MODELLING AND MACHINING OF THE HELICAL GROOVES

In the article, a way of modelling curves situated on cylinder surfaces is presented, which is made with two helical lines. Particular attention was given to the fluent transition between helical lines. The article also presents a mathematical description of a tangent arc that connects two helical lines. Also the way of preparing an NC program for machining complex curves consisting of two different helical lines is presented. A method of programming NC code for the machining of a closed helical groove (a helical groove without endpoints) is presented.

Key words: helical lines, complex helical groove, helical groove turning

1. INTRODUCTION

Helical line is a significant element in the construction of many machine parts. The significance of helical lines is visible within slide bearing applications [1, 3–5, 7]. Helical line description can be accomplished through the application of mathematical relationships. With the assistance of contemporary design software, this task can also be realized within a CAD system. Both of these methods simplify the process of describing helical lines. In cases where two helices are connected by a tangent arc at a shared endpoint, the problems with describing helical lines become more complicated. These problems are visible in the case of lubricant grooves machined into bush bearings. Fluent transition in the form of a tangent arc between two helical lines is required in technological applications, to protect the bit from damage. To obtain such arc proportion between two helical lines with opposite handedness, it is mandatory to consider surface curvature where an arc is placed. Another important problem is the actual machining of helical grooves. One of the conventional machining methods of such geometry is turning on a lathe. Complex groove geometry does not allow for the direct usage of machine cycles. Also, standard machining strategies that are offered in

* Dr hab. inż. ** Mgr inż. The Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology.
CAD/CAM systems do not allow the machining of such geometry [6]. CAD models can efficiently facilitate the manual programming of CNC machines.

2. SPECIFICATIONS AND MODELING COMPLEX HELICAL LINE

The helical line is a straight line winding on a cylinder surface. To describe such a line, the basic parameters such as diameter and spiral lead, which is the distance between each thread line, must be known. In many cases, the helical line’s spiral lead can be calculated based on its height and thread number or based solely on lead angle. The radius and spiral lead describe the coordinate points in a helical line interdependently:

\[
\begin{align*}
    x &= R \sin \varphi \\
    y &= R \cos \varphi \\
    z &= H \left( \frac{\varphi}{360} \right) 
\end{align*}
\]

(1)

where: 
- \( H \) – spiral lead,
- \( R \) – helical line radius,
- \( \varphi \) – angle denoting the deviation of the point [°].

On the basis of dependence 1. the coordinates of any helical line can be calculated. To connect the helical lines, the transition tangent arc must be defined. Maintaining tangency is central in this geometry. The circular arc connects the endpoints of two helical lines that have the same lead angle but opposite handedness. This assumption is required to calculate the coordinate points of their endpoint. This is described in a flattened view in Figure 1.

![Figure 1. Helical lines connection geometry](image1)

![Figure 2. Helical lines’ endpoint arc wise connection](image2)
To calculate the distance from a circle’s center to the lines’ intersection point (OD segment) from dependence (2), the tilt angle of the helical lines in ratio to cylinder surface $\alpha$ and the rounding radius between lines $r$ must be defined.

$$OD = \frac{r}{\sin \alpha} \tag{2}$$

Equation (3) describes the distance from the chord (segment $AB$) to the helical lines’ intersection point.

$$CD = \frac{r \cos \alpha}{\tan \alpha} \tag{3}$$

Chord length (segment $AB$):

$$AB = 2r \cos \alpha \tag{4}$$

The above-presented equation permits the finding of the characteristic transition line, which connects the helical lines at their endpoint. This equation of a circle can be used to find the transition curve’s coordinate points.

In CAD systems, there are tools for modeling helical lines [2]. It is used mainly like a path for cut – sweep. In CAD the curve is separately modeled, which has to be connected using an extra arc with tangency constraint. There is no tool in CAD for rounding two lines lying on a cylinder surface, because of this deficiency the helical lines are projected on a surface, which goes through the cylinder axis and then a closed profile is modeled. This is presented in Figure 2 – a bush with helical lines modeled on an internal cylinder surface. Dashed lines represent the connected helical lines, and the continuous lines present the smooth transition of these two lines.

The circular arc presented between the helical lines, when projected on a surface, does not have a circular profile. The chord length connecting the helical lines’ endpoint will shrink (segment $AB$ on Figure 1). This shrinking occurrence is presented in Figure 3.

