MATHEMATICAL METHOD DESIGN FOR CALCULATION OF THE INITIAL TOOL SURFACE FOR THE SHARPENING OF HOBBING WORMS

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ABSTRACT

Face teeth grinding of special tools such as hobbing worm milling cutters is a complex operation with respect to achieving the necessary accuracy and shape geometry. The grinding wheel shape, its size and the control helix angle of the hobbing worm are the primary factors which influence the groove accuracy during the face teeth sharpening process. An inappropriate combination of these parameters causes undercutting of this surface and a negative impact on the required accuracy. The main aim of the solution is to find a variable and to create a parametric mathematical model to calculate the appropriate grinding wheel shape according to the input factors which affect this issue. This system is used to create the initial grinding wheel surface automated calculation programme using Visual Basic and 3D CAD/CAM Catia V5 software.

ISSUE STATEMENTS

Current research is concentrated on the elimination of the helix groove undercut and attaining the required accuracy of the ground surface. Research currently focuses on hobbing worm milling cutters with zero face teeth angle, marked γ, according to the axis of the tool (see Fig. 1). [6]

![Figure 1 Face teeth angle](image)

The insertion of the grinding wheel cutting parts into the face teeth of the hobbing worm is carried out with consideration of the ground tool geometry and includes the influence of the grinding wheel geometry. The helix pitch angle control of the hobbing worm and the shape and the diameter of the grinding wheel are the main influences on this negative effect. The higher the helix curvature and the bigger the wheel diameter, then the larger is the insertion and clearly higher inaccuracy. If the wheel diameter is theoretically small, as if it were made by a point, no undercut will occur. There would only be a point contact. However, as the wheel diameter increases, then surface contact occurs. But there is the requirement of achieving the tangent contact in each perpendicular plane to the control helix through the whole grinding process in order to maintain accuracy. Taking the helix curvature into account, a wheel with a bigger diameter cannot be placed in every position of its running with a tangent contact with the ground face teeth but with the surface contact [1]. With an increasing wheel diameter and taking the helix curvature into account, we reach a critical combination of both these parameters, beyond which we are not able to achieve a continuous grinding process, even if we consider the possibilities of multi-axis grinding for lead and tilt angles.
If we take a closer look at the ground groove, in the currently used geometry, the default grinding wheel has a straight line profile. When we create a cut through the helical surface in the perpendicular plane to the control helix (which indicates pitch), the face in this view also has a straight line profile. Theoretically such a negative effect of undercut should not occur because of the straight line properties of both input geometries. This effect does occur, but not in this plane, but between this plane and the involute curve (see Fig. 3). This area of the undercut is bigger when the helix curvature is higher and the diameter of the grinding wheel is bigger.

**RESEARCH**

There is a trend to keep technologic know-how in the area of shape surfaces grinding. Based on this trend, new grinding machines have implemented its own closed system, which communicates with kinematics of the machine. It is not possible or it is very hard to get into the core of these systems and into the mathematic tasks which run in the background. These systems are designed by the manufacturer and delivered with the machine and they are specialized for the certain kind of the tool and they are divided into few modules according to the representative type. Each of modules work based on the analytic geometric tasks, which are differentiated by input parameters and properties of the ground tool. Many of these tasks of designed tools are based on the exactly defined ground tool geometry and there is a need to create grinding technology using exact kinematics of used machine and selecting appropriate type and shape of
the grinding tool. These softwares are very comprehensive because of the identification of the ground groove geometry. This area is very complex. Ground grooves are created by various geometric shapes and it’s combination with input required parameters of the resultant groove creates complex geometric surfaces and it is not possible to grind these surfaces by standard grinding tool shapes according to the shape and surface accuracy. It is mainly about helix areas where are we not able to influence the manufacturing process by using different material of the grinding tool or machine kinematics. In this phase we are approaching to the modification of the shape of grinding tools [2].

You can see in the Fig.4 the example result from ANCA software for determination of the initial grinding wheel shape for the tool with specific parameters. The system calculates the curve of the cutting area of the wheel appropriate to the ground groove geometry.

![Image](image.png)

Figure 4 ANCA I flute

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
<th>ANCA ICG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td></td>
<td>-741.2 mm</td>
</tr>
<tr>
<td>Flute Length</td>
<td>70 mm</td>
<td></td>
</tr>
<tr>
<td>Tool Diameter</td>
<td>35.191 mm</td>
<td></td>
</tr>
<tr>
<td>Number of Flutes</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5 ANCA I flute - Input parameters

Because of the input factors and helix groove undercut theory, the main research is focused on designing an appropriate grinding wheel shape. The main aim of this research is to create a parametric mathematical model of the grinding wheel shape appropriate to the ground groove parameters and to find a main variable which will include information about the geometrical parameters (such as further input factors) of the ground tool and the grinding wheel. This could be used for further research in this area for hobbing worms of shaped face teeth, for example globoid or face teeth below the angle $\gamma$. 

