



The methods of globoid surface modeling in CAD

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ABSTRACT

Purpose: Modeling of globoid worm surface is a difficult issue of modeling of complex surfaces in CAD. Worm gears are a challenge for designers because of the construction and the functions that have to be met, as well. There are very few specialized applications to generate this type of gears. The software intended to model of the worm gear wheel only is not accessible, so basing on general intending CAD systems is a necessity. Modeling of globoid worm surface can cause the problem. The examples of globoid helical surfaces modeling in CAD are accessible on the Internet, but often they are not correct in terms of geometry and they do not reflect the actual geometry. These surfaces are modeled on the helix with uniform pitch but diameter variable only. The worm gear development, including these atypical ones, requires looking for new solutions in their modeling.

Design/methodology/approach: The three methods of the globoid surface modeling, using CAD systems - AutoCAD and CATIA were presented. The modeling was carried out on the example of the worm lateral surface of the globoidal worm gears. In the first presented method the external program, that generates the script commands for AutoCAD system and lets generate the points of the globoid helix, was used. In the following two methods to model helixes, the possibilities of CATIA were used: creating the graph of two-dimension functions and comprising them into three-dimension function and kinematic simulation, as well. In the globoid helix the pitch variation is included.

Findings: The described methodologies are universal and allow to generate the globoid lateral-surface of worm on the basis of wormwheel constructional assumption and taken tooth profile. The advantages of CAD systems and their usefulness in the globoid worm gear designing are highlighted in the article.

Research limitations/implications: The main problem concerned the method No. 3 that uses a kinematic simulation of CATIA. The number of simulation "frame" is the limitation.

Practical implications: The proper modeling of worm gear geometry in CAD allows to analyse the geometric cooperation, strength (by the finite element method), or to make a prototype for the preliminary tests with using of the rapid prototyping techniques.

Originality/value: All three presented methods are innovative and allow to provide a correctly modeled globoid surface as a basis to create a complete model of the globoid worm.

Keywords: CAD/CAM; Globoid surface; Globoid worm gear; Globoid worm

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

The globoid worm gears are composed of a cylindrical or tori globoid wormwheel and the globoid worm, whose outline, in a longitudinal section, tightly touches to the wormwheel [1-3]. The wormwheel is positioned in the relation to the worm mostly at an angle of 90°. In comparison with the cylindrical worm gears, the globoid worm gears have lower operating wear and higher efficiency [1,4]. Another advantage is more beneficial location of the contact lines and cooperation of more numbers of teeth [5]. Between of the worm meanders and wormwheel teeth there are high rubbing speeds not only along the contours of the teeth, but also along the tooth, which results from the wheels position in the relation to each other - axle rotating [4,6,7]. When higher loads, the seizure of the teeth happens, because the sliding velocity increases with the increase of growth angle of worm meander line [8]. The disadvantages include technological difficulties and high sensitivity on the accuracy of these gears realisation.

Due to the construction and fulfilled functions the worm gears are a challenge for designers. There are few specialized applications to generate this type of gears. The software only to model worm gear wheels is not commonly available, therefore there is a need to base on the CAD system for general-purpose [9]. The globoid surface modeling is a problem, as well. On the Internet it is possible to find examples of globoid screw surface modelling in CAD, but often they are not geometrically correct and do not reflect the actual geometry. For example, it is modelled on a helix with constant pitch and variable diameter only.

2. Innovative methods of globoid surface modeling

Globoid worm surface designing of the worm gear is the subject of intense analysis. Currently solutions are mostly reserved by the gear producers, therefore the presented way of modelling is innovative.

2.1. The method No. 1: the globoid surface generating in AutoCAD

The developed process of globoid worm lateral-surface modelling was carried out in four stages (Fig. 1): taking the wormwheel constructional assumption, generating the points of the globoid helix, export of the data in the points form to CATIA and the final worm shape modelling.

In the first step the worm gear parameters to create the worm wheel appendant drawing 2D in AutoCAD (*.dwg) should be done. The worm wheel model does not necessarily comply to the final version - for example, the technological holes can be ignored, because at this stage the needed data are primarily points coordinates connected with the characteristic points of the worm outline in an axial section.

