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New technology for manufacturing quasi-globoid worm gearings

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Abstract. The advantage of the globoid worm gearing, that all teeth of the worm are in mesh in every moment, is well-known. The main advantage of the helical worm gearing, the easy production is also known. The paper presents a new gearing construction that tries to combine these two characteristics in one novel worm gearing. This solution, similarly to the manufacturing of helical worm, applies turning machine instead of the special teething machine of globoid worm, but the path of the cutting edge is not parallel to the axis of the worm but has an angle in the vertical plane. The resulted in form is a hyperbolic surface of revolution that is very close to the hourglass-form of a globoid worm. The worm wheel then generated by this quasi-globoid worm. The paper introduces the geometric arrangements of this new worm generating method then investigates the meshing characteristics of such gearings for different worm profiles. The considered profiles are circular and elliptic. The meshing curves are generated and compared. For the modelling of the new gearing and performing the meshing analysis the Surface Constructor 3D surface generator and motion simulator software application was used.

1. Introduction

One of the most loadable types of gearings is the globoid gearing that has hourglass-like worm. This gearing is famous from its precision and durability. These advantages originate from the very long summated meshing line acting simultaneously [1]. But one of the disadvantages also comes from this property: the high sensitivity of manufacturing and assembly errors [2]. Because of this the production of these gearing requires extra precision which makes the manufacturing expensive. One of the components of the expensive production is the special teething machine that applies a circular motion of the cutting tool for manufacturing the worm as demonstrated in figure 1. Additionally the original Cone-type gearing suffers from an undercut region in the middle of the worm wheel teeth and parallel to surface-surface mesh edge-surface contact also exists [1]. These drawbacks induced many researches that aimed to eliminate the undercut zone. Zhao at al. suggested concave worm profile with grinded surface to achieve better meshing characteristics and to avoid the undercut region [3]. Zhao and Zhang modified the mentioned gearing type with increasing the height of the tool relatively to the unmodified worm and improved such a way the meshing pattern [4]. Utilizing the gathered experience Zhao and Wu developed a universal modification method for the globoid drives [5]. In this modifying effort they performed a strict meshing analysis with numerical computer simulation to exclude the most dangerous contact point from the meshing [6]. Team of Lagutin analysed the load capacity of the new modified globoid drives [7]. The patented shaping method of Wildhaber [8] also eliminated the undercut region.

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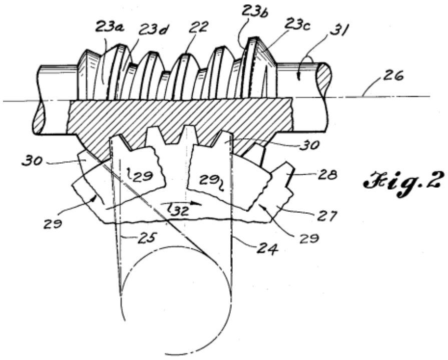

Figure 1. Teething of the Cone-type globoid worm (Figure with the original numbering as given in the patent.) [9].

Some of the improvements like the method patented by Kobayashi (see figure 2) suggested modified technology that applies rotating tool instead of discrete edge resulting in such a way the grindability of the worm [10]. The additional advantage of this solution is that the grinded worm can be more precise and has better sliding features.

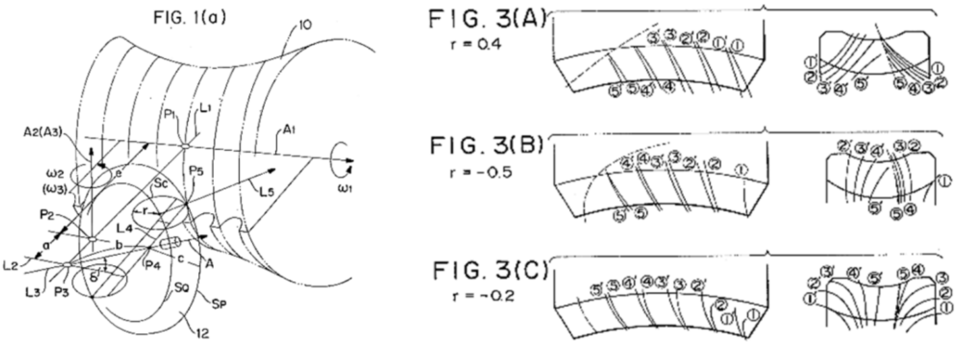

Figure 2. The generation of the worm suggested by Kobayashi applies rotary cutter or grinding wheel and results in advantageous meshing lines (Figures with the original numbering as in the patent documentation.) [10].

