OPEN ACCESS
Global Journal of Research in Engineering & Computer Sciences
ISSN: 2583-2727 (Online)
Volume 02| Issue 02 | March-April | 2022
Journal homepage: https://gjrpublication.com/journals/
Original Research Article

Simulation of the 3d Model of Worm Gear Using Finite Element Analysis

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DOI: 10.5281/zenodo.6386441 **Submission Date:** 17th March 2022 | **Published Date:** 26th March 2022
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Abstract
The manufacturing of the exact geometry of the worm gear toothing is a complicated issue since the flank surface of the worm gear tooth is a curved surface explicitly indefinable [5]. The accurate geometry of the toothing can be obtained by running the manufacturing simulation application written in Auto Lisp. However, the obtained 3D model shows a flank surface of the tooth which consists of several small surfaces irregularly positioned and sized. To facilitate the FEM analysis using this 3D model is necessary to clean the obtained tooth groove and the flank surfaces. This work deals with the machining of the accurate 3D tooth profile and the reshaping of the 3D model of the worm gear without impacting the accuracy of the obtained geometry.

Keywords: Worm, worm gear, gear toothing, machining simulation, flank surface.

INTRODUCTION

A worm drive (Fig. 1) is a gear arrangement in which a worm, which is a gear in the form of a screw, meshes with a worm gear. The worm and gear drive is the simplest way to obtain a large speed reduction with high torque in a compact space.

The worm and gear set is a kinematical and force relation between cylindrical shafts of skew axes at the location of their shortest secants. The angle of their axes is usually 90°. A worm and gear set is in fact a helical cylindrical gear set where the number of teeth of the driving gear, called worm, is one, two or three, rarely more. The driven component is called the worm gear or gear wheel.

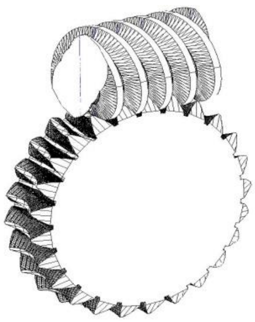

Fig. 1: CAD model of the worm gear set

OBJECTIVES

In spite of the number of investigations devoted to worm and gear set research and analysis, they still remain to be developed. We still need to find out the best manufacturing approach capable of predicting the effects of manufacturing method in gear geometry, contact and bending stresses, stiffness and transmission errors. The geometry of the worm and gear set is a complicated issue. So far, none of the CAD systems contain appropriate tools that would allow the generation of an accurately shaped gear toothing by simply inserting predefined parameters. The aim of this work is to find out methods suitable for modelling the accurate 3D model of gear tooth for the strength analysis by using the Finite Element Method (FEM) on a personal computer.

The Worm Toothing Definition

The worm, which has a profile composed of segments in the section cut with the plane perpendicular to the helical generatrix curve at the center is called general worm. The flank surface of the spline is generated by a helical motion of a straight line skew to the axis of the worm. The exact profile of the thread groove with straight flank can only be generated by a turning operation. In the practice, the ordinary worm is machined by a side and face cutter or a hobbler, so that the tool's rotation axis is skew to the worm axis [1].

The described technology means the machining of the worm thread groove with a conical tool witch's axis is skew to the machined worm axis [2]. The inclination is equal to the climbing angle. It is also common to use the so called shank-type gear shaper cutter for worms with bigger dimensions. This cutter is a conical tool with axis perpendicular to the axis of the machined worm.

The Worm Gear Toothing Definition

The flank surface of the worm thread groove is a helical surface generated by a helical motion of a straight line secant to the axis of the worm. This does not apply to worm gear since a simple helical motion of a straight line cannot define its profile. This particularity makes the manufacturing of the exact geometry of the worm gear difficult. The flank surface is an arbitrary curved surface (Fig. 2).

