Research Status Update

Submitted to

AGMA Foundation

April 17, 2008

Development of a Generalized Mechanical Efficiency Prediction Methodology for Right-angle Gear Pairs: Phase II

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Background

Efficiency of spiral bevel and hypoid gears has been a main concern for automotive, aerospace and industrial gear train producers. Such gear pairs experience significant relative sliding at their meshes resulting in mechanical efficiencies far below their parallel-axis counterparts. Given their complex geometry and numerical challenges in contact and stress analyses, theoretical investigations on efficiency of hypoid gears had been very limited. In 2004, a one-year research project proposal was submitted on this subject matter to the AGMA Foundation and the Foundation decided to fund it. This phase I project focused on developing a new friction coefficient model based on an elastohydrodynamic (EHL) theory and a hypoid gear an efficiency computation module that combines this friction model with a commercially available loaded hypoid gear contact analysis model to predict mechanical efficiency losses of hypoid gear pairs. Results of the year-1 project were documented in a final report submitted to AGMA Foundation and were presented to gearing community in the form of papers in AGMA Fall Technical Meeting, ASME Power Transmission and Gearing Conference and sponsors meetings of the Ohio State Gear Consortium.

Upon successful conclusion of the Phase I study, we proposed a Phase II project to focus on performing detailed design and manufacturing parameter sensitivity studies to identify and rank order the key parameter influencing hypoid efficiency, developing new hypoid contact model based on the current LDP formulation that is faster computationally and developing optimization schemes for designing hypoid gear for maximized efficiency. AGMA agreed to support this Phase II study as well.

Research Plan

This project proposed development of a general-purpose simulation methodology to predict the mechanical efficiency of hypoid and spiral bevel gear pairs. Also as a part of this study, the efficiency prediction models were proposed be used to describe the influence of:

(i) operating conditions such as torque transmitted and speed,
(ii) basic design parameters such as shaft offset, face width, etc.,
(iii) lubricant parameters and temperature,
(iv) tooth surface roughness parameters, and
(v) gear pair assembly, mounting and manufacturing errors

on mechanical efficiency of right-angle (spiral bevel or hypoid) gear pairs in order to determine the key parameters impacting efficiency and to arrive at design guidelines for improved efficiency.

The objective of this Phase II study was to investigate the influence of operating conditions, basic design and lubricant parameters, tooth surface roughness parameters, and assembly, mounting and manufacturing errors on gear efficiency to arrive at a set of guidelines on how to design, machine and assemble right-angle gear pairs for maximized efficiency. The Phase II year focuses on the streamlining the model to minimize the computational effort so that such extensive parameter studies can be performed to arrive at design guidelines on how to increase mechanical efficiency of a hypoid gear pair.

Current Status and Next Steps

The Phase II project to date focused on development of the computationally efficient hypoid gear contact model intended to replace the finite-elements based contact model used in Phase I. Towards this goal, the following tasks have been accomplished:

- Geometries of gear and pinion have been derived from cutter geometry parameters, machine settings and basic design parameters. As the two most common manufacturing methods used to cut hypoid gears, face-hobbing and face-milling, are fundamentally different, both processes have been simulated separately to obtain an accurate description of tooth surfaces.
- A robust procedure for performing unloaded tooth contact analysis (TCA) of a hypoid gear pair has been developed using a novel approach based on ease-off principles. This approach is more robust and accurate than the conventional method with no risk of numerical problems.
- A tooth compliance model has been developed based on the shell theory. This new model includes Hertzian, bending and shear components of the tooth deflections. It is several orders of magnitude faster than the finite elements method. This method has been shown to compare well with the finite element based model used in Phase I study.
- A loaded tooth contact model of the hypoid gear pair has been developed by combining the unloaded TCA with the tooth compliance model to predict the load distributions and loaded transmission error of both face-hobbed and face-milled systems.

The current activity focuses on importing this new contact model into the hypoid gear efficiency methodology that was developed during the Phase I study. We expect to finalize this task by July 2008 and proceed with extensive parametric studies of the influence of various parameters on hypoid gear efficiency.