Similar investigation was published by Zhao et al. which presented a double-enveloping hourglass worm characterised by point-like meshing. Unfortunately such a gearing has not constant transfer ratio as it applies modified worm wheel, but the error insensitivity is remarkably improved and it works with less noise and vibration [11]. See figure 3.

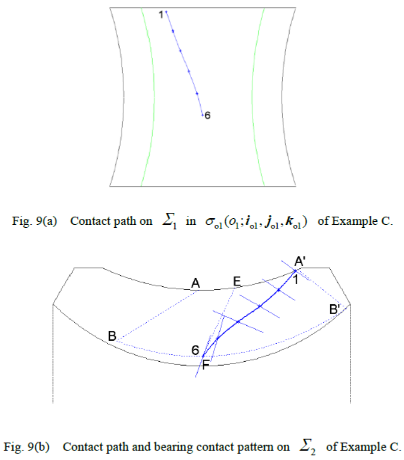

Figure 3. Contact path on the worm and on the gear (Figures are shown with the original captions.) [11].

Though all these investigated gearing types resulted in better meshing properties eliminating the undercut region and the edge-surface contact, they require special teething machine for manufacturing the worm providing circular motion of the tool. The worm wheel can be produced with usual gear hobbing machine.

The need for the expensive teething machine of the worm of the above mentioned gearings induced a new generation method for producing the worm on a normal lathe that has a tilting appliance for setting the linear motion path of the cutting tool. As the form of the worm will be similar to a surface of revolution shape having hyperbolic profile in the axial section, this worm is named quasi-globoid worm. Instead of single edged tool this technology makes possible of using rotary cutting tools like milling tool or grinding tool.

In the following sections the paper will describe the inexpensive generating of the worm and the generating of the worm wheel surface using the worm. The mating characteristics of this new gearing type will be analysed for different cases of the shape of the generating edge. All the surface generations and the analysis of meshing properties through the shape and wandering of the meshing lines will be accomplished by the Surface Constructor (SC) software application [12]. This tool applies the original meshing theory named Reaching Theory of the author [13]. The structure and some of the windows of SC are shown in figure 4 and in figure 5.

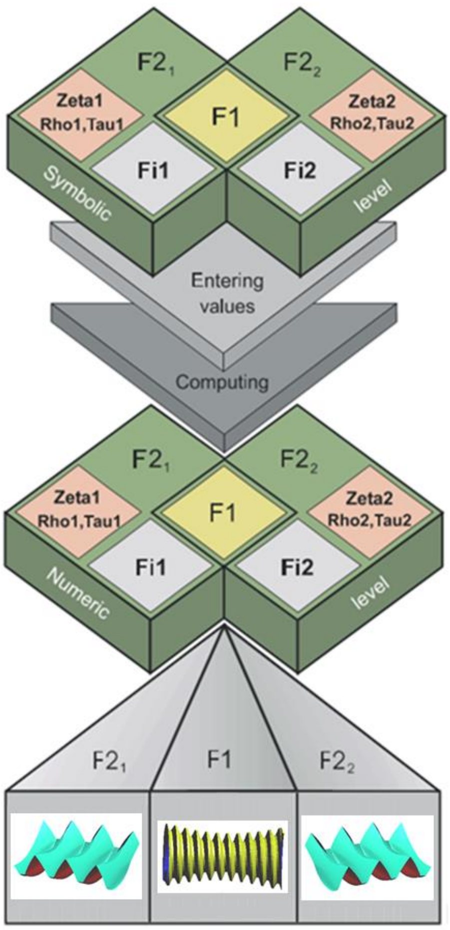

Figure 4. The structure of the Surface Constructor surface generator and kinematic modelling software.

