Roughing helical flanks of the worms with frontal-cylindrical milling tools on NC lathes

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Abstract

At the roughing of the helical flanks of the worms with frontal-cylindrical milling tools positioned perpendicular to the axis of symmetry of the half-product we can use tools of different diameters, with the mill position being different in each case. In this article the milling position is determined on the basis of the contact between the toroid surface of frontal-cylindrical milling tool and a helical surface, so that it remains the desired addition of processing. Determination of contact between the toroid part of frontal-cylindrical milling tool and the helical surface is done using coordinate transformations. The points thus obtained shall be brought in the axial plane, compared with the points belonging to the desired profile to obtain and determine the location of a mill at each crossing. The milling position at each crossing shall be determined by means of a program that compares the curve of contact between the helical surfaces brought into the axial plane of the worm with a straight line inclined with the angle of pressure of the studied worm located in the axial plane. For the cutting depth considered, the difference between coordinated on the OX of the curve and of the line, represents the movement of the tool along the axis of symmetry in the sense indicated by the sign of the difference. The program is designed in AutoLISP and the result of the calculated displacement is returned in AutoCAD.

Keywords: worm; milling; helical surfaces; milling of roughing; NC lathe.

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1. Introduction

This paper presents aspects of roughing worms using frontal-cylindrical milling tools. Regardless of the worm type, the helical flanks of the worm need roughing so as to maintain for finishing the desired addition of processing. To process worms in the new manufacturing technology using the tools that are not profiled by roughing frontal-cylindrical milling tools are used, which can be positioned as follows:

- In the axial plane of the worm perpendicular to the axis of symmetry (Fig.1.a.);
- In the axial plane of the worm inclined towards the axis of symmetry (Fig.1.b.).

If the tool is positioned perpendicular to the axis of symmetry of the half-product, roughing is done in several passes with the tool positioned closer to the axis of symmetry of the half-product. So there is a possibility to remove the desired addition of the processing. We will need to determine the exact position of the tool at each crossing. Also, when the tool is inclined towards the axis of symmetry of the piece, the position of the mill must be accurately known to keep the addition of processing necessary to finishing. In this case the position of the mill is determined by the mill position to finishing, aspects of positioning at finishing being presented in another paper. Determining the position of a mill in case of roughing with mill positioned perpendicular to the axis of symmetry of the half-product is done using a program designed in AutoLISP running in AutoCAD. The working algorithm is as follows:

- Determine the contact between mill and a helical surface using coordinate transformations,
- Indicate the straight line (d) delimiting the area containing the addition of processing,
- For each coordinate y belonging to the contact between tool and helical surface is determined the coordinate x of the straight line (d),
- Calculate the difference between the x coordinates obtained in both cases and the minimum value of this difference is moving the position of the mill on OX axis towards the middle of the goal.

| Nomenclature       | Description                                      |
|--------------------|--------------------------------------------------|
| r                  | the connection radius of the milling tool         |
| γ                  | angle of inclination of milling tool              |
| α, β               | mill surface parameters                           |
| φ                  | the angle of rotation of the half-product         |
| h                  | helical parameter                                |
| r₁                 | radius of the cylinder on which the milling tool rests |
| e                  | eccentricity                                     |
2. Determination of the contact between the toroid part of the mill and the helical surface

For the determination of the contact between the two surfaces we start from the parametric equations of the toroid surface written in the tool system (Fig. 2.a.), then the coordinate transformation is made from tool system in half-product system (Fig. 2.b.), provided that the normal to the both surfaces is the same and we obtain the relationship between the surface toroid parameters.

- Parametric equations of the toroid zone of the mill written in the tool system are in accordance with (Fig. 2.a.):

\[
\begin{align*}
  x & = (b + r \cos \alpha) \cos \beta \\
  y & = -r \sin \alpha \\
  z & = (b + r \cos \alpha) \sin \beta
\end{align*}
\]

(1)

for \( \alpha \in \left[0, \frac{\pi}{2}\right] \) and \( \beta \in [0,2\pi] \). Equations of the normal unit vector are:

\[
\begin{align*}
  n_x & = \cos \alpha \cos \beta \\
  n_y & = -\sin \alpha \\
  n_z & = \cos \alpha \sin \beta
\end{align*}
\]

(2)

- We determine the parametric equations of the wrapped surface and normal surfaces using the transformations of coordinates (Fig. 2.b.) and vectors

\[
\begin{align*}
  r_2 & = M_{2,1} \cdot \eta_1 = M_{2,0}M_{0,1}(2)M_{1,0}(2,1)^{1/3} \eta_1 \\
  n_2 & = R_{2,1} \cdot \eta_1 = R_{2,0}R_{0,1}(2)R_{1,0}(2,1)^{1/3} \eta_1
\end{align*}
\]

(3)
The rotation matrix is shown in (4), and translation matrices in (5):

\[
M_{2,0} = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos \varphi & -\sin \varphi & 0 \\
0 & \sin \varphi & \cos \varphi & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
M_{0,1(2)} = \begin{bmatrix}
\cos \gamma & \sin \gamma & 0 & 0 \\
-\sin \gamma & \cos \gamma & 0 & \sqrt{1 - e^2} \\
0 & 0 & 1 & e \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
M_{1(2),1(3)} = \begin{bmatrix}
1 & 0 & 0 & \phi \cos \gamma \\
0 & 1 & 0 & \phi \sin \gamma \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

(4)

