

Contact Analysis of Gears Using a Combined Finite Element and Surface Integral Method

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ABSTRACT:

A new method is described for the solution of the contact problem in gears. The method uses a combination of the finite element method and a surface integral form of the Bousinesq and Cerruti solutions. Numerical examples are presented of contacting hypoid gears, helical gears and crossed axis helical gears.

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INTRODUCTION

The complete and accurate solution of the contact problem of three-dimensional gears has been, for the past several decades, one of the more sought after, albeit elusive solutions in the engineering community. Even the arrival of finite element techniques on the scene in the mid seventies failed to produce the solution to any but the most simple gear contact problems.

The reasons for this are manifold. When gears are brought in contact, the width of the contact zone is typically an order of magnitude smaller than the other dimensions of the gears. This gives rise to the need for a very highly refined finite element mesh near the contact zone. But given the fact that the contact zone moves over the surface of the gear, one would need a very highly refined mesh all over the contacting surface. Finite element models refined to this extent cannot be accommodated on even the largest of today's computers. Compounding this difficulty is the fact that the contact conditions are very sensitive to the geometry of the contacting surfaces. General purpose finite element models cannot provide the required level of geometric accuracy. Finally, the difficulties of generating an optimal three-dimensional mesh that can accurately model the stress gradients in the critical regions while minimizing the number of degrees of freedom of the model have kept the finite element method from being widely used to solve the complete gear contact problem.

Research in the mid and late eighties showed that the gear contact problem was not unsurmountable, but required an approach that combined the strengths of the finite element method with those of other techniques such as boundary element and surface integral methods. Concepts from mathematical programming could be used to advantage in solving the contact equations. An innovative approach towards the formulation of the finite elements themselves could go a long way towards solving the mesh generation and geometric accuracy problems. With the idea of incorporating the best of these and other technologies in mind, development of what is now CAPP (Contact Analysis Program Package) was begun four years ago. It has evolved into a powerful collection of computer programs that provide the gear designer with an insight into the state of stress in gears that has thus far never been possible. Some of the features that CAPP supports are: friction, sub-surface stress calculation, stress contours, transmission error, contact pressure distributions and load distribution calculation.

Figures 1 to 5 show examples of gear sets for which this process has been successfully used.

CONTACT ANALYSIS

In earlier studies [Vijayakar 1988,1989; Bathe 1985, Chowdhury 1986] of contact modeling, a pure finite element approach was used to obtain compliance terms relating traction at one location of a body to the normal displacement at another location on the contacting

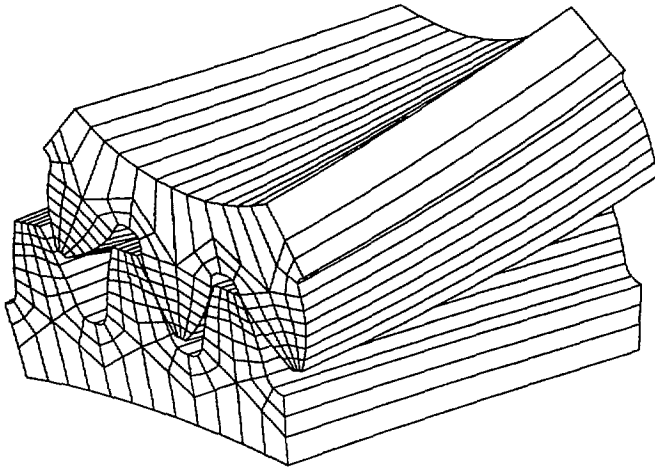


Figure 1- Contact analysis of helical gears.

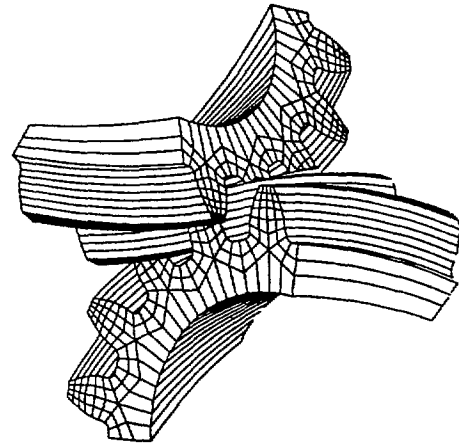


Figure 4- Contact analysis of a 90° crossed axis external helical gear set.

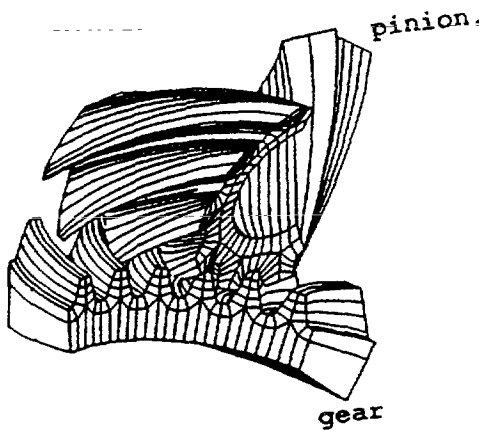


Figure 2- Contact analysis of hypoid gears.

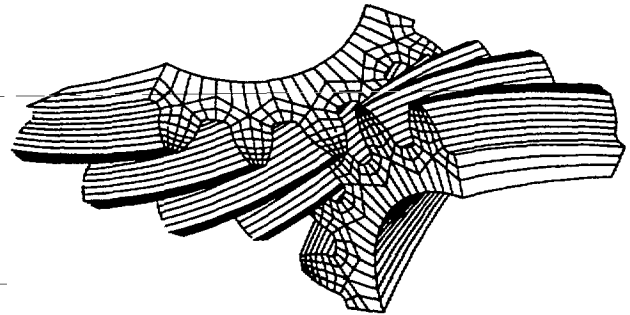


Figure 5- Contact analysis of a 90° crossed axis external helical gear set.

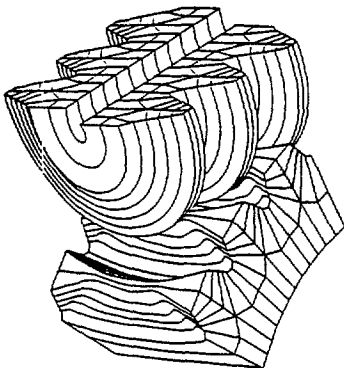


Figure 3- Contact analysis of worm gears.

body. It became apparent that in order to obtain sufficient resolution in the contact area, the size of the finite element model would have to be inordinately large. A finite element mesh that is locally refined around the contact region cannot be used when the contact zone travels over the surfaces of the two bodies.

Other researchers working in the tribology area [de Mul 1985, Seabra 1987, Lubrecht 1987] have obtained compliance relationships in surface integral form by integrating the Greens function for a point load on the surface of a half space (the Bousinesq solution) over the areas of individual cells demarcated on the contact zone. This method works well as long as the extent of the contacting bodies is much larger than the dimensions of the contact zone, and the contact zone is far enough from the other surface boundaries so that the two contacting bodies may be treated as elastic halfspaces. These conditions are, however, not satisfied by gears

The approach that is described here is based on the assumption that beyond a certain distance from the contact zone, the finite element model predicts deformations well. The elastic half space model is accurate in predicting relative displacements of points