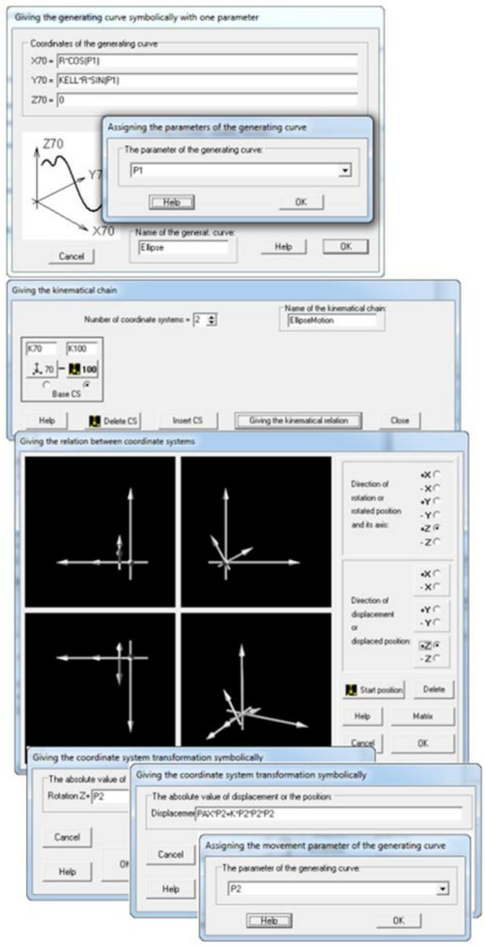

Figure 5. Some windows of the tool for entering a generator curve and the motion of the curve with expressions.

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The application is intended for innovation of machine parts having enveloping surfaces, like gear improvement. SC proved its power many times, e.g. for modelling a patented internal combustion engine having only rotary parts [14]. In the closing part along with the summation of the advantages and disadvantages of the new gearing type a short comparison to globoid and cylindrical gearings also will be given before the future research plans.

2. The generation process of the gearing elements

The generation of the swept by the discrete edge worm surface and the enveloping process of the worm wheel will be presented in this section with the description of the applied coordinate systems.

2.1. Worm surface generation

The advantage of this gearing type is the easy manufacturing of the worm. The manufacturing uses a normal lathe that has some additional parts to provide the relation of the workpiece and the tool as shown in figure 6. The applied co-ordinate systems for the modelling of the worm thread generation are as follows: CS100 co-ordinate system is fixed to the worm, the tool edge is given in the CS70 frame. While the tool moves in z70 direction the edge sweeps the surface of the thread. The hyperbolic head surface is made similarly.

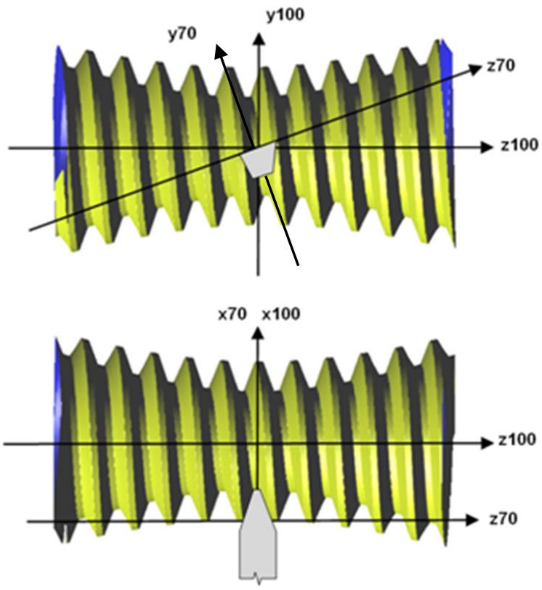

Figure 6. Co-ordinate systems for the worm generation.

The tilting angle can be realised in the practice by shifting the living centre of the tailstock and applying a Cardano-like or CV joint at the driving side or using a tilted tool post slide with a fixture that positions the tool above the workpiece.

