

The tool profile and the localization of the revolution axis for irregular outline milling

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Abstract. For the most cases of manufacturing cutting processes in today's flexible manufacturing systems, the cutting tools which are needed are almost standard. The problem of choosing the appropriate tool shape and dimension is often made by the tool management system according with the shape of mechanical part which must be manufactured. But, the accuracy of profiled surfaces, such as the helical channel of tools depends essentially on three aspects. The first one is the correct determination of geometric profile. The second is the correct execution of that profile. Finally, the third issue is related the positioning of the tool relative to the axis of the blank. The accurate determination of the active profile of the profiled disk milling is an essential constraint, but not the only one to obtain the irregular outline shapes by milling. The settings up parameters are those which supply the closeness of the part spiral shape. The paper presents an iterative analytical calculation procedure for the points from the profiled shape of the disk type of milling cutter. Also, the paper shows a set of analytical expressions for the calculus of the disk type of milling cutter localization parameters, under the condition of rigidity and strength requirement insurance.

1 Introduction

For the most cases of manufacturing cutting processes in today's flexible manufacturing systems, the cutting tools which are needed are almost standard.

The problem of choosing the appropriate tool shape and dimension is often made by the tool management system according with the shape of mechanical part which must be made out the type of workmaterial.

Much more, the tool management system, which is an intermediate link between manufacturing process, manufacturing programme planning, tools and tools storage, can graphically describe through its data base the type, dimensions, shape of tools to be used in NC production, and also can help the tool adjuster and ensures a very fast and simple design of tool and pre-setting sheets [1].

The tool components (cutting tool inserts, shafts, drifts, supporting shims, tool holders and clamping hooks etc) are defined and kept in the tool base by means of the graphic software. By the other modules the shapes of the individual tool components are designed

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and drawn, their dimensions are defined and the tool components are assembled into a necessary tool for particular machining operation. The prepared drawing is attached to the tool and pre-setting sheet are automatically completed with the other technologically data.

Not so simple is the problem of designing the milling tools for the mechanical parts with complex special shapes, when the determination of the tool's profile is a matter of great importance. In Romanian and foreign literature lists numerous ways of solving this problem, especially for specific cases of tools and usually with reference to the facilities offered by various software systems for programming CNC machine tools [2-4].

How the profiled shape of the disk type of milling cutter can be find in an analytically way is shown in the following.

2 Calculation methodologies

In the conceiving process of the mechanical part, different kinematical laws and rules must be taken into considerations. As a result of the analytically calculation, the characteristic shape points obtained are usually situated on different analytical unknown curves [5, 6].

Much more, even the analytic equation of the profile line can be established, in the practical achievement of the tool, it is necessary for the execution workshop to approximate the point by point profile by other easy to manufacture curve like areas of circles and straight line segments. Using these approximations a reduced number of profile points are taken into account with high accuracy if the errors of approximation are minimized by mathematical methods carried out using the computer power calculation.

2.1 The equation of helicoidally shape of the part

That is why, most of complex profiles can be considered that are generated by the movements of a curved line (C_M) (see figure 1) along a curve (C_S) with a known mathematical equation [7].

For example, to simplify the calculus method described, if it consider (C_M) a segment of circle (in cross section of the cylindrical part) and (C_S) a helicoidally curve, the parameter equations of the part cross profile, in the mobile reference system $OM_xM_yM_z$ are the following (r_{wp} – the radius of workpiece; r_{cM} – the radius of circle (C_M)):

$$\begin{aligned} M_x &= r_{cM} \cdot \sin \theta \\ M_y &= r_{wp} - r_{cM} \cdot \cos \theta \\ M_z &= 0, \end{aligned} \quad (1)$$

where t take values between $-\pi/2$ and $\pi/2$ along OM_z or OS_x axis.

The part helicoidally shape will be obtained by an axial movement of the curve (C_M), at the same time and in correlation with a rotation by φ degree around OM_z or OS_x axis.