![Figure 3. Arc geometry on a cylinder surface](image-url)
When comparing geometry from Figure 1 and 3, it can be stated that the distance between the chord and helical lines section is the same (equation 3). Chord length change can be calculated based on Figure 3:

$$A'B' = 2R \sin \left( \frac{r \cos \alpha}{R} \right)$$ \hspace{1cm} (5)

To model the transient arc, the distance from the arc center to the helical lines section (segment $ED$ – Figure 1) is used, which is the same on the cylinder surface and the surface that goes through the cylinder axis. This is described in the following equation:

$$ED = \frac{r}{\sin \alpha} - r$$ \hspace{1cm} (6)

All created lines lay on the surface (plane) that goes through the cylinder axis. To create a closed helical line, the lines must be projected on the internal bush surface. The created helical line can be used as a path to cut – sweep a helical groove, as presented in Figure 4.

3. NC PROGRAM FOR HELICAL GROOVE MACHINING

Presented mathematical dependence allows for direct calculation of the helical line coordinates and enables the preparation of the NC program, also, the equation allows for the modeling of complex helical lines and displays the coordinates from the model to prepare the NC program in CAD systems. The second method provides the same result but it is more convenient and gives a graphic description of the helical groove. To prepare a tool path on a turning lathe, three parameters must be known: the coordinate on the $X$ axis which defines helical groove, diameter and its depth, motion along the $Z$ axis and the $C$ axis angle to synchronize these motions. To prepare such a tool path it is sufficient to know the motion along the $Z$ axis and $C$ axis rotation angle. Programming a tool path for the connection of the helical lines is very laborious. The arc points must be projected on the surface and should be evenly distributed (Figure 5). As a result of this operation, the arc point coordinates’ positions are obtained.

The obtained coordinate enables the programming of the rotation around the $C$ axis. The second important value is the depth of motion in the $Z$ direction, which can be read from the CAD model. And to do this, the distance from the
characteristic point to the reference line must be measured, the reference line is also the base for the NC program. These dimensions are path coordinates in the Z direction. Such dimensioning geometry is presented in Figure 5. Knowing the distance and angle arc points’ positioning enables the programming of the NC program. The bigger the number of coordinates, the more precise the helical line can be, however such approach is more laborious.

![Figure 5. Evenly distributed surface and coordinate points in the Z direction from the reference line.](image)

Figure 6 shows helical groove machining in a bearing bush. The helical groove was machined on the internal surface of 42CRMo4 steel bushing, which was made specifically for grinding.

A cemented carbide boring cutter was used in the turning of bushing to create the helical groove. A round bit was used because the geometry of the bit is dependent on the desired geometry of the helical groove. The machining was done on a CNC through the use of the C axis. The depth of the groove depends on the durability of the cutting tool, the groove presented in Figure 6. has a depth of 3 mm, the dying with the bit occurs with the simultaneous movement of the X, Z, and C axes. The amount of passes depends on the depth of the groove. A fragment of the NC code is presented below:

![Figure 6. Bearing bush with closed helical groove machining by turning](image)
N1 G55 – base selection
N2 T1212 M03 – tool and rotation direction selection
N3 G98 – selection of units
N4 M154 – connection of the C axis
N5 C0 – axis reset
N6 G00 Z50. – quick movement to the starting point on the Z axis
N8 G00 X58. M08 – quick movement to the starting point on the X axis
N9 Z-6.512 – positioning movement
N10 G01 X59. F50. – positioning movement
N11 (first arc)
N12 C0 Z-6.512 F5000. – dying of the first helical line
N13 C-5. Z-6.59
N14 C-10. Z-6.823
N15 C-15. Z-7.206
N16 C-20. Z-7.731
N17 C-25. Z-8.388
N18 C-30. Z-9.163
N19 C-35. Z-10.037
N20 C-40. Z-10.991
N21 C-45. Z-12.
N22 (DŁUGI ŁUK)
N23 C-315. X60. Z-78. – dying movement
N24 (second arc) – dying of the second helical line
N25 C-320. Z-79.009
N26 C-325. Z-79.963
N27 C-330. Z-80.837
N28 C-335. Z-81.612

4. SUMMARY

The presented problem is an example of the practical application of manual programming to prepare complex geometry machining based on a CAD model. CAM systems do not have any strategies to generate a tool path for such geometry. A bush with a helical groove is one of the many examples where manual programming must be used. Using this presented way, many variants of helical lines can be generated. Preparing the program is very laborious, therefore it would be rational to create a computer application to automatically prepare an NC program.
REFERENCES


MODELOWANIE I OBRÓBKA ROWKÓW ŚRUBOWYCH

Streszczenie

W artykule przedstawiono sposób modelowania krzywej położonej na powierzchni walcowej, będącej złożeniem dwóch linii śrubowych o przeciwnym kierunku zwoju. Szczególną uwagę zwrócono na zapewnienie płynnego przejścia w punkcie łączenia linii. Przedstawiono również sposób przygotowania programu NC do wykonania złożonej krzywej, składającej się z różnych linii śrubowych.

Słowa kluczowe: linia śrubowa, złożony rowek śrubowy, toczenie rowka śrubowego

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