2.2. Worm wheel surface generation

The worm wheel surface is made as usual, using a gear hobbing machine and applying radial feed of the hob. For the modelling of the worm wheel tooth surface the SC software is used. In the generating process the worm surface envelopes the tooth surface. All the teeth have same surface, so it is enough to envelope one and then it can be rotated creating the other teeth. The arrangement of the worm and the worm wheel for the surface enveloping is the same as for modelling the working of the gearing. This relation and the used co-ordinate systems are shown in figure 7. The co-ordinate system CS100 fixed to the worm while CS230 frame holds the worm gear surface. The CS201 co-ordinate system is connected to the gear housing. Using the SC software the tooth surface of the worm wheel can be generated. As every worm wheel teeth are similar only a segment having three teeth was generated. See figure 8.

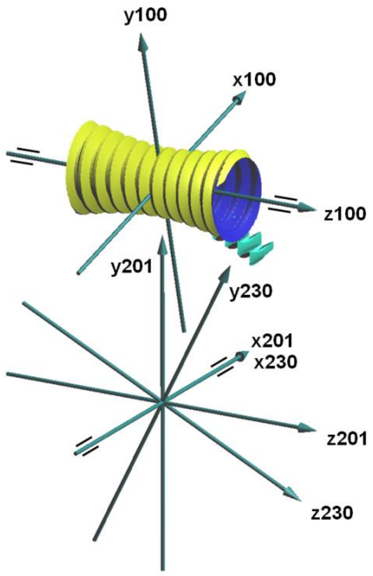

Figure 7. Arrangement of the coordinate systems for the surface generation and for the meshing analysis.

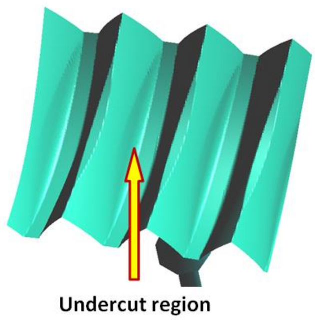

Figure 8. The generated worm wheel segment.

The figure shows that the worm wheel teeth have an undercut region at the dedendum of the gear. It can be eliminated decreasing the base circle diameter. As the shape of the meshing lines is very informative and determines the quality of the mating properties of the gearing, the next step was the analysis of them. For this, three different worm profile curves were used and the results are compared.

3. Analysis of the contact pattern in case of different worm profiles

The results for linear profile revealed that the worm wheel teeth have large undercut region at the foot of the tooth. Moreover the meshing lines were also disadvantageous, almost parallel to the sliding velocity direction, as can be checked in figure 9. In such case the formation of the loadable oil film is almost impossible.

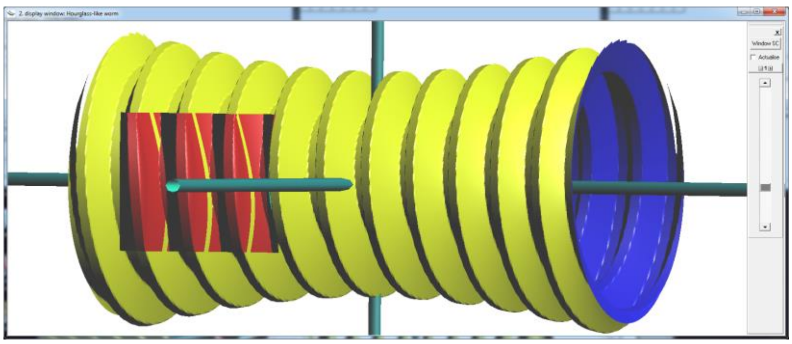

Figure 9. Disadvantageous meshing lines on the gear segment.

The previous practice of the author proved that the circular and elliptical profile curves of the worm result in better meshing line shapes in case of cylindrical worm gearings. Because of this in the following circle and ellipse profile curves will be used for worm generation. After enveloping the mating worm wheel surfaces the contact patterns will be evaluated and the gearings will be compared.