To automate the commands in AutoCAD, the script commands, system macrocommands, the programming language (AutoLISP or Visual Basic) or an external program created in a different programming language and generating the script commands for AutoCAD system can be used. To generate the globoids from points 1-4 being on the wormwheel teeth (the starting points of globoids - Fig. 2) the iterative operation as the batch macrocommands were used.

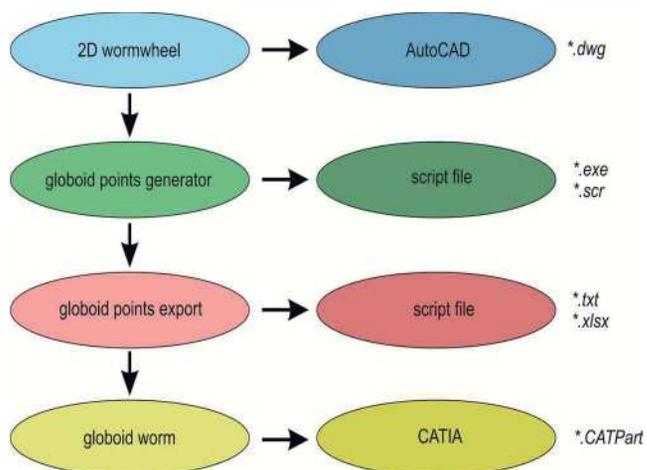


Fig. 1. The generating globoid worm steps

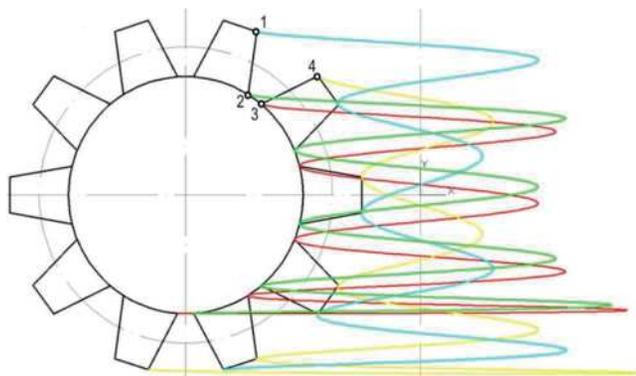


Fig. 2. The globoid helices generated in AutoCAD

During the globoids creating, such factors as the minimum thickness of machining layer, vibration, thermal phenomena, deformation and others are not considered. Obtaining the individual globoids needs a fourfold application of the generator - every time one globoid helix is obtained. The generator saves the points coordinates as an AutoCAD scenario (*.scr). On the basis of the generator it is possible to generate one of globoid helices in the AutoCAD system. It is important to change the coordinate systems - the worm wheel is considered in a plane section perpendicular to the its axis and passing through the worm axis in a 2D space, and the globoids are spatial. The result of all four macrocommands start-up is globoid helices, which represent the edges of the actual worm. On their basis the further modeling of the worm is possible.

The globoids will be done in CATIA, because this system offers more advanced solutions in the complex surfaces modeling. The data about points of each globoid helices is transferred to a text file (*.txt) to export them to CATIA. The export process automates by using macrocommands exporting the points coordinates of the globoid helix from the program such as Excel (*.xlsx) for CATIA system. Obtaining of the point set for each globoid helices requires a separate export them to CATIA system. In the new *.CATPart file the points defined in the geometric sets (Geometrical Set) are obtained. The points need to be verified whether assumed helix won't have the beginning/end outside of the mesh zone. In this case, the points from the Geometrical Set should be removed. Through the rest of the groups of points representing each helix, the splines (Spline) should be run, and as a result there are four globoid helices. In order to perform the surfaces creating the worm it is needed to run the line (Line) connecting the Globoid starting points and then to use the profile extruding (sweep), wherein the profile is the

auxiliary closing two splines line and the paths - splines. As a result the four surfaces, creating the worm, are generated. Globoid surface are the basis to the further modeling - to create a complete model of worm.