To transfer the equations (1) from the mobile system to the stationary system $OS_1S_2S_3$ pendent of part, the following matrix are used (a rotation with the angle φ around OS_z and a translation with $P_H/2$ along OS_z axis in negative sense):

$$\begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix} = \begin{pmatrix} \cos \varphi & \sin \varphi & 0 & 0 \\ -\sin \varphi & \cos \varphi & 0 & 0 \\ 0 & 0 & 1 & -\frac{P_H}{2\pi} \end{pmatrix} \cdot \begin{pmatrix} M_x \\ M_y \\ M_z \end{pmatrix} \quad (2)$$

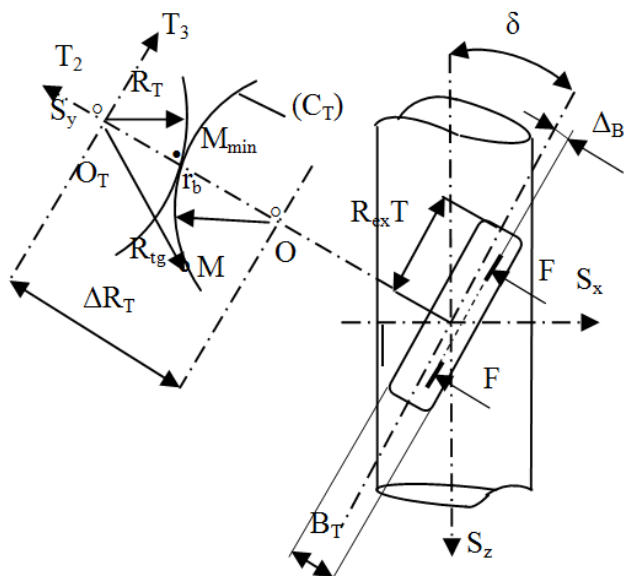


Fig. 2. The position of tool's coordinate system according with part stationary system

The origin O_T of tool's coordinate system is translated along OS_y with ΔR_T value (equation (4), where r_b is the minimum radius of profile on workpiece):

$$\Delta R_T = r_b + R_{exT} \quad (4)$$

To transfer the coordinates of point M from stationary system OS_xSySz in the tool's system of coordinates $OT_1T_2T_3$ will use the following matrix:

$$\begin{pmatrix} T_1 \\ T_2 \\ T_3 \end{pmatrix} = \begin{pmatrix} \cos \delta & 0 & -\sin \delta & 0 \\ 0 & 1 & 0 & -\Delta R_T \\ -\sin \delta & 0 & \cos \delta & 0 \end{pmatrix} \cdot \begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix} \quad (5)$$

The results of the counting matrix (5) are:

$$\begin{aligned} T_1 &= r_{wp} \cdot \sin \varphi \cdot \cos \delta + r_{cM} \cdot \sin(\theta - \varphi) \cdot \cos \delta + p_H \cdot \varphi \cdot \sin \delta / 2\pi, \\ T_2 &= r_{wp} \cdot \cos \varphi - r_{cM} \cdot \cos(\theta - \varphi) - \Delta_B, \\ T_3 &= r_{wp} \cdot \sin \varphi \cdot \sin \delta - r_{cM} \cdot \sin(\theta - \varphi) \cdot \sin \delta - p_H \cdot \varphi \cdot \cos \delta / 2\pi, \end{aligned} \quad (6)$$

To determine the profile curve (C_T) of the tool we must know the value of angle θ . In this case the curve must be sectioned perpendicular on tool axis $O_T T_1$. The equation of sectional plane is $T_1 = \Delta_B$, where Δ_B range between $-B_T/2$ and $+B_T/2$, and its expression is the following:

$$\Delta_B = r_{wp} \cdot \sin \varphi \cdot \cos \delta + r_{cM} \cdot \sin(\theta - \varphi) \cdot \cos \delta + p_H \cdot \varphi \cdot \sin \delta / 2\pi \quad (7)$$

In this manner, the values of angle θ can be established for a desired number of profile points:

$$\theta = \varphi + \arcsin \frac{k - r_{wp} \cdot \sin \varphi \cdot \cos \delta - p_H \cdot \varphi \cdot \sin \delta / 2\pi}{r_{cM} \cdot \cos \delta}, \quad (8)$$

and then all the coordinates of M point of the tool can be determinate.

