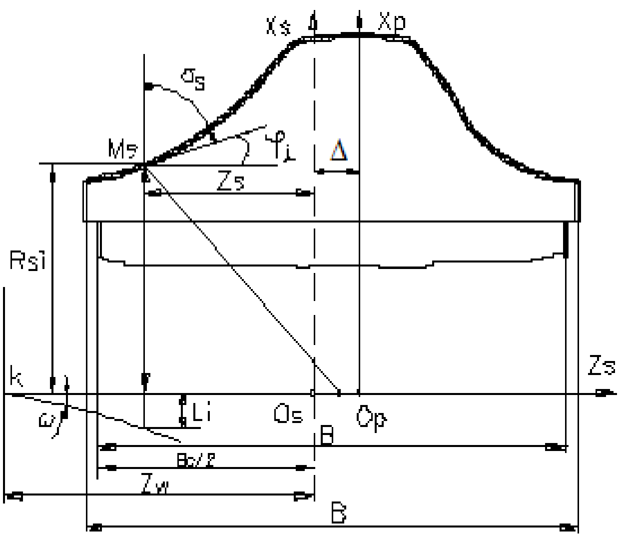


Fig 4 − Mathematical model.

$$\varphi_i = \left|\frac{\pi}{2} - \sigma_{si}\right| \tag{2}$$

Notation: zωi – the distance from the point of turning to current point on the profile generator.

From Figure 4 the following equation results:

$$tg\omega_0 = L_i/z_{\omega i} \tag{3}$$

Expressing zωi – depending on other parameters as:

$$z_{\omega i}=z_{\omega 0}+z_{si} \tag{4}$$

Using equation (1) where replacements are made from eqs. (2), (3) and (4) may determine the relation of choosing the value of zω0:

$$z_{\omega 0} > \max\left(z_{si} \pm \frac{R_{si}}{\mathrm{ctg}\,|\sigma_{si}|}\right). \tag{5}$$

Eq. (5) determines the point of rotation for two successive teeth of the milling cutter disk according to the profile generator of the tool's parameters. For each tooth will be chosen the points on the profile for ensuring an overlap of at least a few millimeters in the central area of the teeth and edge lengths as close in value.

The analysis of the eq. (5) revealed the possibility of choosing points at different distances from the reference system for the two blades. However, the same angle is taken in most cases for the two blades. Based on the considerations presented above, a program has developed so as to allow automatic determination of their parameters for complying the condition of obtaining favorable cutting angle for the whole profile of blades.

4. Contribution Concerning the Calculation of Tool's Profile in the Plane of Cutting Edge

So as to achieve the milling cutter is necessary to know the profile of the blade in its plane. Problem to be solved is the profile generator input coordinates for each point of calculation, geometrical parameters describing the position of milling cutter blade against the tool body and the coordinate's output data of the plane profile for each point.

Solving the problem should be made using a mathematical model that describes the transition from general profile of the tool, considered in its axial section which describes a Fig. 5 rotating surface rotation, in the plane in which there is placed the tooth and also where the tool rotation describes the same surface rotation

Considering Fig. 6 there are set generalized displacements connecting coordinate system attached to general profile of the tool $O_sx_sy_sz_s$ to the coordinate systems attaches to the blade $O_pX_pY_pZ_p$.

Additional systems kxyz, kx'y 'z ' are introduced (k being the point to which the rotating blade are made), $O_px_py_pz_p$. Following plans were noted: T axial plane; T_p the plane of the blade. Switching $O_sx_sy_sz_s$ system with Kxyz system is by translation along the O_sz_s axis.