2.2. The method No. 2: the laws in CATIA

In the second described method of the globoid helix modeling the laws (Law) in CATIA were used [10-12]. The globoid helix can be modeled as a stretched spline on a set of points. Spline points can be determined using an external program (e.g., Matlab, Excel, C++) based on the known mathematical relationships. Then the globoid helices can be used to form proper surfaces between them.

In the Figure 3 the pictorial drawing of globoid worm (the worm and wormwheel) was shown.

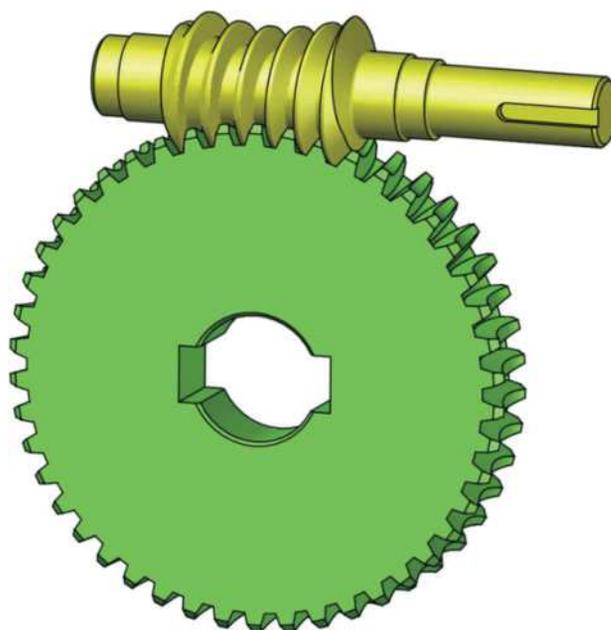


Fig. 3. The pictorial drawing of the globoid worm gear

Transmission ratio of worm gear is:

$$i = \frac{z_2}{z_1} = \frac{\varphi_1}{\varphi_2} \quad (1)$$

where:

φ_1 – the worm rotation angle,

φ_2 – the worm wheel rotation angle,

z_1 – the amount of worm teeth,

z_2 – the amount of wormwheel teeth.

Supporting, the parametric equation of globoid helix will be created as:

$$\begin{aligned} x &= x(z) \\ y &= y(z) \end{aligned} \quad (2)$$

In the Figure 4 the scheme to determine the parametric equation.

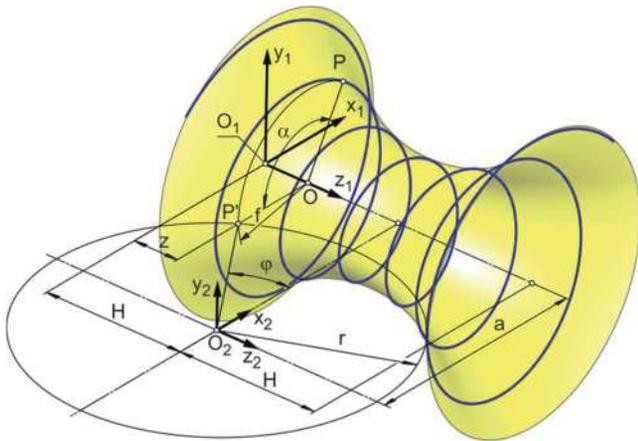


Fig. 4. The globoid helix - an auxiliary scheme

The assumed constants:

- H – a half of the globoid helix axial length,
- a – the distance of the worm axis and the wormwheel,
- r – the globoid radius, whereon there is a considered helix,
- i – ratio.

A coordinate system x_1, y_1, z_1 associated with the end of the worm so that the z_1 axis is the worm axis, was taken. The wormwheel coordinate system x_2, y_2, z_2 was taken that the x_2, y_2 surface is set in the central plane of the worm.

The P free point lying on the considered line is marked by its location and describes as:

- f – the globoid radius in P point,
- P' – section of P point on x_1, z_1 towards z_1 axis,
- O – P point projection on z_1 axis,
- α – P'OP angle,
- φ – the angle between P'O₂ and x_2 axis,
- z – P point coordinate along axis z_1 .