The radius of tool for different values of angle φ (not only positives but also negatives) is given by the following equation:

$$R_T = \left(\sqrt{T_2^2 + T_3^2} \right)_{\min}, \quad (9)$$

In line with the manner fully described already, knowing the axial value ΔR_T and the tool radius R_T , the profile of disk-milling tool is established to the full.

In order to carry into effect the foresaid methodology of establishing the disk-tool profile it must consider step by step the following stages:

- Determining the part profile curve and approximate it by arc segments and straight lines segments;
- Defining the curve (C_S);
- Deciding upon the characteristics of disk-milling:
 - the maximum external radius R_{exT} – by constructive and stress considerations,
 - the breadth of disk-tool B_T – at least as the part profile breadth;
- Calculation of angle θ for a few dozen points (for example it can do values from $-BT/2$ to $BT/2$ to with a step by 0,1 mm);
- Calculation of the coordinates of tool profile points T_1, T_2, T_3 ;
- Calculation of tool profile radius R_T giving values for angle φ as was shown before;
- Drafting the tool profile, checking the accuracy and making adjustments;
- Rough modelling of the tool and simultaneous final modelling whose result is a complete solid model of the tool. Both activities can progress simultaneously in on-line exchange of data in case of using CAD/CAM programs. Another result of final modelling of the tool is the engineering drawing and individual details such as rounding, transitions etc.

2.3 Additional results

The calculation equations of the disk-tool profile established above can be used also in other cases of complex surface part processing. Let afford some proofs on this account:

- for a profiled blanket – $r_{wp} = 0$ and the curve (C_S) is a straight line inclined or not ($\varphi = 0$);
- for a cylindrical part with a non-helicoidally profile – (C_S) is a straight line along OS_z axis $\Rightarrow \varphi = 0$;
- for a part which are manufactured with a ball-end milling cutter, only angles φ and θ exists in equations (6), that is why these will change into the following:

$$\begin{aligned} T_1 &= r_{wp} \cdot \sin \varphi + r_{cM} \cdot \sin(\theta - \varphi) \\ T_2 &= r_{wp} \cdot \cos \varphi - r_{cM} \cdot \cos(\theta - \varphi) - r_b \\ T_3 &= -p_H \cdot \varphi / 2\pi, \end{aligned} \quad \dots(10)$$

The other curve (C_T) which must be tangent to the tool is obtained giving values to the angle φ . This fact is happening when R_T become minimum. In this case, the radius R_T is

identically with tool's radius. To minimize the value of radius R_T , an iterative process must be made by the aide of computer. In this manner the tool profile is known throughout through: the values of profile height T_2 and the profile radius R_{Tmin} .

3 The disk type milling-tool's theoretical installation parameters

In the general case, the relative of the tool as against with the formation surface is measured by six parameters, namely the linear travel parameters l_x , l_y , l_z and the angular parameters G , H_z and L which characterize the spatial rotation of the coordinate system $X_f Y_f Z_f$ against with the coordinate system XYZ . In the particular case of the helicoidally surfaces processing with disk-milling tools in case that the formation is made through self generation, the parameters number for the tool installation decrease at three.

As a general rule, the origin of the coordinate system $X_f Y_f Z_f$ of the tool, this being the case in fig. 3, is displaced along the reference system axes of the piece XYZ , with the values l_x , l_y and l_z (the index corresponds to the axis along which the origin is displaced).