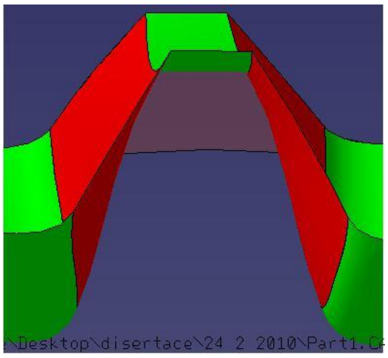

Fig. 2: Flank curved surface

Analytical Definition of the Geometry

One of the possible methods of generating the exact profile of the worm gear toothing is the analytic definition of the toothing. The coordinate of the evolving points and the transition curve can be calculated by a repetitive computing of parametric equations of the evolvement with suitable step of the generatrix. The result of this analytical method could be effective but it is very complicated due to the amount of mathematical equations to solve.

Direct Modeling in Cad Systems

The direct generation of the shape in 3D CAD systems could be the best way to prepare the 3D models for using in software which will perform the computer aided engineering analysis. But 3D CAD systems work in such a way that they use elementary curves and geometry such as segments, spirals, circle, ellipse, etc. and with the combination of operations such as rotation, revolution, sweep, extrude, and Boolean operations, they can generate most of shapes. But for the special case of worm gear, the tooth flank is a curved surface which cannot be exactly defined by any combination of the listed operations, unless we simplify the teeth geometry and substitute some of its part with known elementary geometries. But the obtained result will not provide the exact profile of the gear toothing so this approach doesn't meet the goal of our investigations.

Mathematical Simulation of the Gear Machining

The mathematical simulation of the machining is another possible method but it needs to determine all the coordinates of all points defining the tooth flank shape. This procedure generates the same difficulties as the above mentioned method and is not suitable for obtaining the exact geometry of the worm gear.

Cutting the Worm Gear with a Tool Identical To the Worm

The sought accurate geometry means a shape of the worm gear which can perfectly conjugate with no misalignment at the contact surface. Such an accurate geometry of the worm gear is obtained when the tool used to cut the gear has the same shape as the worm (Fig. 3). The defined technology means the subtraction of a half thread of the worm from the gear blank.

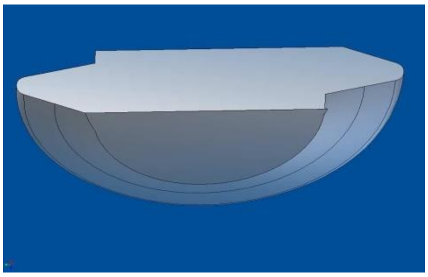

Fig. 3: Tool used to cut the groove

By removing the half thread volume of the worm from the gear blank, the imprint of the worm is left on the blank and this creates the groove which matches perfectly with the worm. After removing two times the thread and creating two adjacent grooves, the remaining part between the grooves represents one tooth. By removing regularly Z time the half thread from the gear blank, we obtain a Z tooth worm gear. To perform the operation, the worm as a tool and the gear blank must be correctly positioned in operating position and both must be actuated by a well-defined motion.

It is also necessary to increase the head diameter of the worm as the tool by the functional clearance Ca (Fig. 4) [2].

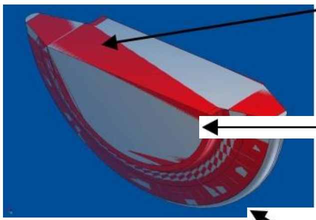

Fig. 4: The worm and the tool shape comparison

PROGRAMMING OF THE MACHINING SIMULATION

The goal of this work is to generate an accurate 3D model by simulating the manufacturing by removing the half part of the worm from the gear blank [2]. To achieve this, it is necessary to write generating program to perform the Boolean operation of subtracting the tool from the blank. The possible environments to use are Math Lab or Auto LISP.

For this work, the Auto LISP was chosen because the 3D model generated after launching the program can be directly converted into known formats such as STP, SAT, IGES, … and edited for other uses. Auto LISP is a dialect of Lisp programming language built specifically for use with the full version of AutoCAD and its derivatives.

Auto LISP is a small, dynamically scoped, dynamically typed LISP dialect with garbage collection, immutable list structure and settable symbols, lacking in such regular LISP features as macro system, records definition facilities, arrays, functions with variable number of arguments or let bindings. Auto LISP code can interact with the user through Auto cad's graphical editor by use of primitive functions that allow user to pick points, choose objects on screen, input numbers and other data.

