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Adaptive finite element simulation of wear evolution in radial sliding bearings

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ABSTRACT

This article employs an adaptive wear modeling method to study the wear progress in radial sliding bearings contacting with a rotary shaft. Mixed Lagrangian–Eulerian formulation has been used to simulate the contact condition between the bearing and the shaft, and the local wear evolution is modeled using the Archard equation. In the developed wear processor algorithm, not only remeshing is performed on the contact elements, but also is executed for their proximity elements. In this way the wear simulation becomes independent of the size of the contact elements. Validation was done for a laminated polymeric composite bearing. The composite has been modeled as a linear orthotropic material. The wear coefficients were obtained from flat-on-flat experiments and were applied as pressure and velocity dependent parameters in the wear processor. Finally, the effect of the clearance on the wear of the radial bearings has been studied numerically. The simulations also demonstrate how the contact pressure evolves during the wear process, and how the clearance influences this evolution.

1. Introduction

Wear is one of the most critical parameters that substantially affects the life span of bearings. In addition, existence of wear in the bearings of a mechanical system can deteriorate the performance of the entire system through the changing kinematics. Therefore, understanding the wear evolution and its effect on the deformation, stress fields and kinematics of bearings can be very helpful for design engineers.

Very often pin-on-disc type standard tribometers are used to study the wear of materials. Since the tribosystem parameters such as contact conditions can be strongly different in practice, these tribotests are not adequate for accurate wear prediction in the design phase. Another method to incorporate wear into design is performance of full-scale tribotests that may mimic operating conditions. This technique, however, is time consuming and can be very expensive.

Numerical simulations in addition to these experimental methods can improve the bearing's design, and can overcome the limitations of the experimental methods. In one hand, simulations help to study the effect of the wear evolution on the contact stress distribution and deformation of a bearing, which can hardly be measured with the experimental techniques. On the other hand, once the simulations are verified with the basic standard or full-scale experiments, they can be used for parametric studies, or to predict the effect of the wear process on the performance of more complex mechanical systems.

Recently, many efforts have been put into developing wear simulation techniques. In the most common simulation method the wear process is simulated based on evolving contact conditions. In this method (called "adaptive wear simulation") the contact geometry varies gradually and results into an iterative procedure in which the contact pressure and the sliding distance are altered at each iteration [1,2].

Yet by now, most of those numerical works have been performed on metallic and bulk polymers and fewer studies have been made for simulation of the wear in anisotropic materials. The few available studies simplify the material properties and geometry of the models.

For example, in 2004, Hegadekatte et al. [2,3] have simulated the dry sliding wear of a brass–steel ring-on-ring test setup and wear in a silicon-nitride pin-on-disc tribometer using the adaptive FE wear modeling. In their model, the Archard coefficient is a fixed value independent of the pressure and sliding velocity, and all materials are linear isotropic. In 2010, Hegadekatte et al. [4] have used their algorithm to simulated the wear of a micro-planetary silicon gear train. Similar to their first model the materials are linear isotropic.

In 2009, Söderberg and Andersson [5] have utilized the adaptive FE method to simulate the wear of a pad-to-rotor mechanism. Using the ANSYS FEM package, a simplified 3D model is built-up which employs the Archard wear equation. The rotor is simulated as a rigid

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body and its deformation is not taken into account. In addition, while the pad is a composite, it is simplified with a linear isotropic material model.

In 2007, Rawlinson et al. [6] have studied the wear of the ProDisc-L disc replacement with the adaptive finite element method. In their article, a simplified 3D model is built up which contains a polyethylene bearing and a rigid plate. The model includes a conforming contact and the material is linear isotropic. Gonzalez et al. [7] have simulated the pin on disc tests on Al–Li/SiC composites. The composite material is assumed to behave as isotropic thermo-elastoplastic. Simulation of the thermo-elastoplastic behavior makes the model very interesting. However, the model is a simplified plane stress model with a rigid shaft.

To the best of our knowledge, by this time, adaptive finite element techniques have been employed only for isotropic materials. Moreover, in the available studies, a fixed Archard wear coefficient is used. While, in principle, for polymeric and polymeric composite materials the wear coefficient can be dependent to the pressure and sliding velocity.

In this work, the wear of a laminated composite radial bearing is simulated using the adaptive finite element method. Contrary to the available models, the anisotropy of the composite material is considered and the bearing is simulated as a linear orthotropic material. Moreover, the wear coefficient depends on the pressure and sliding velocity.