The φ angle can be determined depends on:

$$\sin(\varphi) = \frac{H-z}{r} \quad (3)$$

thus:

$$\varphi(z) = \text{asin}\left(\frac{H-z}{r}\right) \quad (4)$$

$$\alpha(\varphi) = \varphi \cdot i \quad (5)$$

$$f(\varphi) = a - r \cdot \cos(\varphi) \quad (6)$$

$$\begin{aligned} x &= f \cdot \cos(\alpha) \\ x &= (a - r \cdot \cos(\varphi)) \cdot \cos(\varphi \cdot i) \end{aligned} \quad (7)$$

The parametric equations are determined by the mathematical dependence and take the form:

$$x(z) = \left(a - r \cdot \cos\left(\text{asin}\left(\frac{H-z}{r}\right)\right) \right) \cdot \cos\left(\text{asin}\left(\frac{H-z}{r}\right) \cdot i\right)$$

and

$$\begin{aligned} y &= f \cdot \sin(\alpha) \\ y &= (a - r \cdot \cos(\varphi)) \cdot \sin(\varphi \cdot i) \end{aligned} \quad (8)$$

$$y(z) = \left(a - r \cdot \cos\left(\text{asin}\left(\frac{H-z}{r}\right)\right) \right) \cdot \sin\left(\text{asin}\left(\frac{H-z}{r}\right) \cdot i\right)$$

In CATIA the parameters: a, H, r (the *Length* type) and the i parameter (the *Integer* type) were composed. The exemplary value was set to them. Then the two laws (*Law*) were implemented:

Law.X:

$$X=(a-r*\cos(\text{asin}((H-(Z*2*H))/r)))*\cos(\text{asin}((H-(Z*2*H))/r)*i) \quad (9)$$

Law.Y:

$$Y=(a-r*\cos(\text{asin}((H-(Z*2*H))/r)))*\sin(\text{asin}((H-(Z*2*H))/r)*i) \quad (10)$$

The local variates X,Y (the *Length* type) and Z (the *Real* type) were assumed in rules. Z parameter in laws changes in range 0..1.

The “z” coordinate (from (7) and (8) equation) was replaced by the expression $(Z*2*H)$, and it means that it changes from 0 value to 2H value (it gives the whole axis length of the considered globoid helix). The cubic curve in a space can be imaged using its projections on the mutually perpendicular planes. Having two $x(z)$ and $y(z)$ of two equations and two-dimensional curves it is possible to create on their base a $x,y(z)$ curve. To this end, in CATIA the command to compound two curves (Combine) can be used. The equations graph $x(z)$ and $y(z)$ can be created using the command Parallel Curve, where instead of the constant value the distance is introduced by an appropriate law: Law.X in the x, z plane and Law.Y in the y,z plane. After the realising of putting two curves $x(z)$ and $y(z)$ the demanded line is received (Fig. 5).

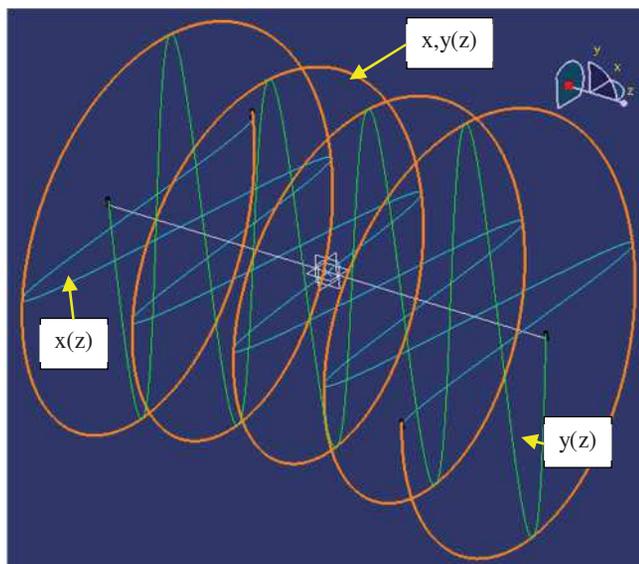


Fig. 5. The globoid helix $x,y(z)$ after the comprising of charts

2.3. The method No. 3: the kinematic simulation in CATIA

To model of the globoid worm surface, the kinematic simulation in Digital Mockup Kinematics module can be used [13-15]. The kinematic system consists of a tool model, the workpiece and the machine tools body. In the Assembly module the compound of independent parts was built. It consists of the parts: a machine tool (1), the worm (2) and the tool (3) – Fig. 6. In addition, to illustrate the globoid surface was formed (4) (Fig. 7).

