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Contractor Report

COMPUTATIONAL GEARING MECHANICS

NSG-3188

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ABSTRACT

This is an expository report summarizing the research efforts and results under NASA Grant NSG-3188 to the University of Cincinnati. Since the grant has now ended this report also serves as a final report for the grant. The focus of the research has been computational gearing mechanics. Research on gear geometry, gear stress, and gear dynamics is discussed. Current research and planned future efforts are also discussed. A comprehensive bibliography is presented.

This report summarizes research activities conducted at the University of Cincinnati with the support of a continuing grant from the National Aeronautics and Space Administration (NASA), Lewis Research Center with grant number NSG-3188. The initial grant was awarded in 1978. The grant concluded in December 1991.

The report is divided into four parts summarizing the principal phases of the research including current and planned future efforts. The references at the end of the report summarize the findings of the research.

I. GEAR GEOMETRY

Initial research efforts focuses upon gear tooth geometry - particularly as encountered in spiral bevel gears. The interest in the geometry of these gears stems from several factors:

1) Spiral bevel gears are integral parts of helicopter transmissions. Their performance, reliability, and life are critical to the successful operation of the transmissions.

2) Spiral bevel gears are among the most advanced and most sophisticated of precision power transmission elements. They are intended to transmit power through orthogonal, intersecting shafts with a minimum of backlash, vibration and noise.

3) Slight changes in the tooth surface geometry of spiral bevel gears can have significant deleterious effects upon gear performance, reliability, and life.

4) In spite of a widespread use of spiral bevel gears over a long period of time, their geometry is not well understood in either an analytical or an empirical sense. Indeed, in the manufacture of spiral bevel gears for service gear tooth modifications is frequently required for smooth operation of the gears.

5) Many spiral bevel gears are fabricated with geometries different than an "ideal" geometry which would evolve from involute spur, helical, and straight bevel gears.

6) If the tooth geometry of a spiral bevel gear is distorted wither by errors in fabrication or due to loading, the conjugate nature of the meshing kinematics is disrupted leading to vibration and noise.

Research results describing and quantifying this geometry are documented in References [J1, J2, J3, J7, P1, P2, P6, R1, R3, R8, D3]*. These results are based primarily on geometrical

*Numbers in brackets refer to the references.

analyses using vector methods and the principles of differential geometry. The results demonstrate both the complexity of the surface geometry as well as the sensitivity of the geometry to slight changes in position and orientation.

More recently, the research produced a new numerical, computer-graphic procedure for studying tooth geometry. This procedure uses I-DEAS software developed by the Structural Dynamics Research Corporation (SDRC) [P4, P7, P8, R8, R10, R13, T2, T3, D1, D3]. The procedure is conceptually quite simple: The gear fabrication is modelled and simulated using computer graphics. Specifically, the cutting tool and gear blank are represented by solid models. Then the impression on the gear blank model by the penetrating and intruding cutting tool model is a model of the gear tooth. That is, the movement of the simulated tool into the blank produces a simulated tooth surface just as the tooth surface would be physically developed. This simulated surface is then a numerical representation of the gear tooth which in turn can be used for kinematic, dynamic, and strength studies.

II. STRESS ANALYSIS

A second phase of the research was stress analysis - ranging from the evaluation of root and fillet stresses [J4, J6, P3, P10, R2, D1] to contact stresses [P12, R11, R12, R14, D5, D6, D7]. The research produced what was perhaps the first documented finite-element stress analysis of gear teeth in the technical literature in the public domain.

These stress analyses have in turn produced a series of computer programs and software for gear stress computation under a variety of loadings and geometries. The focus of the programs which have been developed to date has been the computation of root and fillet stresses for spur gears and straight bevel gears.

A more difficult analysis is involved in the computation of contact stresses. The finite-element method (FEM) is not very well suited for contact stress analysis due to the large stress gradients (stress variation) in the vicinity of the contact region, and due to the a priori unknown extent of the contact area. More effective procedures for evaluating contact stresses have been obtained using the boundary element method (BEM) [P10, D5] and a recently developed method using point-load superposition of fundamental solutions from the theory of elasticity [P12, R11, R12, D7]. (This latter procedure was initially developed for studying wheel/rail stresses in railroad cars.) The procedure has efficiently produced accurate results for a wide variety of gear geometries. The development and application of the method is continuing at the time of this writing.

III. GEAR DYNAMICS AND VIBRATIONS

A third phase of the research focused upon gear and shaft vibration and dynamics [J5, J8, J9, J10, P5, R4, R5, T1, D2]. This research was conducted primarily by Hsiang-Hsi (Edward) Lin who is currently at Memphis State University. The research initiated at the University of Cincinnati (under Grant NSG-3188) has led to separately supported research with Professor Lin at Memphis State University.

The results of this research have produced new insights into gear and transmission vibration which had not been aired previously in the public domain technical literature.

IV. CURRENT RESEARCH AND PLANNED RESEARCH

Although the monetary support for the research under Grant 3188 has ended, the research effort is continuing. The current work is focused upon the further development of the computer-graphic/finite-element analysis of gear stresses. Using recently developed software it is now possible to simulate meshing gears with an animation of the stresses and deformations of the gear teeth as they pass through mesh.

The current work also includes the further development of the point-load superposition method with an attempt to accommodate general geometries under various friction conditions.

Computer programs and user manuals are concurrently being developed.

Future research will involve the further application of these methods with an emphasis upon tooth profile modification for improved precision, strength, and reliability. The objective is to have ideal geometry when the gears are under load.

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