After setting the geometrical characteristics, both components are positioned at the beginning of the operation so that the tool axis is skew to the wheel blank axis and is progressively subtracted from the blank [4].

The blank rotates around its axis while the tool has a translation motion. The center to center distance is set to a = 230.907 mm and that ensures having the head circle of the worm tangent to the root diameter of the worm gear. Below, there are the main functions in the written program:

“defun prime” define the program file called “prime ”, ‘(setq MODUL 10.0 D2 361.814 ZUBU 36)’ sets the module, the pitch diameter and the number of gear teeth. ‘(setq BOD1 (list X 0.0 0.0))’ defines the start position in local coordinate systems which is 110 mm from the gear axis (Fig. 5).

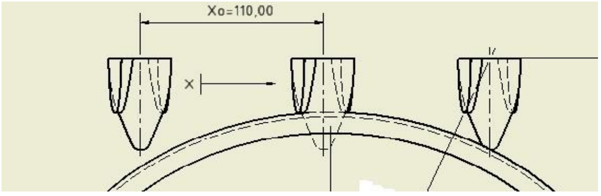

Fig. 5: Relative tool and blank position

As a result after running the program, AutoCAD creates an imprint on the gear blank which represents the groove between two teeth (Fig. 6). This groove mashes exactly with the worm and will conjugate perfectly with it in functional position.

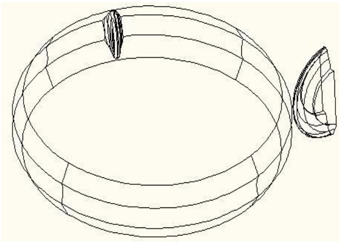

Fig. 6: Tool’s imprint on the blank

Modeling of the Whole 3d Geometry of the Gear Wheel

To obtain the final 3D model of the worm gear we just have to make Z time the circular pattern of the groove. But as the objective of our investigations on the worm gear is to prepare an accurate 3D model for strength analysis purpose by using the finite element method on a classic personal computer, we still have an important piece of work to do on the surface of the generated groove before patterning it. As it is shown on Fig. 7, the surface of the obtained groove is not smooth.

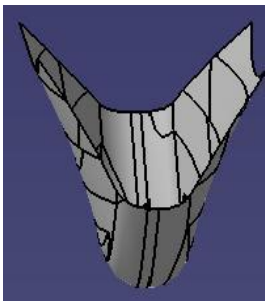

Fig. 7: Isolated groove surface

Auto Lisp created the shape of the groove identical to the worm as it is demanded and realized the Boolean operation of subtraction of the worm from the blank without caring about the quality and the regularity of the surface. The surface is generated by several lines and curves arbitrary positioned to get the demanded shape. When applying a zoom on the areas where the surface curves meet cross we find out that not only the groove surface is made of multiple non-regular small surfaces with arbitrary curves but we can see that some parts of the surface are opened. If we generate the whole gear 3D model with this structure of the groove, it will be impossible to make meshing of the model for strength analysis using the finite element method. The FEM software will display inconsistence error messages or in the best case the meshing and the calculation of such a model will be possible only with a computer with very high memory.

So we need to reshape the groove surface and clean it in order to obtain a much smoother groove surface composed of wide elementary surfaces perfectly connected in line intersections. The goal of this correction is to reduce the number of elementary surfaces to the minimum and at the same time to conserve the form and the dimension of the groove surface.

First of all the, the lines defining the elementary surfaces were brought out and their connection and relative position was studied.

The next step is numbering (Fig. 8) of different vertexes and the reconstitution of the lateral curved surfaces with new curves and lines which lie in the same curved surface as the previous curves.

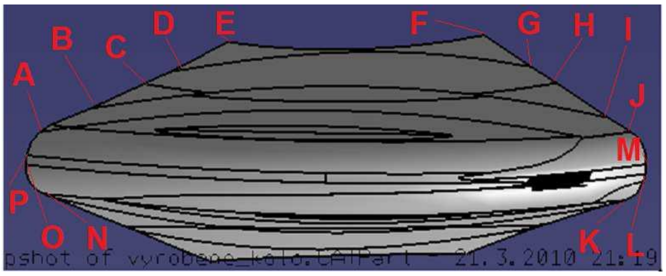

Fig. 8: Flank surface substitution process

The more new surfaces we have, the more the new surface matches with the initial one. During this operation it is not possible to replace the whole initial surface with the new regenerated surface with 100% accuracy. But the errors can be led to the root of the groove, where there is a functional clearance between the worm and the gear according to the gearing definition.