Between the parts there are used constraints: of coincidence (Coincidence Constraint) to the respective axis, and the contact (Contact Constraint) to the appropriate surfaces. The “Machine” part was confirmed (Fix Component). Figure 8 shows the tree of compound structures.

At the worm the gauger, that gets easier the observation its rotation during the simulation, was modeled. Next, the mechanism in DMU Kinematics module was created from the compoundings. The part “Machine” was brought to a standstill firstly. The mechanism “Mechanism.1” was created. Then two joints called the ‘revolute joints: “Tool”-“Machine” (Revolute.1) and “Worm”-“Machine” (Revolute.2) were created. The type of Revolute Joints consist on the joining of two axis and two surfaces. From Revolute.1 and Revolute.2 the gear was made (Gear.1). To do it the Great Joint command was used (Fig. 9).

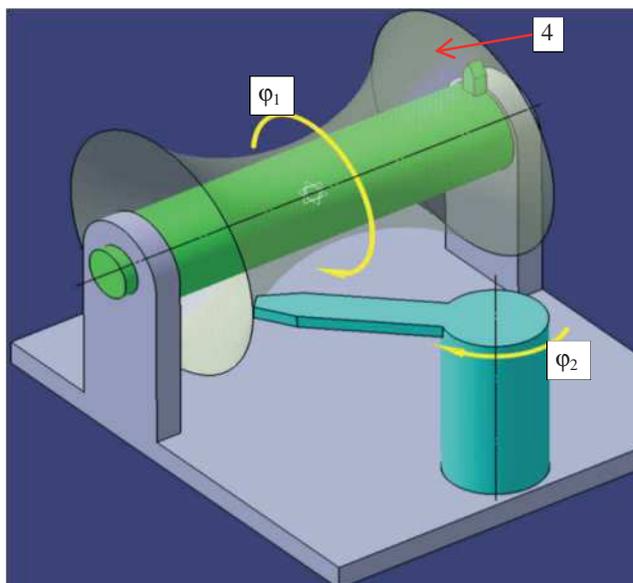


Fig. 7. Scheme of the kinematic system; 4 - an exemplary globoid

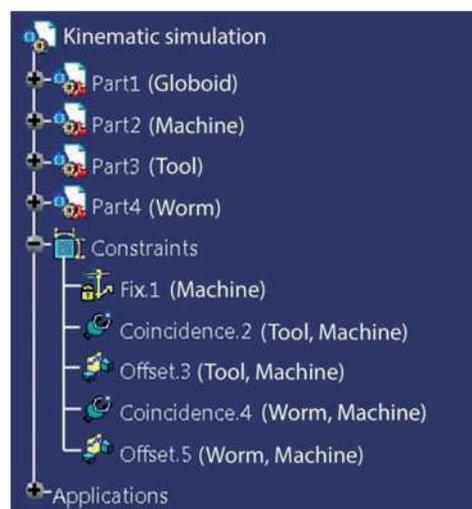


Fig. 8. Compound structures tree

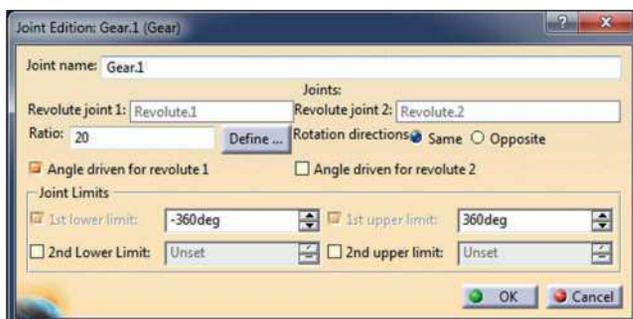


Fig. 9. Creating the constraint joint

Thereupon, the ratio (Ratio) was assumed. The angular force was assigned to the Revolute.1. joint. The exemplary 20 ratio (Ratio) was assumed. The worm gear ratio is:

$$i = \frac{z_2}{z_1} = \frac{\varphi_1}{\varphi_2} \quad (11)$$

where:

- φ_1 – the worm rotation angle,
- φ_2 – the worm wheel rotation angle,
- z_1 – the amount of worm teeth,
- z_2 – the amount of worm wheel teeth.