ANALYTIC SOLUTION

The analytic solution is based on the cutting planes method. This method is used as a standard for investigating the initial tool surface. The solution has a few key steps, which must be followed correctly to obtain the correct result. For simplicity, the calculation is derived from a continuous helix surface regardless of the shape of each tooth and its shape parameters. The main information is about the root circle, the head circle, the control helix curvature and the whole face width. The enumeration of each formula to describe the whole system follows in the description of the design. Primarily it is a mathematical model which contains information about the hobbing worm, the grinding wheel and the geometry necessary for solving this process [7, 8].

The beginning of this concept is described in the following formulas written in reduced form:

Control helix of the face teeth:
\[ x = v_0 \ast (t). \]  (1)
\[ y = r \ast \cos(t). \]  (2)
\[ z = r \ast \sin(t). \]  (3)

Tangent to the control helix:
\[ \frac{\partial x}{\partial t} = v_0. \]  (4)
\[ \frac{\partial y}{\partial t} = -r \ast \sin(t). \]  (5)
\[ \frac{\partial z}{\partial t} = r \ast \cos(t). \]  (6)

The grinding wheel axis vector in the selected axis system:
\[ u_5 = (r, -v_0, 0). \]  (7)

Equation of the grinding wheel circle with the centre in point \( S \) with positioning in main plane:
\[ P(u) = S + R \ast P1 \ast \cos(u) + R \ast P2 \ast \sin(u). \]  (8)

Cutting plane 1:
\[ r \ast x - v_0 \ast y + \left(-r \ast (r \ast p) - v_0 \ast (v_0 \ast p)\right) = 0. \]  (9)

Parameters:
\begin{align*}
& t \quad \text{... angle [rad]} \\
& u \quad \text{... angle [rad]} \\
& v_0 \quad \text{... reduced thread height [-]} \\
& r \quad \text{... helix radius [mm]} \\
& S \quad \text{... centre of the grinding wheel circle [mm]} \\
& R \quad \text{... grinding wheel circle radius [mm]} \\
\end{align*}

Above mentioned equations in general form are the default for the solution of the undercut of the helix groove and the unique mathematical model of this problematic is designed using basics of analytic geometry.

Wolfram Mathematica software was used to check the correction of the solution equations by using its syntax for rendering the mathematical description.
Rendering the mathematical description:

INITIAL TOOL COMPUTATIONAL MODEL

Based on the analytical solution, the programme for the initial wheel surface computation is designed using 3D CAD Catia V5. This software is connected to Visual Basic [9,10] and they are able to communicate together using its syntax. By selecting the appropriate combination of instructions in Visual Basic, the position of the hobbing worm and the grinding wheel and its resultant shape according to the ground groove is automatically created according to these commands in Catia.

Figure 7 Initial tool computational model
With regard to the analytical solution, the macro works with mathematical formulas and variables, which are defined as input factors. There is an assumption that these factors will figure in the mathematical description of the initial wheel surface. Each equation is implemented into the script using subprograms.

Figure 8 Partprogrammes

You can see on the picture bellow part of the mathematical model and its interpretation in Catia throughout the script written in Visual basic.

Figure 9 Interpretation of the part of the mathematical model in Catia throughout the script written in Visual basic
GRAPHIC PART OF THE SOLUTION

Because the solution is based on cooperation between Catia V5 and Visual Basic software, the graphic solution is an integral part of this programme. It is clear that the new shape follows the teeth curvature. This graphic part contains the whole automated design of the position of the appropriate grinding wheel and the hobbing worm in Catia and the wheel shape curve graph (see Fig. 10).

CONCLUSION

The mathematical description of the resultant wheel shape curve is investigated by using the analytic method. This mathematically described curve contains a variable which covers data about the input parameters for the grinding process. These data are the main factors influencing the curve shape. This variable will help towards a better understanding of the grinding process, its running and its resulting accuracy. This curve is a part of the whole mathematical model which is used to create a programme for calculating a wheel shape tailor made for hobbing worms using the VBA tool in Catia. Entering these equations using this tool syntax the parametric 3D simplified model of the hobbing worm and the parametric graphic solution is created. The user interface will only be used to enter input data which directly affect the grinding process or the grinding wheel shape. This means that the proposed solution will cover the graphic and analytic method with a simple user interface.

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REFERENCES


References to a book:


