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Design and strength analysis methods of the trochoidal gear reducers

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A R T I C L E I N F O

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A B S T R A C T

This paper deals with design and strength analyses of trochoidal gear reducers. At first, design software is developed to conduct geometric design of the trochoidal gear reducers in AutoCAD software surrounding. With the help of developed software, gearing parameters and structural dimensions of the trochoidal gear reducers can be determined very simply. Two-dimensional (2D), drawings of the designed reducers can be drawn by the software automatically. Three-dimensional (3D), drawings of the designed reducers can also be drawn very quickly with 3D commands of AutoCAD software when the 2D drawings are available. The developed software can not only save much time of designers, but also makes it possible for inexperienced designers to be able to design the trochoidal gear reducers freely. Secondly a new mechanics model and finite element method (FEM) are presented in this paper to conduct loaded gear contact analysis of the trochoidal gear reducers in order to solve strength calculation and evaluation problems of the reducers. With the help of the model and FEM presented, it becomes practical to be able to conduct loaded gear contact analysis and strength calculations of the trochoidal gear reducers in theory. FEM software is developed based on the model and method. With the help of the developed FEM software, loads and contact stresses distributed on teeth, bushes and rollers of the trochoidal gear reducers are analyzed successfully. Bending stresses of the trochoidal gear are also analyzed, though it is rare for the reducer to have bending failures.

1. Introduction

Trochoidal gear reducers, usually called cycloid gear speed reducers, have found wide applications in industry robots and other aspects because of the advantages of small backlash, high transmission accuracy, large reduction ratio, high torsional rigidity, great load capacity and high shock-resistant ability. Though it has passed more than 70 years since its invention of the reducer by Mr. *Lorenz Braren* and many units of this reducer have been made and used now, many design problems of this reducer have not been solved so far. Specially, strength calculation methods of this reducer have not been found so far in theory.

Lehman [1] conducted theoretical analysis of tooth load distribution of a cycloid speed reducer. Though tooth load distribution was obtained by Lehman, his method cannot be used in real design of a cycloid speed reducer because structural deformation of the cycloid gear was not considered in his research. Also, loads distributed on bushes and center bearing rollers of the cycloid speed reducer could not be studied by Lehman. Malhotra and Parameswaran [2] also conducted a theoretical study on load analysis and efficiency calculation of a cycloid speed reducer roughly using an analytical method. Like Lehman's research, since the effect of the structural deformation of the cycloid gear could not be considered in their analyses, an accurate distribution of loads on teeth could not be obtained. Of course, the effect of the machining tolerances and tooth profile modification of the cycloid speed reducer on tooth load distribution could not be

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studied. Yang and Blanche [3,4] studied the effect of machining tolerances on backlash distribution of the cycloid speed reducers. Ishida et al. [5] firstly made a try to use commercial software of the FEM to analyze tooth loads of a new type of cycloid gear speed reducer (usually called RV speed reducer [6]). Since a very long time was needed to complete the analysis using the commercial software and it is very difficult to find correct contact states of the teeth and rollers, Li [7,8] developed a special FEM for tooth load analysis of the RV speed reducer based on a very long experience on FEM programming. With the help of the developed FEM software, tooth loads of the RV speed reducer were analyzed very simply and quickly. It also became possible to investigate effects of tooth width, gear size, machining tolerances and loading torque on tooth load distribution of the RV speed reducer [9,10].

Though the above-mentioned studies can be found, the real loads distributed on teeth, bushes and center bearing rollers of a trochoidal gear reducer cannot be analyzed. Of course, it is still an unsolved problem how to conduct strength calculations and evaluation of the trochoidal gear reducer when designing it.

This paper presents a new model and a new FEM to conduct loaded gear contact analysis of the trochoidal gear reducers. Based on the model and method presented, special FEM programs have been developed. With the help of the developed FEM programs, loaded gear contact analyses are conducted and loads distributed on teeth, bushes and center bearing rollers are obtained. Contact stresses on the teeth, bushes and rollers are calculated with the *Hertzian*'s formula and bending stresses of the trochoidal gear are analyzed with FEM when the loads on the teeth, bushes and rollers are known.

2. Typical structure concept of a trochoidal gear reducer

Fig. 1 is a typical structure concept of a trochoidal gear reducer used as an example in this paper. This reducer consists of one external spur gear, 34 pins (also called pin gear), 5 bushes, 5 carrier shafts, 13 rollers and one crankshaft. Since the external spur gear uses the trochoidal curve as the tooth profile, here it is simply called the trochoidal gear. On the trochoidal gear, there are 5 holes used to insert the 5 bushes so, these holes are called bush holes in this paper.

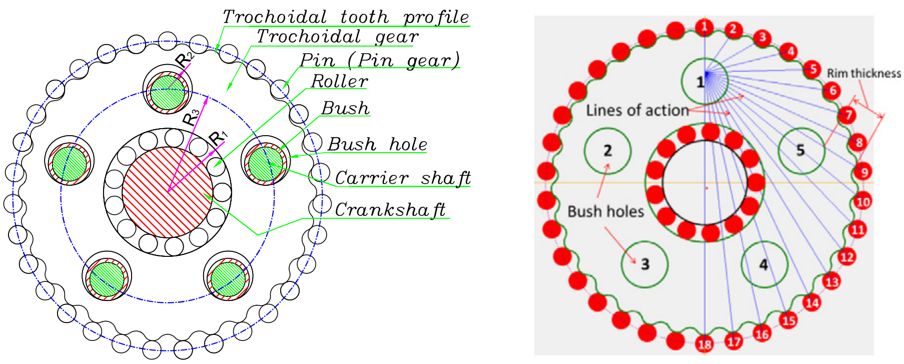
In Fig. 1, the pin gear is used as an internal spur gear to engage with the trochoidal gear. Usually the number of pins is one greater than the number of teeth of the trochoidal gear. The 5 bushes are mounted on the 5 carrier shafts. The bushes are used as the sliding bearings between the carrier shafts and the bush holes. The crankshaft is inserted into the center hole on the trochoidal gear. It is used to produce eccentric movement of the trochoidal gear. The 13 rollers are inserted between the center hole and the crankshaft. They are used as rolling bearing without the inner and the outer rings.

Eccentric direction of crankshaft is defined as an angle between the Y-axis (vertical axis) and the eccentric direction of the crankshaft (the angle θ as shown in Fig. 7). This angle is called *crankshaft angle* in this paper. For the case as shown in Fig. 1, eccentric direction of crankshaft is along the Y-axis. At this case, the crankshaft angle is 0°.

3. Geometric design of trochoidal gear reducers

Based on the principle of kinematics of the trochoidal gear reducer, software used for geometrical design and dimension calculations of the trochoidal gear reducer has been developed successfully in AutoCAD surrounding using the Visual Basic language inserted in AutoCAD software. With the help of the developed software, trochoidal gear reducers can be designed and calculated very simply and quickly. After the design procedure is finished, the designed gear parts or the reducer structure can be drawn automatically on the template of the AutoCAD software.

Figs. 2, 3 and 4 are examples of 2D and 3D drawings of the gears and the reducers designed by the developed software. Fig. 2(a) is a 2D drawing of the designed trochoidal gear. Fig. 2(b) is a 3D drawing of the design trochoidal gear. This 3D drawing is made using 3D commands in the AutoCAD software based on the 2D drawing as shown in Fig. 2(a). Fig. 3(a) and (b) is 2D and 3D drawings of the



(a) (b)

(Crankshaft angle = 0 deg.)

Fig. 1. A typical structure concept of a trochoidal gear reducer.