The substitution of the initial groove with a 5 surfaces groove is shown on Fig. 9. The yellow part is the original shape obtained by the manufacturing simulation with Auto Lisp, the grey part is the

Corrected tooth flank made by regular surfaces. There is a geometrical error of 0.001mm on the tooth flank whereas the groove root shows a 0.2mm. The 0.001mm error is acceptable for the flank surface and the 0.2mm error on the groove is negligible comparing the clearance of Ca=2.2mm

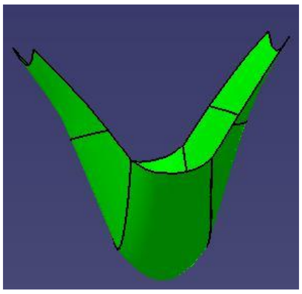

Fig. 9.1: New 5 surfaces groove

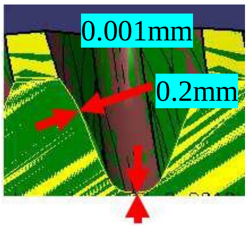

Fig. 9.2: Comparison of the 5 surfaces groove with the initial groove

The whole 3D model of a cleaned worm gear is then obtained by subtracting from the wheel blank a circular pattern made of the groove.

This corrected 3D model is converted by a simple 'save as' to the relevant type of file SAT or IGS or CATpart and can be used for a strength analysis using the finite element method which are representations used to perform the computer aided engineering analysis, they are complementary to the computer aided design which is mainly graphical representation of product. The principle of the FEM leads in meshing (Fig. 10) of the geometry supposed to be calculated. A polygon mesh is often used and it is a collection of vertices, edges and faces that define the shape of a polyhedral object in 3D computer graphics and solid modeling.

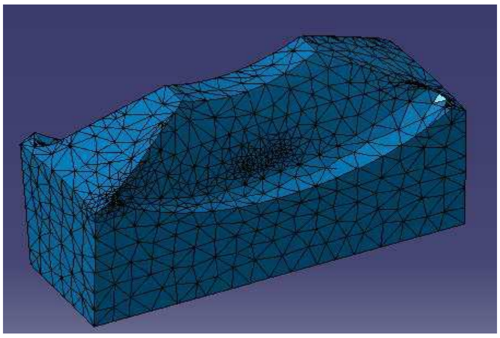

Fig. 10: Polygon mesh applied on the 3D model for FEM analysis

The faces usually consist of triangles, quadrilaterals or other simple convex polygons, since this simplifies rendering. The remodeling of the gear tooth flank surfaces allows the meshing of the 3D model (Fig. 10) and more, this surface reshaping is suitable for localization of the contact surface between the worm and the worm gear for force application.

Conclusion

The 3D geometry of worm gear generated by running the simulation program of the gear machining written in Auto Lisp is very accurate [3]. This method is, indeed, the most appropriate to achieve the required accuracy of the gear toothing. The other methods like the direct generation of the toothing of the gear in CAD systems require a simplification of the shape of the gear. The mathematical definition or the mathematical simulation of the machining are very complicated due to the amount of mathematical equations to solve and the necessity to determinate all the coordinates of all the points defining the tooth shape.

However, the 3D model obtained by running the manufacturing simulation program in Auto Lisp presents a rough tooth flank surface (Fig. 7) which might not be suitable for strength analysis purposes. The flank surface can be cleaned manually or automatically without impact on the shape accuracy [2]. The local errors on the shape can be led to the groove surface where there is a functional clearance (Fig. 4) between the worm and the worm gear.

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CITE AS
Dr. E.N.Ganesh. (2022). Simulation of the 3d Model of Worm Gear Using Finite Element Analysis. Global Journal of Research in Engineering & Computer Sciences, 2(2), 1–6.
https://doi.org/10.5281/zenodo.6386441