3.1. Circle profile curve in the axial plane of the worm

Similarly to the case that is shown in figure 6 the theoretical circular edge is placed in the x70-z70 co-ordinate plane. As the calculation time for the enveloping process depends on the number of surfaces that used in it, to save time only one side of the teeth was used. Figure 10 shows such a model with the used co-ordinate systems.

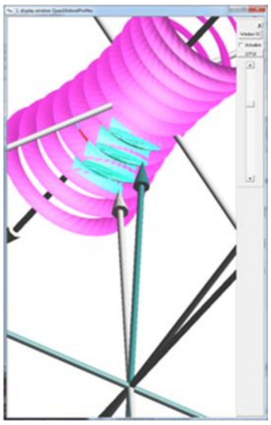

Figure 10. Meshing of the working tooth side surfaces.

In contrast to the expectation the worm wheel tooth side was only generated by the positive half of the worm measured in z100 direction. This happens because of the asymmetric location of the generating motion path to the centrally symmetric helicoids of the threads of the worm. This asymmetric position which bear resemblance to the globoid drive shown in Figure 3 originates from the ALPHA angle measured between z100 worm axis and z70 generating curve translation direction. The axial relocation of the generating edge doesn't modify this characteristic. Figure 11 shows successive phases of the meshing.

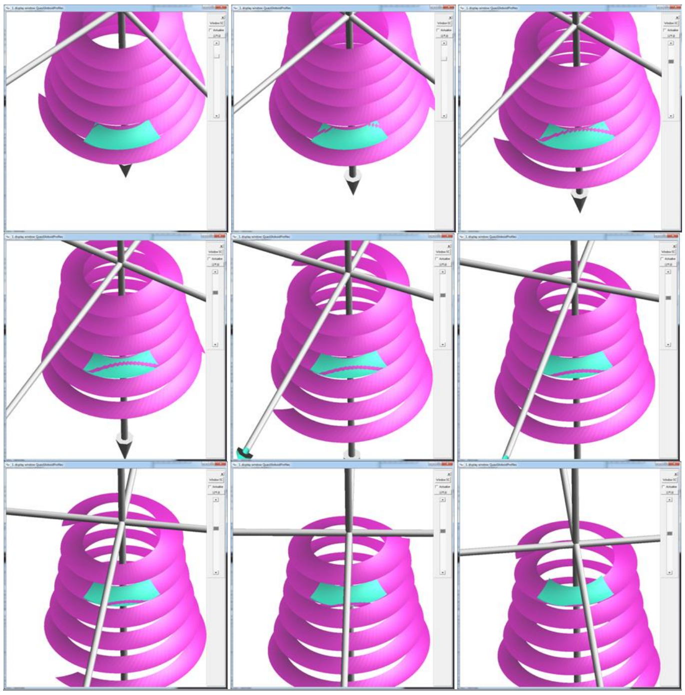

Figure 11. Meshing lines of the mating worm and worm wheel tooth surfaces.

Only the effective positive half of the worm was used. It can be checked that in case of circle profile the enveloped worm wheel, the enveloping worm and the characteristic curve between them show similarity to the helical worm having linear profile form.

3.2. Ellipse profile curve in the axial plane of the worm

The pictures of the mating surfaces of the gearing generated using ellipse profile curve are demonstrated in figure 12. The characteristic lines slightly better curved than the meshing lines of the circular gearing.

Figure 12. The elliptical profile results in slightly more curved contact arcs.

