Determining the optimal position of the frontal-cylindrical milling tool in finishing in the new technology for processing worms

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Abstract

Helical surfaces of the worms flanks can be of two types: ruled and non-ruled. Using a new technology for processing on NC machines, cylindrical worms type ZA of various modules can be processed, using the frontal-cylindrical milling tools of different diameters, the optimal position of the mill being different in each individual case. In this article, on the basis of contact between the surface of frontal-cylindrical milling tools used in processing and a helical surface, is determined the optimal position of the mill so that deviations from the nominal profile of the worm type ZA are minimal. Determination of contact between the frontal-cylindrical milling tool and helical surface is done using coordinate transformations. The points thus obtained shall be brought in the axial plane which is compared with the points belonging to the nominal profile of the Archimedian worm. The method used is a numerical one. To get the optimal value of the angle of inclination of the cutter and eccentricity was conceived a program that verifies the smallest deviation for eccentricity variation within the range [3, 3] mm and for variation of the angle of tilt of the tool towards the perpendicular to the axis of symmetry of the worm in the interval [-1.5 °, 1.5 °] angle value of pressure of the flank. The program is designed in AutoLISP, the resulting calculated deviations are returned in a TXT file of type where the optimal adjustment of the frontal-cylindrical milling tools is specified.

Keywords: worm; frontal-cylindrical milling tools; coordinate transformations; optimal position; deviations

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1. Introduction

It is known that helical surfaces of the worm flanks can be of two types: ruled and non-ruled. In the case of worms with ruled surfaces the generator of the helical curve is a straight line, the resulting surface is a ruled helical surface, and the curve generator of surfaces non-ruled is a well defined curve. According to STAS 6845-82 worms with ruled helical surface is type ZA, ZE and ZN, and with non-ruled surface is type ZK.

In the new technology of machining cylindrical Archimedean worm it processed on NC lathe cylindrical worms using frontal-cylindrical milling tools positioned as follows:

- in the axial plane of the worm and inclined with an angle approx equal to pressure angle of the flank of the worm,
- in a plane positioned to a distance to the symmetry axis of the worm named eccentricity and inclined with an angle approx equal to the pressure angle of the flank of the worm (Fig.1.).

Using the new technology of machining it can be processed cylindrical worms type ZA with different module, using frontal-cylindrical milling tools with different diameters, so that the optimum position of the tool is different in each case in part. In this article on the base of contact between the surface of frontal-cylindrical milling tool use in processing of the flank of worm and a helical surface the optimum position of the milling tool is determined, so that deviations for the nominal profile of the worm type ZA are minimal.

The determination of contact between frontal-cylindrical milling tool and the helical surface is done using coordinate transformations. The points thus obtained shall be brought in the axial plane which is compared with the points belonging to the nominal profile of the Archimedian worm. The method used is a numerical one. To get the optimal value of the angle of inclination of cutter and eccentricity was conceived a program that verifies the smallest deviation for eccentricity variation within the range [3, 3] mm and for variation of the angle of tilt of the tool towards the perpendicular to the axis of symmetry of the worm in the interval [-1.5 °, 1.5 °] angle value of pressure of the flank. The program is designed in AutoLISP, the result calculated deviations are returned in a TXT file of type where the optimal adjustment of the frontal-cylindrical milling tools is specified.

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rs</td>
<td>radius of frontal-cylindrical milling tool</td>
</tr>
<tr>
<td>γ</td>
<td>angle of inclination of milling tool</td>
</tr>
<tr>
<td>β,μ</td>
<td>mill surface parameters</td>
</tr>
<tr>
<td>φ</td>
<td>the angle of rotation of half product</td>
</tr>
<tr>
<td>h</td>
<td>helical parameter</td>
</tr>
<tr>
<td>ri</td>
<td>radius of the cylinder on which sit the milling tool</td>
</tr>
<tr>
<td>e</td>
<td>eccentricity</td>
</tr>
</tbody>
</table>
2. Determination of contact between frontal-cylindrical milling tool and the helical surface

Determination of contact between the surface of mill and helical surfaces is done in the following way:

- We determine the parametric equations of the cylindrical surface of the frontal-cylindrical milling tool in the coordinate system of the mill cutter (Fig. 2.a.) and of normal unit vector;

\[
\begin{align*}
\begin{cases}
x_1 &= r_s \cdot \cos \beta \\
y_1 &= u \\
z_1 &= r_s \cdot \sin \beta 
\end{cases}
\end{align*}
\]

The Equations of the normal unit vector are:

\[
\begin{align*}
n_x &= \cos \beta \\
n_y &= 0 \\
n_z &= \sin \beta
\end{align*}
\]

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

\[
\begin{align*}
r_2 &= M_{2,1} \cdot \eta_1 = M_{2,0} M_{0,1(2)} M_{1(2),1(3)} \cdot \eta_1 \\
n_2 &= R_{2,1} \cdot n_1 = R_{2,0} R_{0,1(2)} R_{1(2),1(3)} \cdot n_1
\end{align*}
\]