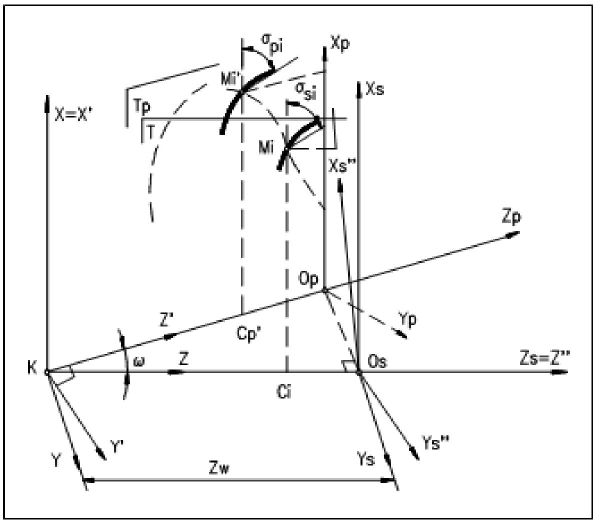


Fig.5 − The profile’s axial section.

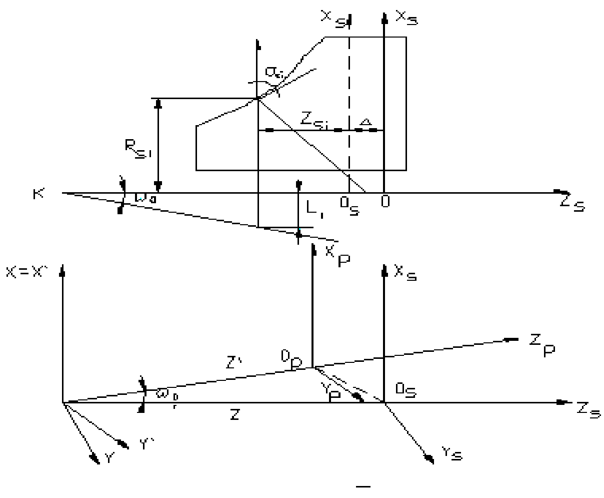


Fig. 6 − Displacements between the coordinates systems.

$$\begin{pmatrix} x_p \\ y_p \\ z_p \\ 1 \end{pmatrix} = A^3(z_{\omega 0})\,A^4(-\omega_0)\,A^3\left(-\frac{z_{\omega 0}}{\cos\omega_0}\right)\begin{pmatrix} x_s \\ y_s \\ z_s \\ 1 \end{pmatrix} \tag{6}$$

After the calculations are obtained the following relations:

$$\begin{cases} x_p = x_s \\ y_p = y_s \cos \omega_0 + (z_s + z_{\omega 0}) \sin \omega_0 \\ z_p = (z_s + z_{\omega 0}) \cos \omega_0 - y_s \sin \omega_0 - \dfrac{z_{\omega 0}}{\cos \omega_0} \end{cases} \tag{7}$$

Tooth plane equation in system $O_p x_p y_p z_p$ is $y_p=0$. Considering the circle related to the point Ci, in system $O_s x_s y_s z_s$, its equation is:

$$\begin{cases} x_s = R_{si} \sin t \\ y_s = R_{si} \cos t \\ z_s = z_{si} \end{cases} \tag{8}$$

and in the system $O_p x_p y_p z_p$, taking into account the relation (7):

$$\begin{cases} x_p = R_{si} \sin t \\ y_p = (z_{si} + z_{\omega 0}) \sin \omega_0 + R_{si} \cos t \cos \omega_0 \\ z_p = (z_{si} + z_{\omega 0}) \cos \omega_0 - R_{si} \cos t \sin \omega_0 - \dfrac{z_{\omega 0}}{\cos \omega_0} \end{cases} \tag{9}$$

With the intersection between tooth plane and the circle which corresponds to profile generator of the tool there are obtained point coordinates in the plane of the tooth:

$$y_p = 0 \Rightarrow (z_{si}+z_{\omega i}) \sin\omega_0 + R_{si} \cos t \cos \omega_0 = 0 \tag{10}$$

The angle *t* that determines the position of point on the circle is given by:

$$t = \arccos \left[- \frac{(z_{si} + z_{\omega 0}) \operatorname{tg} \omega_0}{R_{si} \cos \omega_0}\right] \tag{11}$$

Replaced in the formulas in equation (9) there are obtaining coordinates:

$$\begin{cases} x_{pi} = \pm \sqrt{R_{si}^2 - (z_{si} + z_{\omega 0})^2 \operatorname{tg}^2 \omega_0} \\ z_{pi} = \dfrac{z_{si}}{\cos \omega_0} \end{cases} \tag{12}$$

Using these equations the shape of the blade of milling cutter results, for a male rotor of SRM screw compressors with D≈120mm, $\omega_0=10°$.

