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DETERMINING AND VERIFYING THE GEOMETRIC CHARACTERISTICS OF HELICAL GROOVES IN THE WORM IN PLANETARY TOROIDAL DRIVES IN A MORE EFFECTIVE WAY

Summary. In the toroidal drive, a screw-shaped groove is cut into the globoid worm. There is contact with the rolling element in this groove. This helix can be described by parametric equations. When calculating the values of the first and second curvature of the curve, as well as the radius of curvature, we must calculate the individual derivations. A new, more effective way is to determine the values already mentioned by using NX software only. When using Siemens PLM NX software, it is not necessary to determine individual derivations and their values, although the NX software determines the radii of the first and second curvature, based on the defined helix curve.
Keywords: groove in the globoid worm; helix; curvature; parametric equations

1. INTRODUCTION

In practice, different types of rolling transmissions are used. The helical grooves in which the rolling elements are rolled can be described by equations. These grooves correspond to the teeth in the toothed gears. The values of the radii of curvature of the groove and the rolling elements influence the contact pressures in the transmission. The article deals with the values

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of the first and second curvature and the radii of curvature of the helical grooves that are on a non-cylindrical surface. Helical grooves can also be cut into a globoid or toroidal surface, mostly in special rolling transmissions. An example is a toroidal planetary drive. So far, the above-mentioned values, that is, the first and second curvature and the radii of curvatures, have been solved only by mathematical methodology, i.e., by calculating the individual partial derivations and then calculating the radii of curvature. Siemens PLM NX10 software provides the option to determine these required characteristics in a more efficient, simpler way, without calculating derivations. The aim of this article is to propose a new method, which is very effective on globoid and toroidal surfaces. On such surfaces, the values of the radii of the first and second curvatures are variable in their entirety.

After the design process, various types of checks are performed (e.g., by FEM [1, 2]). Then, it is necessary to be mindful of the diagnostics during the operation of the element (e.g., by non-invasive methods [3-7]).

2. DRIVE MEMBERS

Mechanical planetary toroidal drives consist of the following basic members (Fig. 1): 1) globoid worm, which is the driving member, 2) rollers, 3) divided stator, 4) planet and 5) carrier. [8, 9]. Turning the worm into motion is provided by means of the rolling body in the planet. Without a stator, the planet would only rotate around its own axis. The carrier is activated by the grooves cut in the stator, which is the output of the transmission. Such a drive can be classified as transmissions with very low clearance and good efficiency [8].