We write the transformation matrices, make the calculations and we obtain parametric equations of the wrapped surface:
\[
\begin{align*}
\begin{cases}
x_2 = r \cos \gamma \cos \beta + u \sin \gamma + \varphi h \\
y_2 = \cos \varphi \sqrt{\eta^2 - e^2} + u \cos \gamma - r_1 \cos \beta \sin \gamma - \sin \varphi (r_1 \sin \beta + e) \\
z_2 = \sin \varphi \sqrt{\eta^2 - e^2} + u \cos \gamma - r_1 \cos \beta \sin \gamma + \cos \varphi (r_1 \sin \beta + e)
\end{cases}
\end{align*}
\] (4)

and the parametric equations of the normal:

\[
\begin{align*}
n_x &= \cos \gamma \cos \beta \\
n_y &= -\cos \varphi \cos \beta \sin \gamma - \sin \varphi \sin \beta \\
n_z &= -\sin \varphi \cos \beta \sin \gamma + \cos \varphi \sin \beta
\end{align*}
\] (5)

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

\[-n_2 y_2 + n_2 z_2 y_n + h n \times x_2 = 0\] (6)

and we obtain the condition that the normal at the two surfaces is the same:

\[
\beta = \arctg \frac{e \sin \gamma + h \cos \gamma}{\sqrt{\eta^2 - e^2 + u \cos \gamma}}
\] (7)

- The points of contact between milling surface and helical surface are brought in axial plane with the help of equations [9]:

\[
\begin{align*}
x_a = x_1 - h \delta \\
y_a = \sqrt{y_1^2 + z_1^2} \quad \text{where} \quad \delta = \arctg \frac{z}{y}
\end{align*}
\] (8)

3. The optimal position of the frontal-cylindrical milling tool

3.1. Theoretical determination of the optimal position

Determination of the optimal value of the eccentricity \(e\) and angle of inclination of milling cutter \(\gamma\) (Fig.1.) for a given diameter of the tool so that the deviation from the nominal archimedian flank profile to be minimum is done in the following manner:

- for each value of the angle \(\gamma\) in the range \([-1.5+\alpha, 1.5+\alpha]\) we determine the deviation from the nominal profile for eccentricity \(e\) variation within \([-3, +3]\) mm. The smallest value of deviation will be obtained with \(\gamma\) and \(e\), which we consider optimal.

- For a value of the angle \(\gamma\) and an actual value the eccentricity \(e\) we proceed as follows (Fig.3.):

a. We calculate the coordinates of the curve of contact between the two surfaces in axial plane, then for each \(y_{cn}\) belonging to the curve, having straight-line equation representing the axial profile of worm to be obtained we calculate the value \(x_{dn}\) belonging to straight line (d).

b. The value shall be calculated for each point obtained
\[ \Delta x_n = x_{dn} - x_{cn} \]  

(9)

and the smallest value obtained represents the distance to be moved from the tip of the tool V along the axis OX for obtain the deviation from the nominal profile.

c. We resume the steps a and b but with tool offset with the value calculated in step b \( \Delta x_{\gamma} \) minimum, and value \( \Delta x_{\gamma} \) maximum obtain now is the value of deviation from nominal profile for \( \gamma_F \) and e considered.

![Fig.3. The calculus of deviation from the nominal profile](image)

The values calculated for each \( \gamma \) and e included in mentioned ranges are written in a TXT file.

3.2. Practical determination of the optimal position

```
Command: optim
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
Enter the diameter of the mill (12): 10
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 (17): 17
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 (pressure angle): 20
Enter the correction on the axis OZ (0): 0
Enter the correction on the axis OX (0): 0
Optimal calculated is: (gama e1 e2 delta) \( \rightarrow \) (19.8 1.8 0.453046 0.00261246)
```

![Fig.4. Determination of the optimum adjustment of the finishing mill; a) Axial section of the worm; b) Input data need for the program.](image)

To run the program designed for determination optimal value of mill adjustment, in the first phase we must represent two spire of the worm in the axial section (Fig.4.a.) specifying clearly the right
representing profile of the worm type ZA and then enter the values shown in (Fig.4.b.). With arrow is indicated the straight line (d) with indication of any point, representing the worm flank profile in axial plane.

The text file is of the form:

```
<:18.5 e:-3 x>:-1.0045 ab:1.0122
<:18.5 e:-2.95 x>:-0.9925 ab:1.0073
<:18.5 e:-2.9 x>:-0.9804 ab:1.0024
<:18.5 e:-2.85 x>:-0.9682 ab:0.9975
<:18.5 e:-2.8 x>:-0.956 ab:0.9925
```

……………… ..

indicating the angle of inclination of milling cutter, the eccentricity, displacement on the axis OX and the calculated deviation. A graphical representation of the contents of the file can be seen in (Fig.5).

![Deviation from the nominal profile](image)

**Fig.5. Obtained deviations**

### 4. Conclusions

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

- Helical Surfaces of ZA worms can be processed using the milling method with frontal-cylindrical milling tools on NC machines,
- Milling processing Method introduces an error which by order of magnitude may be acceptable,
- Minimal deviations from the nominal profile of the worm type ZA are obtained by adjusting the milling tool to be positioned eccentric to the axis of the worm, in this case deviations being very small of a few microns.
- The process of machining with frontal-cylindrical milling tool ensures a processing in superior conditions in terms of working time compared with the processing method of turning,
- The procedure involves the use of a machine NC in 5 axes.

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