The coordinate system rotation XYZ round about the axis Z_f (round about the active surface axis) with angle H_z leads at the motion which realized the surface self generation. Therefore the angle H can have a certain amount.

The rotation H_z together with rotation G , performs round about the axis Y_f , will keep it in mind to ensure for the plan $Y_f O_f Z_f$ a parallel position with the axis Z .

In that case the distance "a" will be finding between the axis Z and Z_f , and the pivoting angle L of the coordinate system $X_f Y_f Z_f$ round about the axis X_f , will be the supplement angle between the crossing axes Z and Z_f (see figure 3).

In this way the angle H_z will be the rotation angle in elevation of the coordinate system $X_f Y_f Z_f$ round about the axis Z .

It admits "a" and " H_z " the installed parameters of the tool, it results the relative displacements l_x and l_y can be calculated with the following relations:

$$\begin{aligned} l_x &= a \cdot \cos H_z, \\ l_y &= a \cdot \sin H_z. \end{aligned} \quad (11)$$

It results that the axis position of the disk tools as against the piece will be determined with the helping of four parameters: A , ε ($\varepsilon = \pi - L$), H_z and l_z .

If it considers that the axis X_f of the tool is in the piece plane XOY then $l_z = 0$ and so the axis position of the disk type milling tool can be determined by three theoretical parameters a , ε and H'_z

3.1 The determination of the angle H'_z

The value of the angle H'_z differs from the angle H_z through of the origins motion O and O_f of the systems of coordination along the axis Z .

Thus, if the distance between the origins is l_z (see figure 3) the totalized angle H'_z will have the following value:

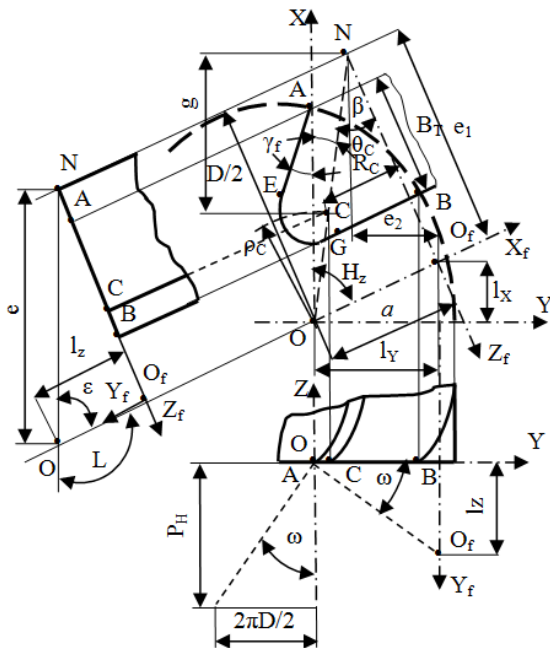


Fig. 3. The calculus scheme for the installation parameters of disk-milling tool

$$H'_z = H_z - \frac{l_z}{p}, \quad (12)$$

If the values of H_z and l_z are they defined from figure 3 as is detailed shows in [8], then H'_z has the following equation:

$$H'_z = \arccos \frac{ctg \varepsilon}{tg \omega} + \theta_c + \frac{a}{p} \sqrt{tg^2 \omega - ctg^2 \varepsilon}, \quad (13)$$

and must ensure the third condition of cutting process:

$$H'_z \geq \frac{\rho_c^2 \cdot \sin 2\gamma_f}{p^2} + \gamma_f; \quad p = \frac{P_H}{2\pi}. \quad (14)$$

3.2 The determination of the angle ε

Linked with the installation parameters of the disk-tool (a , ε and H'_z), often for to facilitate the calculations we can use other two auxiliary parameters of calculation, namely:

- ρ_c – the primitive radius of the piece, respectively
- R_c – the primitive radius of the tool, dependent on a , ε and H'_z .