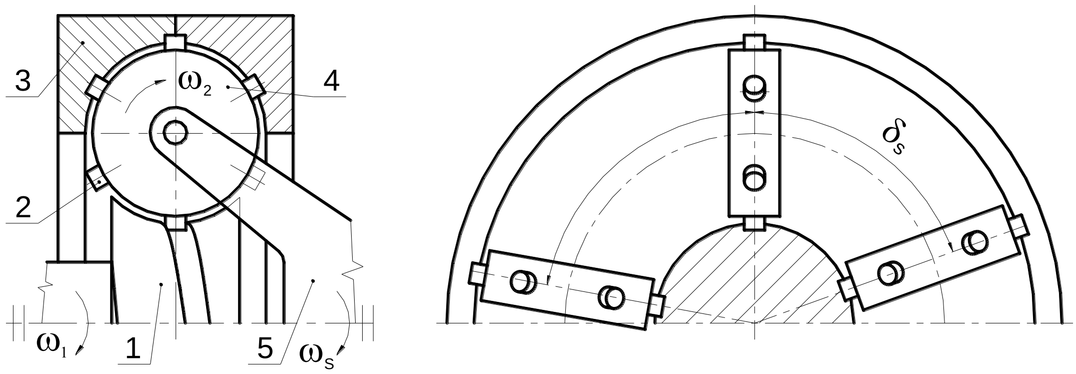

Fig. 1. Planetary toroidal roller drive

3. SCREW GROOVES IN THE GLOBOID WORM

There is a screw-shaped groove in the globoid worm. In Fig. 2, there is a defined general point of the helix before cutting the shape itself, which takes into account whether the rolling elements are rollers or balls. For defining this helix, which is the basis for the groove modelling, equations are used. When describing parametric equations, the parameter used here is an angle, which is a general parameter. In Siemens PLM NX software, the main parameters are first determined by the command *EXPRESSIONS*, namely, the number of grooves z_1, the number of rolling bodies in the planet z_2, the diameter of the worm d_1 and the diameter of the planet d_2 in the middle section. One groove in the worm is considered in the article, i.e., $z_1 = 1$. In parametric equations, the angle parameter φ_1 is defined by the vertical axis. The variance of the angle φ_1 is defined by the parameter *t*, which takes values from 0 to 1 with a step. The helix is created as a *LAW CURVE* using coordinates *xt*, *yt*, *zt* (Fig. 3). In Fig. 3, $z_1 = 1$, $z_2 = 8$, $\varphi_1 = 60^0$.

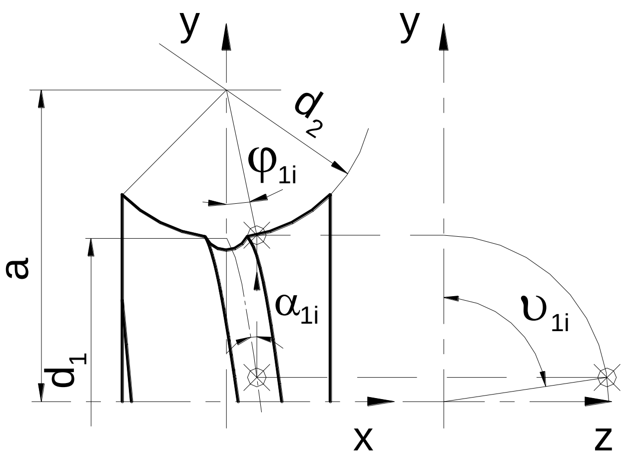

Fig. 2. Helical groove in the worm

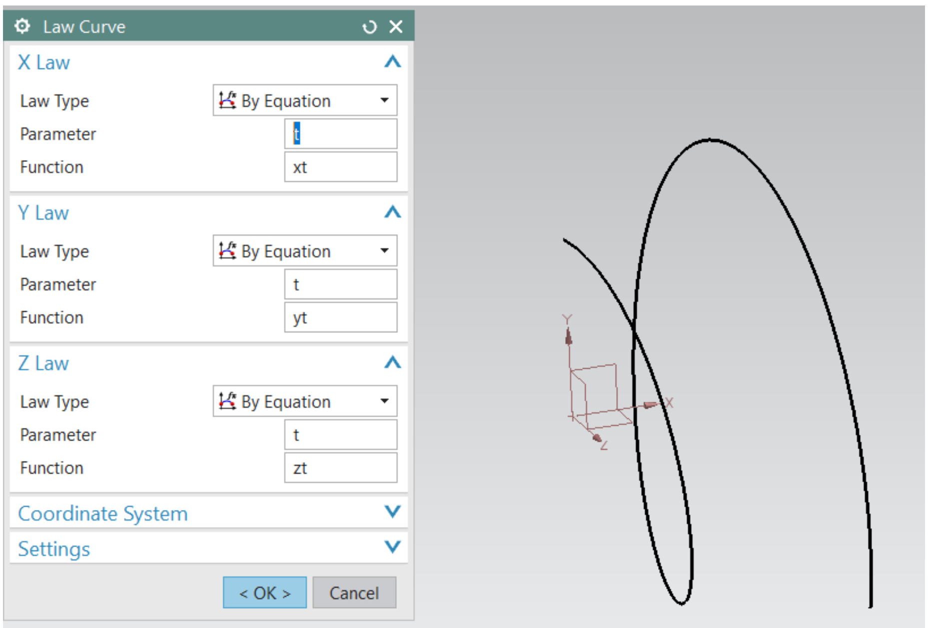

Fig. 3. Law Curve: helix on the globoid surface of half of the worm

The worm diameter at the general point (Fig. 2) is:

$$d_{1i} = d_1 + d_2 \cdot (1 - \cos \varphi_{1i}) \tag{1}$$

where d_1 is the worm diameter in the middle section, d_2 is the planet diameter, and $\varphi_1$is the rotation of the planet from the vertical axis.