The simulation by the Simulation command was created (Fig. 10). The smallest possible interpolation step was assumed. The angle range, where the simulation has to be done in, was set (in the Kinematics Simulation - Mechanism.1 dialog box).

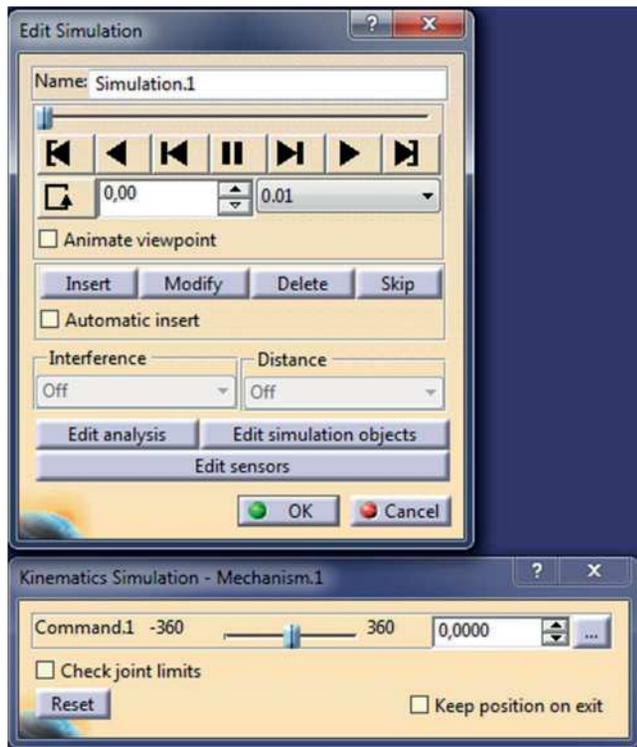


Fig. 10. Simulation creation

Then the simulation was compiled by the Compile Simulation (Fig. 11). The Time Step was assumed possibly small.

In spite of the Time Step name, this step is not connected with a unit of time. That means the all simulation is divided by the step converse (in this case into

a hundred placements). The step can be connected with a unit of time, but in this case it is not necessary. The recording named Replay.1 was created.

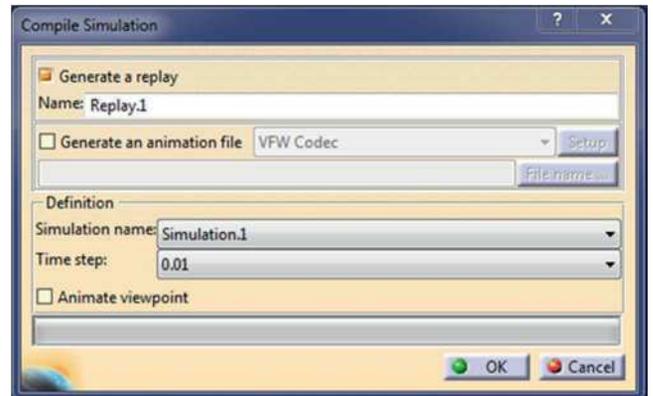


Fig. 11. Simulation compilation

After the simulation to create the globoid helices, the Trace command (Trace) was used. This command, on the basis of kinematic simulation, allows to trace the position of another points and lines. When the tracked object is a line, the result of the Trace command is a set of lines with points describing their ends. In both cases, for the track formed from both the points and the line (splines or cross-sectional lines), it is possible to create the meanders worm surface.

The Figure 12 shows the points and splines formed as a result of tracking points. In the Figure 13 the result of Trace command to follow the line, was shown.