Table 2a
Characteristic points of the two blades

	R_{si}	Z_{si}	Z_{pi}
1	104.119	4.909	0
2	115.500	0	-4.909
3	115.500	0	-4.909
4	120.032	-4.493	-9.502
5	120.242	-12.664	-17.573
6	120.649	-20.731	-25.640
7	116.589	-25.646	-30.555
8	103.867	-29.487	-34.396
9	75.645	-46.371	-51.280

Table 2b
Characteristic points of the two blades

	R_{si}	R_{si}	Z_{pi}
10	120.038	-5.018	0
11	120.032	-4.593	0.425
12	115.500	0	-5.018
13	115.500	0	5.018
14	84.063	18.514	23.632
15	73.051	44.081	49.099

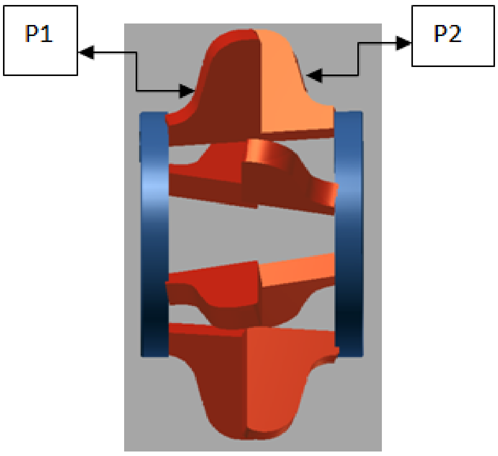


Fig. 7 – The graphical method.

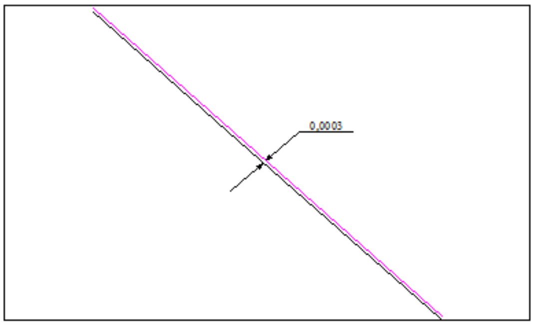


Fig. 8 − Maximum deviation between the profiles.

In Table 2 are presented the characteristic points of the two blades, and in Fig.7 are presented provided blades using the method graphic using the program Autodesk Inventor. In Fig. 8 is represented maximum deviation between the profiles obtained by the two methods and analytical graphics.

REFERENCES

Plesu Gh., *Contribuții teoretice și experimentale privind optimizarea utilajului tehnologic pentru prelucrarea suprafețelor elicoidale complexe.* Teză de doctorat, Universitatea Tehnică, Iaşi, 1999.

Csibi V.I., *Contribuţii la calculul numeric al angrenării, cu aplicaţii la generarea şi angrenarea suprafeţelor elicoidale cu profil special.* Teză de doctorat,- Universitatea Tehnică, Cluj-Napoca, 1990.

Kudeviţkii Ia. V., *Fasonnîe frezî*. Maşinostroenie, Leningrad, 1978.

STUDIUL FREZELOR CU DINŢI IN ZIG-ZAG ŞI PROIECTAREA ACESTORA PENTRU PRELUCRAREA COMPRESOARELOR ELICOIDALE

(Rezumat)

Proiectarea frezelor cu dinți în zig-zag este un element important pentru generarea suprafețelor elicoidale. Aceste suprafețe sunt produse în mare parte prin frezare. Metodologia propusă în lucrare abordează problema de proiectare a frezei cu dinți in zig-zag pentru prelucrarea suprafețelor elicoidale. La primul punct al acestei probleme se prezintă metoda analitică de calcul a profilului plăcuțelor așchietoare. Al doilea punct prezintă metoda grafică de obținere a profilului plăcuțelor așchietoare. Obiectivul principal al acestei lucrãri este de a compara rezultatele obținute prin cele douã metode.