The helical groove parametric equations are:

$$\begin{aligned} x &= r_2 \cdot \sin \varphi_1 \\ y &= (a - r_2 \cdot \cos \varphi_1) \cdot \cos(i_{12} \cdot \varphi_1) \\ z &= (a - r_2 \cdot \cos \varphi_1) \cdot \sin(i_{12} \cdot \varphi_1) \end{aligned} \tag{2}$$

where:
x, y, z – Cartesian coordinates of the helix point
a – internal axial distance
r_2 – planet radius
i_{12} – gear ratio between rolling bodies and worm

For writing in the NX software, you need to define a variable angle using the parameter *t*:

$$\varphi_{1i} = fi_1 \cdot t \tag{3}$$

where t is a variable parameter from 0 to 1, and f_{i1} is maximum angle φ_1.

For the lead angle:

$$\tan \alpha_{1i} = \frac{v_2}{v_{1i}} = \frac{d_2 \cdot \omega_2}{d_{1i} \cdot \omega_1} = \frac{d_2}{i_{12} \cdot d_{1i}} \tag{4}$$

where v is the circumferential speed, and ω is the angular velocity.

For the pitch:

$$p = \pi \cdot d_{1i} \cdot \tan \alpha_{1i} = const \tag{5}$$

The screw groove in the worm is characterized by a constant pitch (Equation 5), defined by the number of grooves in the worm and the number of rolling bodies in the planet. The pitch of the helix varies, depending on the diameter of the worm.

A helix with a radius of 50 mm and a pitch of 50 mm was used to verify the software. For a cylindrical helix, the values of the first and second curvatures are constant, but the values are different. The *CURCE ANALYSIS* command determines the value of the first radius of curvature as a variable with a minimum of 50.6067 mm and a maximum of 51.6097 mm for 200 points on the helix. The calculation is the radius of 51.2665 mm. The second curvature (torsion) is possibly found in *More CURVE ANALYSIS Info*. The value of a standard helix with the above parameters is a minimum of 3.015375e-03 mm^{-1} and a maximum of 3.145,624e-03 mm^{-1}, as specified by the software. The second curvature (torsion) is calculated as 3.104,462e-03 mm^{-1}. As we can see, the accuracy levels are very high.

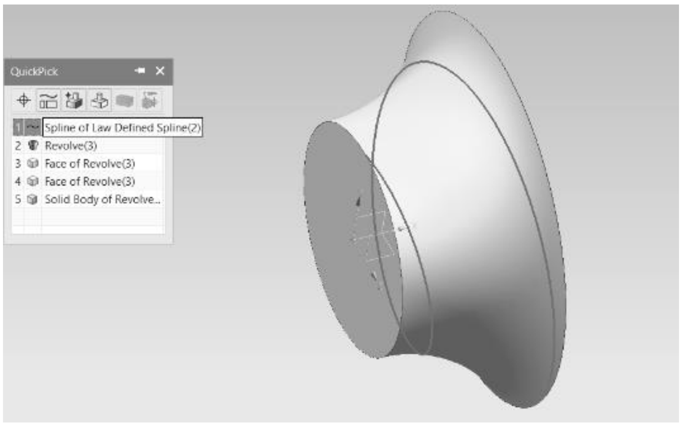

Fig. 4. Helix on the surface of the worm for z_2=8

For the globoid worm, the first and second curvatures are not constant, but they vary depending on the ratio between the worm and the planet i_{12}, as well as the ratio between the planet diameter and worm diameter.