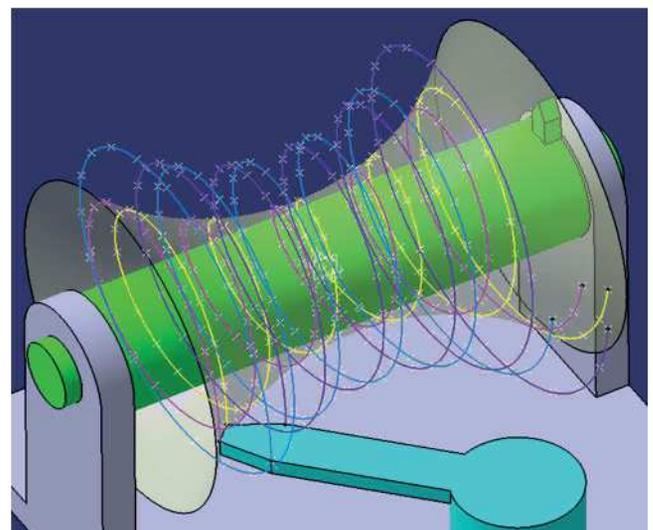


Fig. 12. The created points and splines

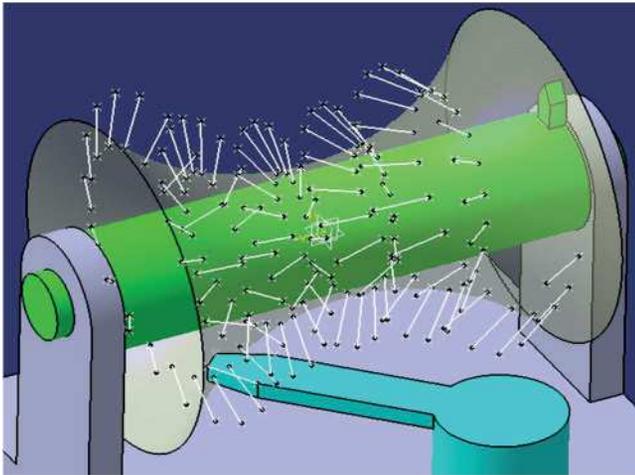


Fig. 13. The trace command to follow the line

3. The work results

Worm gears are the challenge for designers is because of the construction and the functions that must be met, as well. There are few specialized applications to generate this type of gears. The problem is the globoid worm surface modeling. The examples of globoid helical surface in CAD are possible to find on the Internet, but often they are not valid in terms of geometry and they do not reflect the actual geometry. These surfaces are modeled on the helix with uniform pitch but diameter variable only. The worm geometry modeling in the CAD allows to do the analysis of geometric cooperation, strength (by the finite element method), or to make a prototype for the preliminary tests with use the rapid prototyping techniques.

The three methods of the globoid surface modelling, using CAD systems – AutoCAD and CATIA were presented. The modelling was carried out on the example of the worm lateral surface of the globoidal worm gears. In the first presented method the external program, that generates the script commands for AutoCAD system and lets generate the points of the globoid helix, was used. In the following two methods to model helixes, the possibilities of CATIA were used: creating the graph of two-dimension functions and comprising them into tree-dimension function and kinematic simulation, as well.

3.1. The resulted surfaces

In each of the described methods there were created globoid surfaces, which are the basis to create the complete

globoid worm model. This worm is correctly modeled due to the alternating pitch.

The following figures show the resulted example surfaces:

Fig. 14 – globoid surfaces modeled with use of the AutoCAD system and CATIA based on the authorial external program – scripting commands generator,

Fig. 15 – the created globoid surfaces on four globoid helices generated with use of the laws in CATIA,

Fig. 16 – globoid surfaces being the result of the kinematic simulation in CATIA - creating these surfaces is based on the determination of trace point/line during the machining simulation.

