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Effects of Axle Deflection and Tooth Flank Modification on Hypoid Gear Stress Distribution and Contact Fatigue Life

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Hai Xu, Jay Chakraborty and Jyh-Chiang Wang, Dana Holding Corporation

[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

As well known in involute gearing, perfect involute gears never work perfectly in real world. Flank modifications are often made to overcome the influences of errors coming from manufacturing and assembly processes as well as deflections of the system. The same discipline applies to hypoid gears. This paper, first of all, presents an approach on validating FEA predicted axle system deflections. Next, influences of axle deflections and typical flank modifications (lengthwise crowning, profile crowning and twist) on contact pattern and stress distribution of the hypoid gear set are simulated by using an example face-hobbed hypoid gear design. Finally, two groups of experimental hypoid gear sets are made with two different designed flank modifications. Actual tooth surface topographies are examined by using a Coordinate Measuring Machine (CMM) to assure the desired flank modifications are achieved. These experimental gear sets are tested to investigate the impact of flank modifications on actual gear life cycles. Test results of the sample gears are reported to illustrate the effect of tooth flank modifications on contact fatigue life cycles.

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Introduction

Hypoid gears are widely used in many applications, such as axles and All/Four-Wheel-Drive transmissions for on and off highway vehicles. Recent studies on hypoid gearing are found in the subject of tooth surface generation and contact analysis of hypoid gears manufactured by face hobbing process [1–4], noise [5] and dynamics [6], friction and efficiency [7–8], wear [9–10], lubrication [11], as well as lapping and super-finishing [12]. For a hypoid gear drive applied in heavy vehicle axles, the durability has been the primary concern. Axle deflections have a significant impact on gear tooth strength [13] while axle deflection data are typically obtained through experimental measurements of a loaded axle under certain controlled condition [14]. Unexpected deflections can cause severe edge loading that is detrimental to gear surface life as well as noise performance. As well known in involute gearing, perfect involute gears never work perfectly in real world. Flank modifications are often made to overcome the negative impacts of errors coming from manufacturing and assembly processes as well as deflections of the system. The same discipline applies to hypoid gears. For heavily loaded hypoid gears, flank modifications are particularly critical to achieve required durability performance under relatively large axle deflections [4]. There are basically three types of flank modifications, namely profile crowning, lengthwise crowning and twist [15]. For hypoid gears, in addition to tool geometry and basic machine settings, higher order machine settings are also very important to achieve desired flank modifications [15–16].

The objective of this paper is to study the impact of axle deflection and tooth flank modification on hypoid gear stress distribution and contact fatigue life. Firstly an approach to validate axle system deflections will be proposed. Secondly, by using computer programs and an example face-hobbed hypoid gear design, influences of axle deflections

and typical flank modifications on contact pattern and stress distribution of the hypoid gear set will be simulated. Finally, several experimental hypoid gear sets are made with two different designed flank modifications. These samples are tested under high cycle fatigue drive side only condition in an axle assembly to investigate the impact of flank modifications on actual gear life cycles.

Methodology

Axle deflection

Axle deflection is one of the most critical information for design and analysis of hypoid and spiral bevel gear drives. Axle deflection is commonly defined, as shown in Figure 1, in terms of E , P , G and α , which are normally derived from experimental measurements. Positive E , P , G and α represent deflections under certain load condition that would enlarge pinion offset, pinion mounting distance, gear mounting distance and shaft angle, respectively. Many gear design and analysis software have been developed and are commercially available today that take a predefined set of E , P , G and α to describe the rigid body motions and incorporate them into gear contact analysis to simulate the loaded contact characteristics of the gear drives.

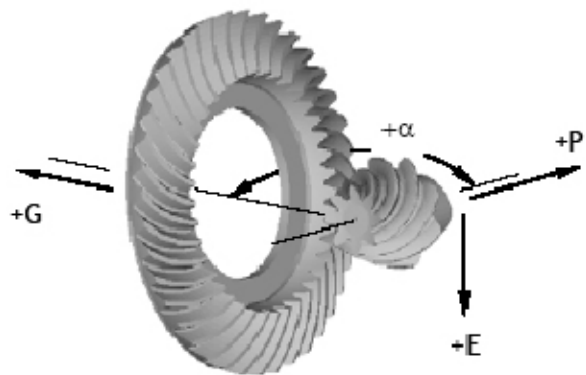


Figure 1. Definition of E , P , G and α

Without knowing the deflections of the axle for which the gears are designed, an ideal gear design on paper or a perfect development showing on loose gear set may possibly lead to poor performances in axle assembly, such as excessive gear tooth wear, low fatigue or impact life cycles, unacceptable noise and dynamic behaviors. Before a physical axle is built, numerical or analytical method is the only way to estimate the deflections. In this study, an FEA model is created using ANSYS as shown in Figure 2. The predicted deflection data need to be validated or corrected.

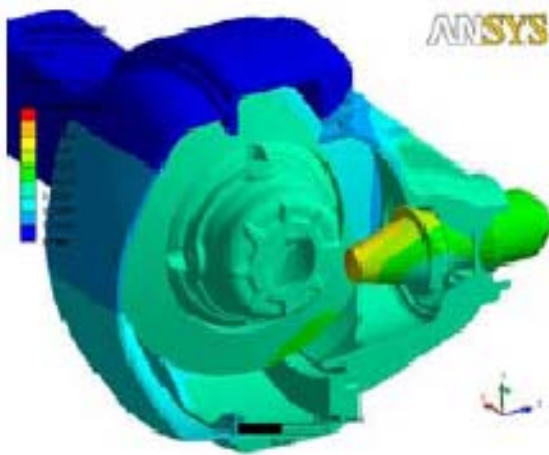


Figure 2. FEA model of an axle deflection analysis

Experimental measurement of the axle deflection is the conventional approach to validate the FEA predictions. With the availability of a physical axle, actual measurement can be conducted. In this study, measurements are taken based on the procedure that is similar to Gleason's procedure [14]. Figure 3 illustrates the setup used in this measurement. However, this type of measurement is very costly and time consuming. Furthermore, measured results for a particular axle do not apply to other axle models or the same model but with different configurations. It is not practical, if not possible, to repeat the measurement across different axle models or different configurations. To overcome these disadvantages, in this study, an indirect approach is proposed to validate the FEA predicted deflections.



Figure 3. Experimental measurement of an axle deflection

It is known that axle deflections will alter gear contact patterns in terms of contact area size, contact path, positions and shapes on tooth surfaces as well as transmission errors. In other words, under certain controlled conditions, variations of contact patterns for a gear set are the direct responses from axle deflections. This led to the idea to use computer simulations with FEA predicted deflections to compare simulated contact patterns to the ones from actual loaded contact tests. If, under the same load condition, the simulated contact patterns agree with the actual patterns obtained from loaded contact tests, then one can consider that the deflection data predicted from FEA are valid. If not, the FEA model needs to be refined. This is also a development process to achieve a valid FEA model for axle deflection analysis. In this study, the validation is carried out following the procedures described below:

- 1) Conduct loaded contact test per Dana Commercial Vehicle System procedure. In this study, perform loaded contact tests at five loading conditions, i.e. No Load, 25% of Full Load, 50% of Full Load, 75% of Full Load and 100% of Full Load. Pictures of the contact patterns under these loads are recorded as shown in Figure 4(a'-e');
- 2) Use a computer program (LTCA, Loaded Tooth Contact Analysis) to simulate the contact patterns under the same five levels of loads.