The first curvature of curve-squared (for the general parameter φ):

$$\left({}^{1}k\right)^{2} = \frac{\begin{vmatrix} x' & y' \\ x'' & y'' \end{vmatrix}^{2} + \begin{vmatrix} x' & z' \\ x'' & z'' \end{vmatrix}^{2} + \begin{vmatrix} y' & z' \\ y'' & z'' \end{vmatrix}^{2}}{\left(x'^{2}+y'^{2}+z'^{2}\right)^{3}} \tag{6}$$

where the partial derivations are:

$$x' = \frac{dx}{d\varphi} \qquad y' = \frac{dy}{d\varphi} \qquad z' = \frac{dz}{d\varphi} \tag{7}$$

For the radius of the first curvature of the worm:

$$r_{1k} = \frac{1}{{}^{1}k} \tag{8}$$

For the second curvature of the helix:

$${}^{2}k = \frac{\begin{vmatrix} x' & y' & z' \\ x'' & y'' & z'' \\ x''' & y''' & z''' \end{vmatrix}}{\begin{vmatrix} x' & y' \\ x'' & y'' \end{vmatrix}^{2} + \begin{vmatrix} x' & z' \\ x'' & z'' \end{vmatrix}^{2} + \begin{vmatrix} y' & z' \\ y'' & z'' \end{vmatrix}^{2}} \tag{9}$$

Tab. 1
Cartesian coordinates of the helix in the worm, worm diameter and lead angle for
d_1= 90 mm, d_2= 85 mm, z_1=1, z_2=6

φ_1 (^{0})	Point (mm)		d_1 (mm)	α_1 (^{0})
0	x	0.000	90.000	8.945382
	y	45.000		
	z	0.000		
30	x	21.250	101.388	7.954295
	y	-50.694		
	z	0.000		
60	x	36.806	132.500	6.102780
	y	66.250		
	z	0.000		

In Table 1, only three helix points are selected and their coordinates are calculated, along with the value of the diameter d_{1i} and the angle α_1. In the calculation, the rounding of the coordinates to six decimal places in mm and angles to eight decimal places in degrees was considered. Table 2 presents the first curvature of the helix and its reciprocal value of the radius of curvature. In the next column, the NX software defines the radius of curvature. The difference between the radius of curvature is determined by the calculation, with the rounding considered; the software value is small and represents a variation of about 0.3%. In turn, it is possible to determine the first and second curvature of the curve, as well as the radii of curvatures using the NX software.

Tab. 2
The first and second curvature of the helix, their radii of curvatures, as per the calculation, and the software NX for d_1= 90 mm, d_2= 85 mm, z_1=1, z_2=6

φ_1 (^{0})	^1k calculation (mm^{-1})	r_{1k} calculation (mm)	r_{1k} NX (mm)	^2k calculation (mm^{-1})	^2k NX (mm^{-1})	r_{2k} calculation (mm)
0	2.1116e-02	47.357	47.225	3.1321e-03	3.1131e-03	319.277
30	1.9105e-02	52.344	52.213	2.2494e-03	2.2173e-03	444.570
60	1.4986e-02	66.730	66.526	0.8252e-03	0.8256e-03	1,211.254

NX10 software allows you to determine and display the values of the radius of curvature or the first curvature at individual points, while their number can be determined as needed. NX also allows you to specify minimum and maximum values, as well as other data. Fig. 5 presents a graphic view of helix curve analysis with a scale and extreme values of the radii of curvature. For the determination of the contact pressure, it is necessary to determine the second curvature of the helix. The second curvature of the curve (torsion) can be determined by listing the individual values as needed. The software determines the points on the curve according to parameter *t*, which adjusts according to the number of points in which the data are to be detected. The accuracy of the values varies slightly depending on the number of points.