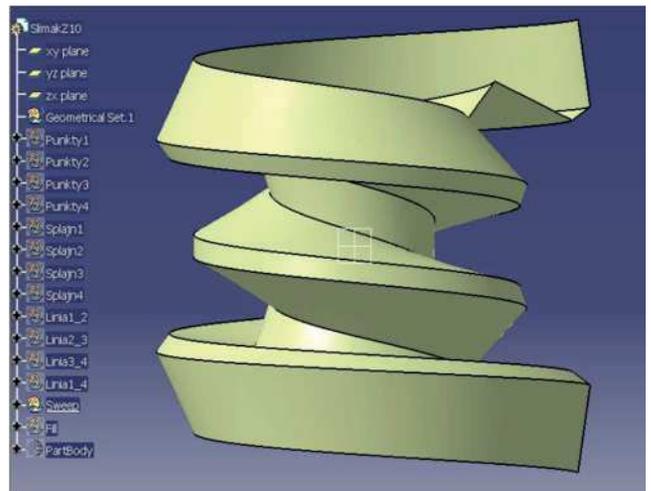


Fig. 14. Exemplary surface of the globoid worm coils – method No. 1

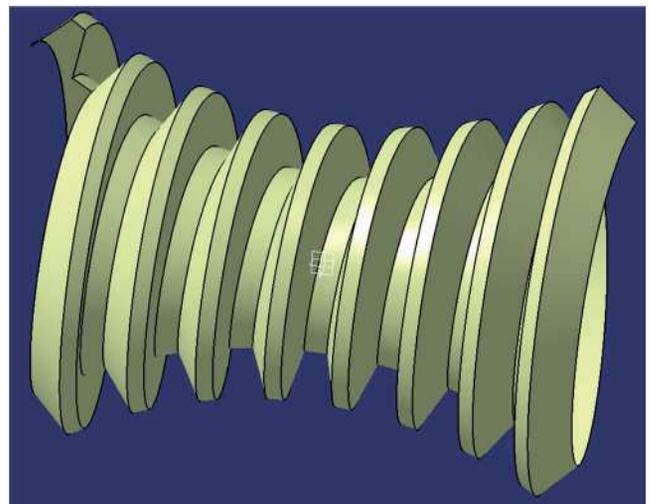


Fig. 15. Exemplary surface of the globoid worm coils – method No. 2

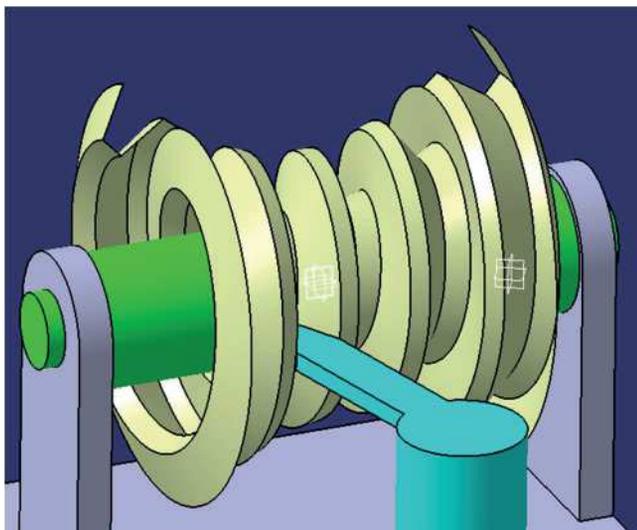


Fig. 16. Exemplary surface of the globoid worm coils – method No. 3

The globoid worm surface modelling is a difficult issue of complex surfaces modelling in CAD.

- 1) The conclusion of the method number 1: The developed methodology is universal, but it requires a lot of work.
- 2) The conclusion of the method number. 2: The presented method allows to create the expecting line in a simpler way than it was shown in the method number 1. The limitation is the length of the worm - the $H < r$ requirement must be fulfilled. Otherwise the $x(z)$ and $y(z)$ graphs are incorrect.
- 3) The conclusion of the method number 3: the use of kinematic simulation allows, in a relatively easy way, to create the complex surfaces that are the results of machining of the tools with straight-line cutting edge. The number of simulation „frames” is the limitation. For greater accuracy, the simulation should be divided into several segments. However, the problem, that happens then, is necessity to splines combine (for tracking the points).

4. Conclusions

The worm gear development, including these atypical ones, requires looking for new solutions in their modelling. The described methodology is universal and allows to generate the globoid lateral-surface of worm on the basis of wormwheel constructional assumption and taken tooth

profile. The proper modelling of worm gear geometry in CAD allows to analyse the geometric cooperation, strength (by the finite element method), or to make a prototype for the preliminary tests with using of the rapid prototyping techniques.

Additional information

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