We write transformation matrices, make the calculations and we obtain parametric equations of the wrapped surface:

\[
x_2 = \cos \gamma \cos \beta (b + r \cos \alpha) - r \sin \alpha \sin \gamma + \phi \\
y_2 = \cos \varphi \sqrt{1 - e^2} - \sin \gamma \cos \beta (b + r \cos \alpha) - r \sin \alpha \cos \gamma] - \sin \varphi \sin \beta (b + r \cos \alpha) + e \\
z_2 = \sin \varphi \sqrt{1 - e^2} - \sin \gamma \cos \beta (b + r \cos \alpha) - r \sin \alpha \cos \gamma] + \cos \varphi \sin \beta (b + r \cos \alpha) + e
\]

(6)

and parametric equations of the normal:

\[
n_{x2} = \cos \alpha \cos \beta \cos \gamma - \sin \alpha \sin \gamma \\
n_{y2} = -\cos \varphi (\sin \gamma \cos \alpha \cos \beta + \sin \alpha \cos \gamma) - \sin \varphi \cos \alpha \sin \beta \\
n_{z2} = -\sin \varphi (\sin \gamma \cos \alpha \cos \beta + \sin \alpha \cos \gamma) + \cos \varphi \cos \alpha \sin \beta
\]

(7)

We must impose the condition that the normal in the contact point between frontal-cylindrical milling tool and helical surface be common [10]:

\[-n_{y2} z_2 + n_{z2} y_2 + h n_{x2} = 0
\]

(8)

and we obtain that the normal at the two surfaces are the same:

\[
\cos \beta (e \sin \gamma \cos \alpha + h \cos \alpha \cos \gamma) + \sin \beta (e \sin \alpha \cos \gamma + \sqrt{1 - e^2 \cos \alpha}) = h \sin \alpha \sin \gamma
\]

(9)

We note with:

\[
A = e \sin \gamma \cos \alpha + h \cos \alpha \cos \gamma \\
B = e \sin \alpha \cos \gamma + \sqrt{1 - e^2 \cos \alpha} \\
C = h \sin \alpha \sin \gamma
\]

(10)

Solving the equation we obtain:
\[ \beta = \arctg \frac{B}{A} + \arccos \frac{C}{\sqrt{A^2 + B^2}} \]  \hspace{1cm} (11)

The points of contact between the milling surface and the helical surface are brought in axial plane with the help of the equations [11]:

\[ \begin{align*}
  x_a &= x_1 - h \delta \\
  y_a &= \sqrt{\frac{y_1^2 + z_1^2}{2}} \\
  z_a &= 0
\end{align*} \]

where:

\[ \delta = \arctg \frac{z}{y} \]  \hspace{1cm} (12)

3. Determination of the position of the mill

In the case of processing of roughing with the milling positioned perpendicular to the axis of the half product (Fig.3.), the data required by the user are: cutting depth (y-coordinate), milling tool diameter used and its connection.

To understand the workings of the program we note, as shown in (Fig.3.b.) with:

- (C) the curve in axial plane representing the contact of the mill with the helical surface,
- (xc, yc) coordinates of a point on the curve (C),
- (d) the straight line which is the right flank after roughing,
- (xd, yd) coordinates of a point on the straight line (d).

The working mode of the program is as follows: we calculate the coordinates of the curve of contact \((x_{cn}, y_{cn}) \in (C)\) and for each \(y_{cn}\) having the equations of the straight line (d) we calculate the

![Fig.3. The position of the point V](image)

![Fig.4. Viewing contact position cutter-helical surface to correct the position with the value calculated using the program](image)
corresponding point on the straight line and get a value \( \Delta x = x_{\text{c1}} - x_{\text{c2}} \).

The minimum value of \( \Delta x \) is the value by which should move the V point on the OX axis to get the addition of processing you want to obtain for the left flank of the worm and the maximum value \( \Delta x \) for the right flank of the worm.

In case the point V must move in the negative sense of the OX axis at the processing the left flank of the worm, or in the positive side in the processing right flank should be studied and the resulting graphics by running the program (Fig.4.) (with the same time and move the axis OX) because there is the danger of interference of the mill with the opposite flank, in this case the solution being the choice of tools with smaller diameter or the same size of the mill but with a higher connection.

In the detail shown in (Fig.4.) you can see the contact between tool and the surface flank in axial plane with the addition of the desired processing.

For the roughing of the helical flanks of a worm with module 10, diametrical coefficient 7.6, with a mill with a diameter of 12 mm and a connection radius of 0.8 mm to a depth of 5 mm, input data can be seen in (Fig.5.).

The program returns the value with that the tool should be moved along the axis OX.

| Enter the worm diametrically coefficient (7,6): 7.6 |
| Enter the worm module(10): 10 |
| Enter the number of beginning (2): 2 |
| Enter the connection radius of the mill (0.8): 0.8 |
| Enter the diameter of the mill (12): 12 |
| Enter the system’s origin (the intersection of the axis of symmetry gap Tooth -worm): 0,0 |

Select a point on the straight line who represent the finished flank: 

| Enter the depth of milling (5,10,15): 5 |
| Enter the flank to process it (s-left/d-right): s |
| Enter the pressure angle of the left archimedian flank: 20 |
| Enter the pressure angle of the right archimedian flank: 20 |
| Enter the angle of inclination of the cutter to OY (0): 0 |
| Enter the correction on the axis OZ (0): 0 |
| Enter the correction on the axis OX (0): 0 |

The tool must be displaced on the axis OX with the value: 3.66069 mm.

Fig.5. Input data

4. Conclusions

In the case of roughing cylindrical worms using frontal-cylindrical milling tools it can be concluded that:

- the processing can be done with mono-block mills or with milling tools with removable plates,
- by positioning the tool according to the calculations made using the program by viewing the tool position, there is no risk to be left without the addition of the desired processing on each flank,
- processing and finishing are preformed on the same NC machine.

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