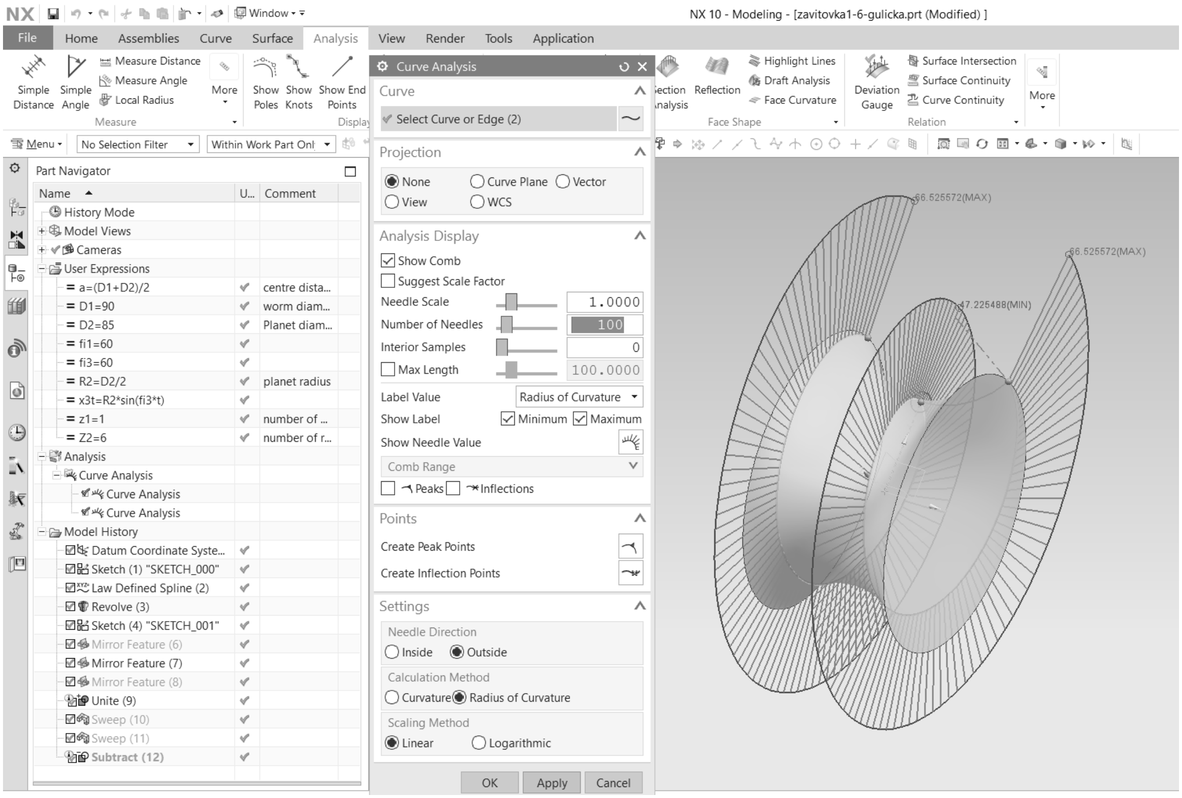

Fig. 5 The radius of curvature of the helix in the scale of NX software

4. CONCLUSION

In those transmissions where the rolling elements are in the screw grooves on globoid and toroidal surfaces, it is necessary to determine the radii of both curvatures of curves. Only certain software packages allow you to determine both curvatures of curves. NX software lists, in addition to the coordinates, the radius of the first curvature, or the first curvature of curve, as well as the torsion, i.e., the second curvature of curve. Furthermore, the curve values can be determined by using NX software, even without calculating individual derivations, which appears to be a more effective and faster method for determining both radii of curves. The accuracy of the values is high. To determine values at specific points, it is better to specify the point precisely because the software modifies the parameter *t* in its own way. This method can also be used for other transmissions containing helices.

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