

Effects of Wear on the Meshing Contact of Worm Gearing

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American Gear Manufacturers Association



TECHNICAL PAPER

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

In this paper, a combination of loaded tests, coordinate measurements, surface reverse engineering and a special finite element method is employed to study the effect of break-in wear on meshing contact between the mating surfaces of worm gearing parts. Three different wheel tooth geometries are investigated in this paper: the as-cut geometry cut by a fully oversized hob, the conjugate tooth geometry generated by the mating worm thread and the broken-in wheel tooth surface. The broken-in wheel tooth is measured with a coordinate measurement machine and reverse engineered. The contact stresses between the worm thread and these three different wheel tooth geometries are studied with the CAPP Software (Contact Analysis Program Package [13]). Based on the obtained contact pressure values, the effects of wear on contact stresses are investigated. It is found that the three maximum contact pressures differ significantly. The contact patterns, the load sharing and the transmission errors are also discussed.

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EFFECTS OF WEAR ON THE MESHING CONTACT OF WORM GEARING

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1. INTRODUCTION

In this paper, a combination of loaded tests, coordinate measurements, surface reverse engineering and a special finite element method is used to investigate the effect of wear on meshing contact of worm gearing. The hob used to cut the worm wheel can be viewed as a replica of the mating worm. In practice, the hob cannot be made exactly the same as the worm and it differs from the worm not only in having a larger outside diameter to produce clearance between the worm tip and the wheel root area, but also with a larger pitch diameter to allow re-sharpening. The difference between the hob diameter and the worm diameter is called the hob oversize. After each re-sharpening, the oversize decreases and the hob has to be replaced prior to the oversize reaching zero. Two extreme cases of the wheel teeth are cut by two extreme dimensions of the hob:

As-cut geometry: defined as the shape of the wheel tooth cut by a new hob with full oversize. The as-cut geometry of the wheel is determined by the design geometry of the hob and the corresponding hobbing setup.

Conjugate geometry: defined as the shape of the wheel tooth generated by the mating worm (viewed as a hob with zero oversize). The conjugate geometry is determined by the design geometry of the worm and the corresponding meshing setup.

In the literature, the as-cut geometry of the wheel is often used by researchers on kinematical aspects [1, 2, 3, 4] while the conjugate geometry is used both on kinematical [5, 6, 7, 8] and on load and stress calculations [5, 9, 10]. Because neither of these two extreme cases represents the actual geometry of the wheel, it is not appropriate to use either of these two surfaces to do contact stress calculation. It is not a surprise that the contact stresses found by Narayan [11] and Narayan et al [12] based on the as-cut geometry are significantly higher than those estimated based on the conjugate geometry [10]. In this paper, a third geometry is introduced:

Broken-in geometry: Due to considerable wear on the wheel teeth during the break-in period of a worm gearing mesh, the wheel tooth topography experiences significant change during this stage. At the end of the break-in period, the contact area is increased and the contact pressures are reduced to a level where the lubricant film is strong enough to separate the two mating surfaces. From then on, the wear rate slows down and the wheel tooth geometry becomes stable. This shape of the wheel teeth is referred as the broken-in geometry in this study.

A worm gear drive test rig was built to introduce break-in wear. The wheel tooth surface after the break-in period was studied through reverse engineering, wherein best fitting is used to define the measured broken-in tooth surface. For the above three geometries, the contact stresses are analyzed with the CAPP Software (Contact Analysis Program Package [13]). Finally, the effect of cumulative wear on contact characteristics is investigated.

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2. CAPP PROGRAM AND TEETH MODELING

CAPP is a Contact Analysis Program Package developed by Vijayakar [13]. CAPP uses finite quasi-prismatic elements to model the gear teeth [14]. Its approach is to combine the finite element model with an elastic half-space model [15]. The finite element model is used to obtain gross deformations of the gear away from the contact zone, while the elastic half-space model is used to obtain relative deformations within the contact zone. The finite element deformations are then 'matched' with the local deformations in a least square sense. In order to use the elastic half-space formulae for the local deformation, the contact zone is discretized into a contact grid consisting of many small cells. The contact pressure is assumed to be constant over each individual cell, and the local deformations due to the load on a cell is obtained by numerically integrating the Bousinesq solution over that cell.

