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OPTIMIZATION OF THE DESIGN AND SETTING UP OF A DISK TYPE TOOL FOR HELICAL SURFACES

Summary: The universal algorithm and programme for disc cutting tool calculations have been worked out. The tool is designed for any helical surfaces in such a way that undercutting can be minimized.

1. Introduction

There are many publications connected with the algorithm of a disk tool for helical surfaces calculations (profile defining) nevertheless still new papers appear.

The main cause of the fact is that all algorithms received up to now do not take into account the phenomenon of undercutting. The undercutting often can not be eliminated but can be minimized. To eliminate it, the algorithm should consist of two parts: the first leads us to the disk tool profile and is based on the known envelope condition of the tool surface family, the second is the computer simulation of machining for making corrections of the tools setting up. Repeating both parts of programme leads for optimization of the tool design and it's setting up.

Another problem, that has been solved here, was how to build a universal algorithm that could be used for any helical surface.

In the paper the right hand orthogonal reference systems have been used:

x_1,y_1,z_1 - the system connected with the surface profile,

x,y,z - the system connected with the workpiece,

x_o,y_o,z_o - the system connected with the tool.

2. Algorithm for tool profile calculation

The solution is based on two equations:

- external equations determines the relationship between the reference systems shown in the fig. 1

$$\begin{bmatrix} x_o \\ y_o \\ z_o \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\Sigma_o & \sin\Sigma_o \\ 0 & -\sin\Sigma_o & \cos\Sigma_o \end{bmatrix} \times$$
$$\left[\begin{bmatrix} \cos\varphi_1 & \sin\varphi_1 & 0 \\ -\sin\varphi_1 & \cos\varphi_1 & 0 \\ 0 & 0 & 1 \end{bmatrix}^T \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\chi_1 & \sin\chi_1 \\ 0 & -\sin\chi_1 & \cos\chi_1 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ p\varphi_1 \end{bmatrix} \right] + \begin{bmatrix} -a_o \\ 0 \\ 0 \end{bmatrix} \tag{1}$$

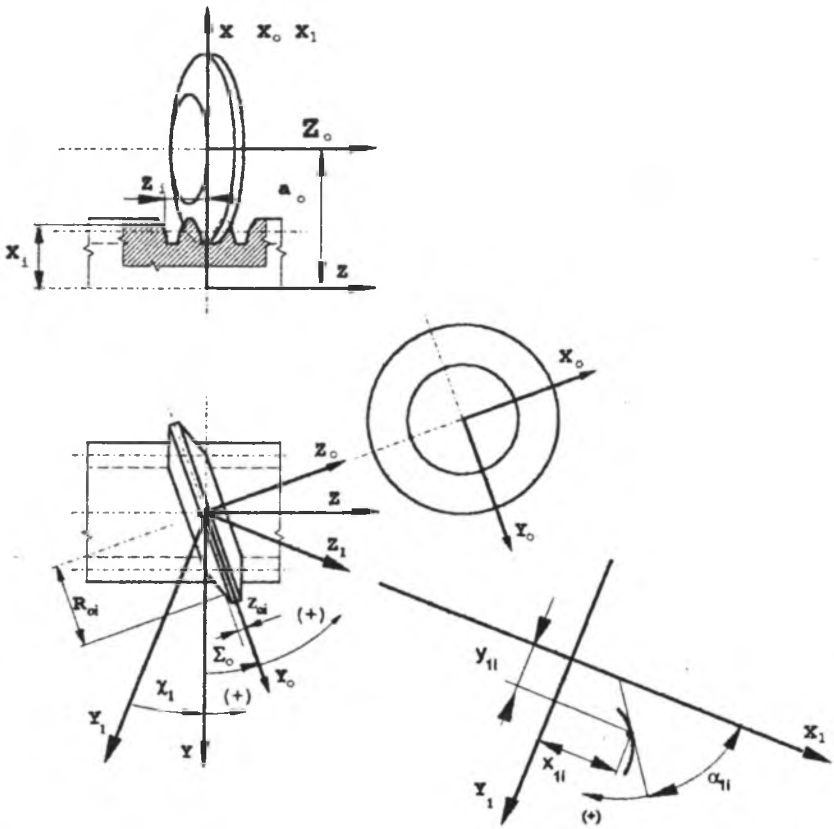

Fig.1. Right-hand orthogonal reference systems used in the paper. Sign plus (+) means the positive direction of the system rotations