In the figure 3 it represents a helicoidally surface characterized by the amounts ρ_c and R_c . The primitive radius ρ_c it is obtained from the condition that the angle of the helix line, which passes through the cylinder of radius ρ_c , it be equal with the angle ε .

From figure 3 it can see the following:

$$ctg \varepsilon = \frac{2\pi \cdot \rho_c}{P_H}, \quad \rho_c = \frac{P_H}{2\pi} ctg \varepsilon = p \cdot ctg \varepsilon, \quad p \cdot ctg \varepsilon > \rho_c \cdot \cos \gamma_f. \quad (15)$$

in accordance with the first processing condition [9].

Also, from figure 3 it deduces that:

$$R_c = a - \rho_c \cdot \cos(H_z - \theta_c), \quad (16)$$

$$a = (g + \rho_c) \cdot \cos(H_z - \theta_c). \quad (17)$$

Accordingly with these forenamed, it result the following:

- the parameter “a” is entirely determinate through equation (17);
- the parameter ε is given by the condition (15);
- the parameter H'_z must simultaneous satisfy the condition (14) and the equation (17).

If the inequality 4 isn't coming true, then the profile of the helicoidally flute which is manufactured will be under cutting on the point A zone;

If the equation (17) isn't carrying out, then the profile of the disk type milling tool will has the top radius R_c smaller than that maximum possible. Because, isn't permitted that the flute profile to be rounded around point A zone, the inequality (14) must be compulsory carrying out. The unfulfilled of equation (17) is admissible. Naming with H'_{zAG} the value of H'_z given by the inequality 4(1) and with H'_{zAG} the value of H'_z determinate through equation (17), the installation of tool is optimum if:

$$H'_{zGE} \geq H'_{zAG} \cdot \quad (18)$$

To compute the optimum installation and localization parameters for a disk type milling tool, two parameters are necessary to be known: the angle ε and the external diameter of the disk-tool D.

It is well known that for the parameters ε and D, some range of values are admitted, from among only the optimum values will be selected

The angle ε is choosing on a value which carrying out on the limit the inequality (15).

The maximum value of the angle ε after allowing for the inequality 15) is marked with ε_{\max} . In the case $\varepsilon < (\pi/2) - \omega$, the equation (17) has not a real solution, in which case the inequality (18) can't be coming true for such values of angle ε .

Such a situation is meeting when the profile of the flute has a great radius of rounding R_c , and the number of tool's tooth are small.

For a value of ε which is in accordance with the inequality:

$$\text{ctg}\varepsilon > \frac{\rho_c \cdot \cos\gamma_f}{p}, \quad (19)$$

the inequality 4, which limits the minimum value of H'_z , will exceed surely the value H'_{zAG} . As a consequence, the section AG of the tool's profile can be made for any value of the angle H'_z .

Decreasing of the angle ε with a quota, such as the inequality (15) is coming true, also decrease in a large measure the possibility to carrying out the inequality (18), and finally leads to increasing the breadth of disk type milling tool B_T .

4 Conclusions

To solve the problems attached to the part shape formulation by milling is necessary to know the parameters which characterize the calculation points M. These points are emphasizing for the disk or ball-end milling tool. Using the established equations in this article, the tool profile can be entirely defined.

The optimum value of the parameters a , ε and H'_z will be considered those that on the one hand ensures carrying out processing conditions of the nominal surface of the piece, and on the other hand ensures carrying out the constructive and exploitation conditions of the tool, still in the designing phase.

For this reason, often for the realization of a rationale construction tool, it prescribes the analysis of the installation parameters influence of the tool axis over its one or the other constructive parameter.

Using the established equations in this article, the tool profile can be entirely defined. The results can be used in a fully automatic process of tool manufacturing.

Once it was determined by analytical equations, the profile of tool and its installation parameters, should be checked the curve that will get the points, will make approximations with arcs or line segments, where appropriate, depending on the possibilities of programming machine tools and, very important then, it will check for any undercut areas by generating simulation profile processed.

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