CAPP reads in the tooth geometry through a finite element 'mesh file' for each gear [13]. A mesh generator is needed for each type of gear in order to generate the 'mesh file'. Two mesh generators were written, one for the worm tooth and the other for the wheel tooth. The explicit wheel tooth equations derived in [16] are used to calculate the wheel teeth. The finite quasi-prismatic elements used in CAPP require the modeled gear teeth to be smooth along the face width directions. The top boundary of the wheel tooth forms two sharp corners at positions B and C (Fig. 1) when the throat edge intersects the top edge. While CAPP is capable of modeling this kind of discontinuity by dividing the tooth into three portions [11], this practice is less efficient in computation. A different approach was attempted in which the whole top edge was fit by a fourth order polynomial (shown in Fig. 1). This model provides unlimited order of continuity along the top edge.

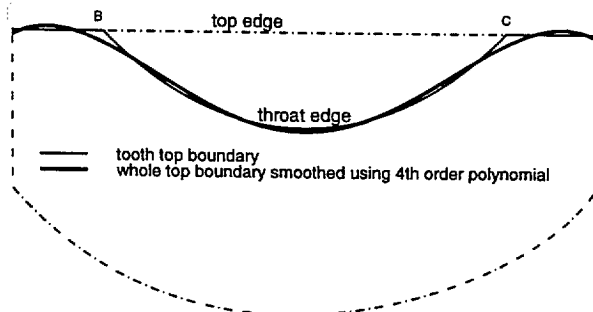


Fig 1. Modeling of top edge of a wheel tooth.

For the study of wear effects, a four-threaded ZK type of worm gear drive was used. Four pairs of teeth were modeled for the finite element analysis. The finite element models of four worm teeth and

four wheel teeth used by CAPP are shown in Figs. 2 and 3, respectively. The four teeth are numbered as tooth 1, 2, 3 and 4 from top to bottom for both the worm and the gear. Figure 4 shows the grid of cells generated by CAPP in potential contact areas after the two gear models are assembled at one meshing position (only the wheel is shown in this figure).

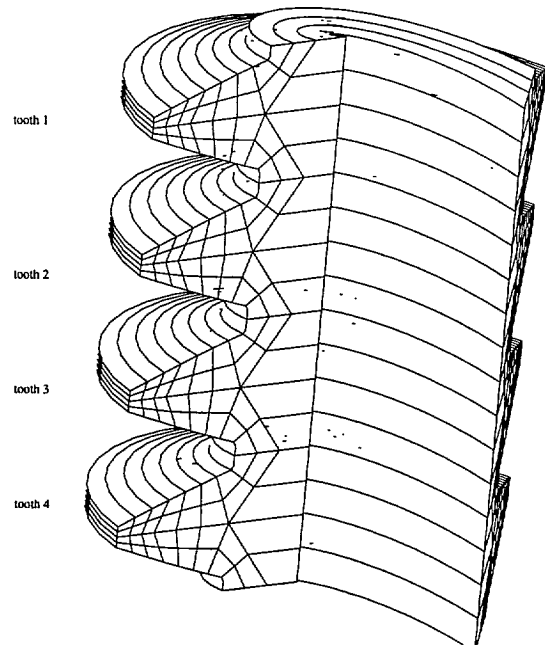


Fig. 2. Finite element model of four worm teeth.

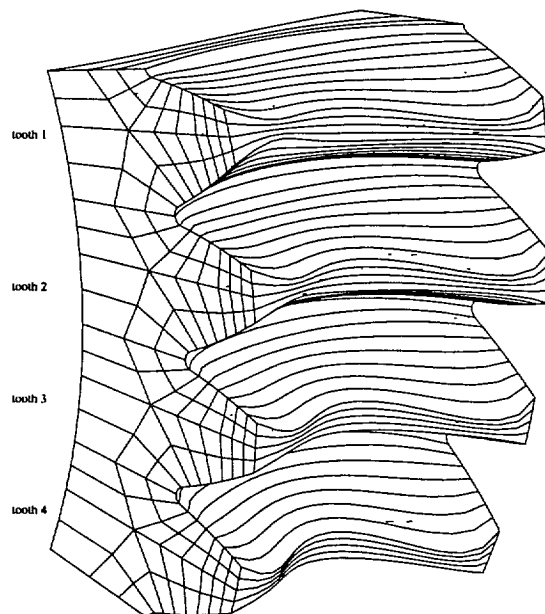


Fig. 3. Finite element model of four wheel teeth.