where:

$$p = \frac{S}{2\pi} \tag{2}$$

Σ_o - setting up angle of tool,

φ_1 - surface parameter,

χ_1 - angle of input profile

a_o - tool and workpiece axes distance.

- internal equation expresses the condition of tangency of two surfaces: workpiece surface and tool surface

$$\bar{n}_o \bullet \bar{v}_o = 0 \tag{3}$$

where:

$\bar{n}_o$ - normal vector to the workpiece surface,

$\bar{v}_o$ - tangent vector to the tool surface

After finding the above vectors the condition (3) looks as follows:

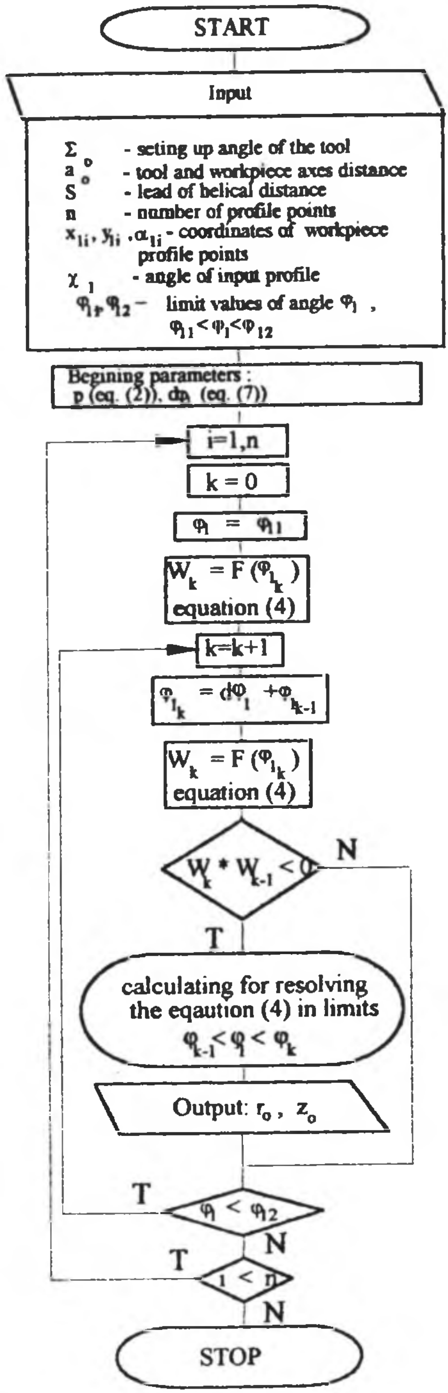

Fig. 2. Flowing chart of the programme of the disk tool calculations

$$F=[n_o]^T[v_o]=\left[\begin{bmatrix}1 & 0 & 0\\ 0 & \cos\Sigma_o & \sin\Sigma_o\\ 0 & -\sin\Sigma_o & \cos\Sigma_o\end{bmatrix}\begin{bmatrix}\cos\varphi_1 & \sin\varphi_1 & 0\\ -\sin\varphi_1 & \cos\varphi_1 & 0\\ 0 & 0 & 1\end{bmatrix}\right]^T$$

$$\left[\begin{bmatrix}(\sin\xi\ \cos\chi_1\ +\ \cos\xi\ \cos\varphi_2\ \sin\chi_1\ )\ \sin\alpha_1\\ \cos\xi\sin\varphi_2\sin\chi_1\sin\alpha_1\ -\ \sin\xi\cos\alpha_1\\ \cos\xi\ \cos\varphi_2\ \cos\alpha_1\ +\ \cos\xi\ \sin\varphi_2\ \cos\chi_1\ \sin\alpha_1\end{bmatrix}\right]^T\begin{bmatrix}-y_o\\ x_o\\ 0\end{bmatrix} \tag{4}$$

