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Dynamic analysis of fretting-wear in friction contact interfaces

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ABSTRACT

A numerical treatment of fretting-wear under vibratory loading is proposed. The method is based on the Dynamic Lagrangian Frequency Time method. It models unilateral contact by using Coulomb's friction law. The basic idea is to separate time into two scales, a slow scale for tribological phenomena and a fast scale for dynamics. For a given number of vibration periods, a steady state is assumed and the variables are decomposed into Fourier series. An Alternating Frequency Time procedure is performed to calculate the non-linear forces. Then, a hybrid Powell solver is used. Numerical investigations on a beam with friction contact interfaces illustrate the performances of this method and show the coupling between dynamic and tribological phenomena.

1. Introduction

Friction dampers are widely used in industry and civil engineering to control the vibrations of structures. Friction damping is often obtained via the design of the mechanism, which is the case, for example, in turbomachinery applications when a bladed disk includes dovetail attachments. The positive effect of such dampers is that they decrease vibrations, but friction also introduces micro and/or macro slip that can be accompanied by fretting-wear. Indeed, some aeronautical companies have observed that the predictions underestimate wear on the dovetail profiles of long-haul aircraft. However, this problem has not been encountered on short-haul aircraft equipped with the same type of engines. Considering that wear predictions have been performed in quasi-static take-off and landing situations, for which vibratory effects are neglected, it is presumed here that coupling between wear and vibrations occurs during the portions of the flights occurring at cruising speed, which is especially true since these operating modes last much longer for long-haul aircraft than other types. An academic example is proposed to illustrate the most pertinent phenomena.

Roughly speaking, the state of the art concerning the modeling and calculation methods available for solving such problems is as follows. On the one hand, recent methods enable the calculation of vibrational response of bladed disks in the presence of friction in blade attachments (Charleux et al., 2006; Petrov and Ewins, 2003; Nacivet et al., 2003), but wear is not taken into account; on the other hand, most fretting-wear studies are performed in quasi-static situations for which inertial – and thus vibratory – effects are neglected. Apart from Levy (1980), and Sextro (2002), coupling between fretting-wear and vibrations is very seldom taken into account in the literature, due to the complexity it introduces. Nevertheless, certain experimental studies have investigated the effect of frequency on fretting wear (Berthier et al., 1988; Soderberg et al., 1986; Leonard et al., 2009).

Wear itself is a complex phenomenon because wear debris can depend on hardness, plasticity, grain structure, temperature, etc. According to (Meng and Ludema, 1995), about 180 wear laws have been proposed. Archard's model (Archard, 1953) is that most commonly used to quantify wear. It considers that the wear volume is linked to the product of normal force and sliding velocity. Wear coefficient quantification is conventionally performed by evaluating the worn volume as a function of normal load. The loss of material can be known by measuring loss of mass, loss of dimensions, the evolution of Vickers microhardness imprints, or directly by surface profilometry. The Archard model will be used here.

In the absence of vibratory effects, wear laws are often used with the Finite Element Method (FEM) as post-processing steps in looping procedures to solve deformable contact problems and obtain the evolution of wear rates and worn geometries. Commercial software can be used to model wear-cycles with an external routine to compute wear and remesh the geometry (McColl et al., 2004; Mary and Fouvry, 2007). This strategy is highly time-consuming. In order to reduce calculation costs, several simplified approaches have been developed based on Winkler's foundation to predict wear (Põdra and Andersson, 1997). Various approaches have also been proposed to predict wear based on semi-analytical models (Gallego et al., 2006) or on Boundary Element Methods

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