To this purpose, a wear-processing program has been developed using the UMESHMOTION feature of ABAQUS with FORTRAN programming language. This wear-processor calculates and implements the incremental wear evolution into the finite element model performed by ABAQUS.

The developed wear-processor was first verified with the flat-on-flat tribotesting of ORKOT [8] marine composite bearings. The tests were performed on a setup designed for tribotesting of medium-scale flat bearing specimens. Through these experiments the Archard wear coefficients corresponding to the normal pressure and sliding velocity of contacting surfaces were obtained. The obtained coefficients were implemented in a two-dimensional finite element model. Finally, the simulation results were compared to the wear depth measured in the experiments.

The final work implements the developed wear-processor into the model of a full-scale radial sliding bearing test setup. In this model all clearances and degrees of freedom of the system are simulated, which makes the model more realistic.

After validation of the model, effects of the clearance between the bearing and the shaft on the wear of the composite bearings were studied numerically. It must be noted that in these simulations wear of the shaft was not simulated because it was negligible compared to the wear of the bearings.

2. Methodology of the adaptive FE wear modeling

The adaptive finite element wear modeling has been developed to simulate the wear of two contacting surfaces through the movement of the contact nodes based on the following parameters:

- The normal stresses at the contacting nodes.
- Relative sliding of the contacting nodes.
- Empirically determined wear coefficients.

The model provides a time dependent geometry of the contacting surfaces, which gives a more realistic simulation of the contact stresses and kinematics of the worn components. The concept of the adaptive FE wear modeling is presented in Fig. 1.

The simulation process starts through solving the initial finite element model based on the original mesh, material model, boundary conditions, and contact conditions. Therefore, in the first step the static infinitesimal contact between the deformable bodies is simulated. Afterwards, simulation is followed by the second step which is called the wear-processing. In the wear-processing step, the relative motion between the contacting surfaces is added to the first model. The incremental solution procedure is considered for this step, and the step time is divided into very small intervals. Simulation of the boundary problem for the first increment of this step is accomplished by invoking the wear-processor algorithm. The wear-processor accesses the contacting nodes one-by-one, and calls and records the following properties for each node: nodal coordinates, contact stresses, and relative slip rate in the last increment. Based on the recorded nodal stress and slip rate, the algorithm calculates the adequate wear coefficient of the current node. Knowing the wear coefficient, contact pressure and sliding distance leads to the calculation of the wear depth. This is then followed by computing the inward surface normal at the current node. Finally, once the above process is accomplished for all contact nodes, the nodes are swept in the inward normal direction and the material quantities

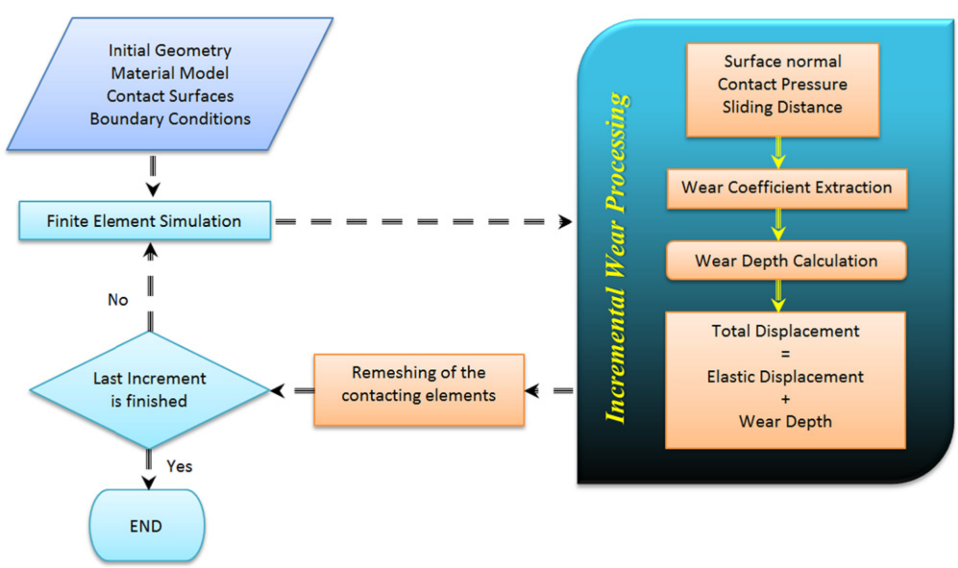

Fig. 1. Conceptual diagram of the adaptive finite element wear simulation.