where:

$$r=\sqrt{x^2+y^2} \tag{5}$$

$$\xi=\arctan\left(\frac{S}{2\pi r}\right), \tag{6}$$

$$d\varphi_1=\frac{\varphi_{12}-\varphi_{11}}{100} \tag{7}$$

α_1= angle of tangent line to the profile of workpiece

In the fig. 2 the flowing chart of the programme is shown. Calculations are made in two loops:

- internal loop which the variable parameter φ_1 helical surface is changed with the step $d\varphi$ (symbol k),
- external loop in which succeeding points of helical surface profile are taken (symbol i).

3. Computer simulation of helical surface machining

In order to find the best solution (also for non symmetrical profiles) a displacement c_B has been assumed. Tool profile is known in $x_By_Bz_B$ system (fig. 3) and can be displaced (with this system) in relation to the $x_oy_oz_o$ system. For symmetrical profiles the systems $x_oy_oz_o$ and $x_By_Bz_B$ coincide.

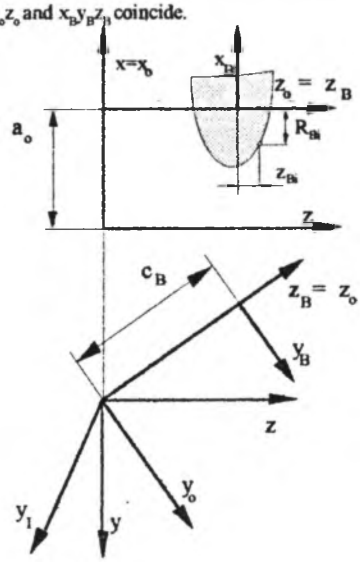

Fig. 3.

Fig. 3. Reference systems for simulation of helical surface machining.

Having tool profile co-ordinates R_{Bi}, z_{Bi} (fig.3), tool surface A_o can be described by rotation the profile about z_o axis

$$\begin{bmatrix} x_B \\ y_B \\ z_B \end{bmatrix} = [\varphi_{ol}]^T \begin{bmatrix} R_{Bi} \\ 0 \\ z_{Bi} \end{bmatrix} \tag{8}$$

where:

$$[\varphi_{ol}] = \begin{bmatrix} \cos\varphi_{ol} & \sin\varphi_{ol} & 0 \\ -\sin\varphi_{ol} & \cos\varphi_{ol} & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{9}$$

Intersecting the family of tool surfaces with the plane z=0 (transverse section) we came to the picture shown in the fig. 4

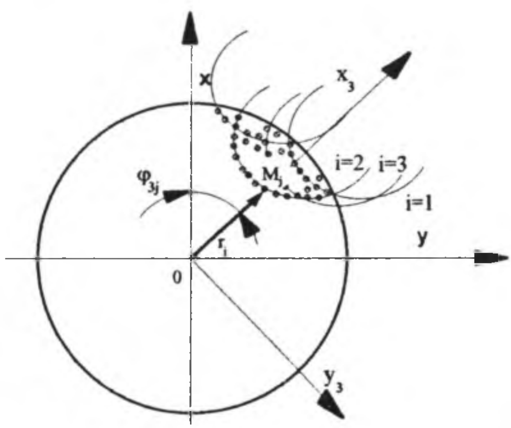

Fig. 4. Solution of equation (10) r_j, φ_{3j} - co-ordinates j - point M_j

$$\begin{cases} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = [\varphi_4]^T [\chi_3 = \Sigma_o]^T \left([\varphi_{ol}]^T \begin{bmatrix} R_{Bi} \\ 0 \\ z_{Bi} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ c_B \end{bmatrix} + \begin{bmatrix} a_o \\ 0 \\ 0 \end{bmatrix} \right) + \begin{bmatrix} 0 \\ 0 \\ p\varphi_4 \end{bmatrix} \\ z = 0 \end{cases} \tag{10}$$

where :

