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A Boundary Element Procedure for Predicting Helical Gear Root Stresses and Load Distribution Factors

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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:

A method to accurately predict gear root stress for parallel axis gears is explored using a combination of three analysis techniques: boundary elements, elastic body contact analysis, and the moment-image method. The method is computationally faster than three-dimensional finite element programs and avoids the use of semi-empirical relationships. The three techniques are combined to determine gear root stress across the face width and predict these stresses through the mesh cycle for both spur and helical gears. The method allows the user the flexibility to determine stress at any mesh position. This is in contrast to semi-empirical methods that typically determine stress for a single load position in the mesh cycle at a single stress location on the gear tooth. The root stress predictions are compared to both experimental strain gage results and finite element modeling techniques for verification. Results are presented for the prediction of load distribution factors as a function of misalignment and crowning types with comparisons being made with AGMA factors.

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Nomenclature:

The following nomenclature is used in this paper:

(x, y, z) = Cartesian co-ordinates
 a = width of plate/gear
 h = thickness of plate
 c = distance of load from clamped edge
 $\left(\xi = \frac{x}{a}, \eta = \frac{y}{a}, \zeta = \frac{c}{a}\right)$ = dimensionless co-ordinates
 M_x = bending moment
 F_w = face width
 l = load Height
 t = base tooth thickness
 $\sigma(y)$ = stress across face width
 $K\sigma_{bem}(x)$ = boundary element stress factor
 K_x = normalized moment term
 G = tooth stiffness constant
 p_b = transverse base pitch
 W_t = transmitted tangential load
 e_t = total lead mismatch
 C_{mf} = face load distribution factor
 K_m = load distribution factor for bending strength
 Z = transverse plane length of action

Introduction:

The objective of this study was to develop a computationally fast method to accurately predict gear root stresses based on the true tooth shape estimated from the gear cutter geometry. The methodology combines three classical techniques: gear tooth contact analysis, moment-image method, and boundary elements. The unique combination of these methods allow gear root stress to be estimated at any tooth radius for any mesh position. Typical stress prediction methods give stress at a single mesh position for particular load heights and stress radii. The advantage of this technique is its ability to estimate the load distribution and stress across the face width of the gear so the

gear stress sensitivity to gear errors and tooth modifications can be explored.

The three classical techniques mentioned previously have been shown to predict gear deflections, load, and stress adequately for many cases; however, each alone does not fully describe the stress condition through a mesh cycle for stresses at any location across the face width. One can develop three-dimensional models of geared systems and use finite element techniques, though model development time and computational intensity can be extreme, and contact conditions are seldom modeled properly.

The presented stress predictions are results of existing computer programs developed for general gear analysis. These programs include the Load Distribution Program (LDP) that predicts loading across the face width for multiple mesh positions and the post processing program GGRAPH. The stress determination technique can be applied with data from any load prediction technique of a gear pair. This technique does not replace finite element techniques for very accurate three dimensional states of stress but provides an approach that is fast, yet not constrained by empirical limits.

The following sections present the developed technique and compare the computational results with experimental strain gage results and three-dimensional finite element results. Further comparisons are made with AGMA factors and show load distribution factors and stress factors as functions of misalignment and crowning types. The study of load distribution and root stress changes with respect to types of gear errors and modifications demonstrates the sensitivity of gear stress to these factors.

Background:

The computational method to predict gear root stress is based on the work by Jaramillo [1] for thin cantilever plates with constant thickness and infinite length. The series solution for bending moments is based on the deflections due to point loads at arbitrary heights on the cantilever plate. The application of the plate theory to gear stresses was proposed by Wellauer and Seireg [2] for the prediction of bending moment distribution for plates of finite length. They proposed that the moments reflect at the edge of the tooth, causing higher summed