4. Summary

The paper analysed the advantages and disadvantages of today modern globoid worm drives. Every unmodified or modified solution uses the expensive teething machine for cutting the threads of the worm with circular motion of the tool. The paper suggests a novel drive construction that is very similar to the globoid gearings, but uses a normal lathe with a tilted worm holder to cut the threads of the worm. Really this worm has hyperbolic form which is very close to the hourglass-like form of the globoid worms. As the production of such gearings seems to be cheaper it worst to investigate the meshing properties of such a gearing type. The paper accomplished this analysis for three drive types that have worms with linear, circular and ellipse tooth profile in the axial plane of the worm. The modelling was performed with the SC software of the author (see figure 13). The upper three input windows are used for entering data for the generating curve, for the generated worm and for the generated worm wheel segment. The lower seven different visualisation windows are opened at the same time to analyse the motion of the gears and to visualise the wandering of meshing lines during motion. The variations showed that the meshing properties become better if the worm profile is more curved. It was a not expected finding that only the half length of the worm is in contact with the wheel in the meshing. This feature is similar to the meshing pattern of one of the modified globoid drives. The future improvements have to deal with the searching for suitable parameter set and worm profile shape that results in balanced localisation of the meshing lines. Other investigations may apply surface

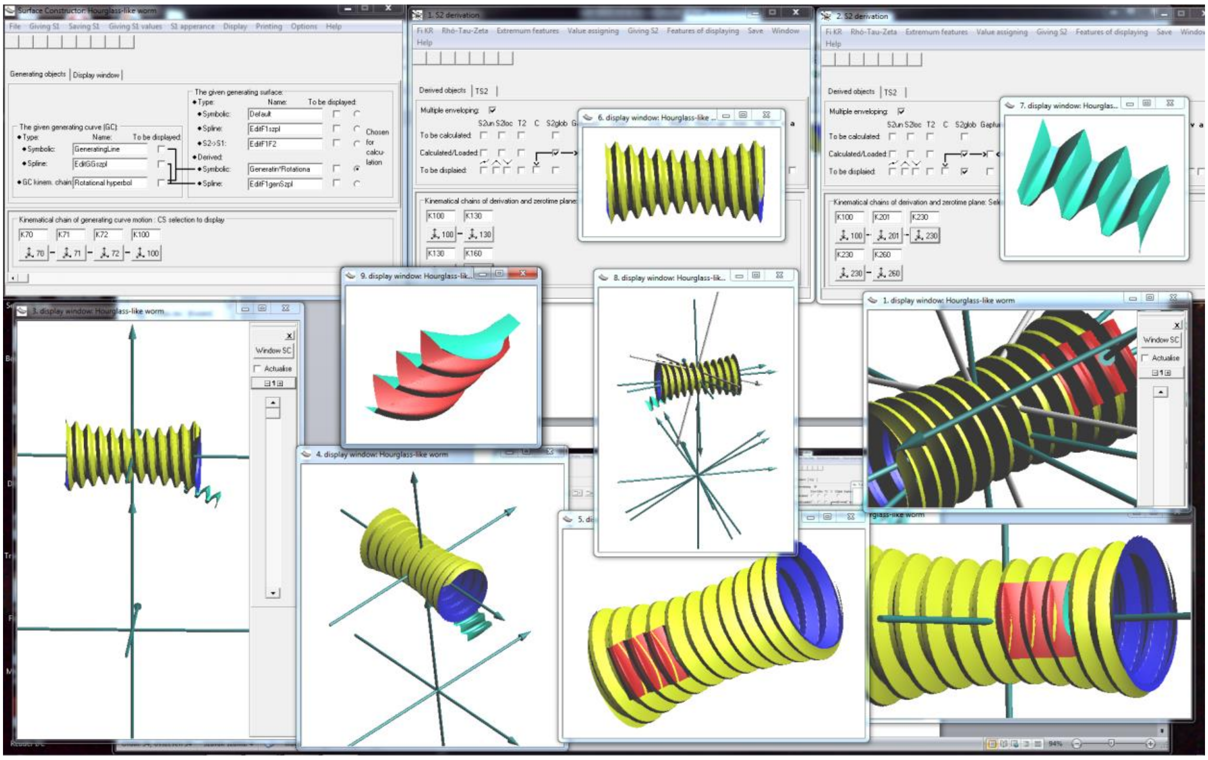

Figure 13. The Surface Constructor tool is in the midst of development.

of revolution tool for the generation of the worm. As this type of worm gearing can be manufactured more easily than the normal globoid types and all the applied profile modifications that can be used for producing cylindrical worms can be used in this worm generation also, it is worth to continue this research and improve the meshing pattern.

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