χ_3 - angle between axis z, z_o

$$[\chi_3]^T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\chi_3 & -\sin\chi_3 \\ 0 & \sin\chi_3 & \cos\chi_3 \end{bmatrix} \tag{11}$$

φ_4- variable parameter, angle of rotation around z axis.

$$[\varphi_4]^T = \begin{bmatrix} \cos\varphi_4 & -\sin\varphi_4 & 0 \\ \sin\varphi_4 & \cos\varphi_4 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{12}$$

The last calculation it is selection of that points which are deepest inside material e.g. the point M_j with the co-ordinates φ_{3j}, r_{ij}, (fig.4).

The solution of the equation system (10) that is shown in the fig. 4 is more difficult for so called closed profiles than for opened profiles (fig. 5). The solution for closed profiles is still being worked.

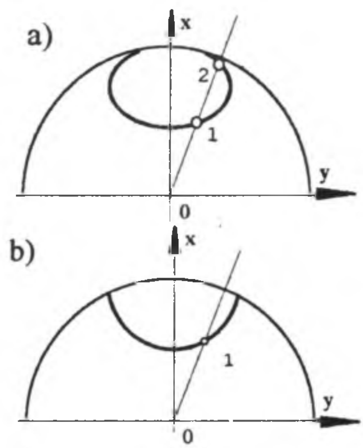

Fig. 5. Two types of profiles: a) closed, b)opened

Flowing chart of the program is shown in the fig.6. There are three loops signified i, j, k for resolving the equation system (10)

- the loop i (external) is used for changing successive points of tool profile R_{Bi}, z_{Bi}.
- the loop j (middle) is used for changing the angle φ_{3j} (fig. 4.). It chooses of successive points of workpiece profile r_j, φ_j.
- the loop k (internal) is used for changing the angle φ_{ol} with the step

$$d\varphi_{ol} = \frac{2\pi}{100} \tag{13}$$

Conclusion:

The universal algorithm for optimization of disk cutting tool and its setting up, while helical surface machining, has been worked up. The work is being continued for combining two independent parts in one program that also would take into account closed profiles (fig. 5).

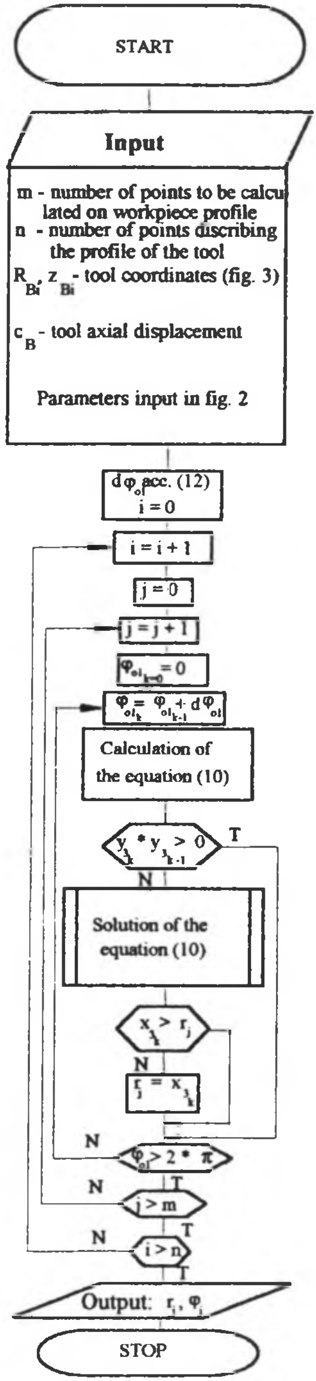

Fig. 6. Flowing chart of the programme. Computer simulation of helical surface machining

Revised by: Jan Darlewski