2D/3D Nonlinear and Non-Hertzian Tooth Deflection Analysis for Compliant Gear Dynamics

Abstract

One of the most reliable ways to transmit mechanical power is to use geared mechanisms and gears have indeed been used since ancient times in the most different fields. In recent years, and especially in the aeronautical and aerospace industry, an ever growing need to reduce the weight of the components and increase the transmitted power density through the increase of the rotational velocity has become evident and a lot of research has been done to understand them. This trend has led engineers to experience complex dynamic phenomena that could lead to failures if not properly accounted for in the design phase, which has become ever more complex in terms of the contradictory balance between robustness and low weight to be achieved for optimal results.

Aim of this work is to develop a dynamic model able to integrate the instantaneous contact conditions between the flanks and the compliances of the gear webs and shafts in a numerically efficient way, so that this approach could be effectively used in the design or verification phase of the engineering process. During gear engagement the main source of dynamic excitation is the time-varying mesh stiffness and thus the first step of this work is the development of a method to determine it. This is done through an algorithm that considers the flexibilities of the different parts of the gears, such as the web, the rim, the fillet and the involute profile. A nonlinear algorithm is considered to find the actual contact point as it moves due to the deflection of the engaging profiles. To correctly estimate the mesh stiffness an accurate description of the contact is needed and therefore a 2D rough frictionless contact is introduced and the effects of tip-corner contact and some profile modifications are highlighted. Most of the profile modifications applied to gears during manufacturing are also done along the face width and as such cannot be studied with a 2D approach. For this reason, 3D rough frictionless contact is introduced coupled with a detailed description of the gear geometry through the use of 3D solid finite elements and the effects of profile modifications on the static transmission error and mesh contact stiffness are discussed.

In order to validate the results obtained from the presented approaches an experimental test bench to measure the quasi static transmission error is presented and the computational results are compared against the experimental ones. This test bench features an innovative design especially regarding the measurement, since the angular encoders reading the deformations are mounted so that the tangential displacements are uncoupled from the radial and axial ones, ensuring accurate readings.

Next, a time domain dynamic model is presented, which includes the results of the contact analyses and 3D finite element discretization to capture the flexible behavior of gears during engagement with fast computational times. This is achieved trough the use of reduced order models, rotations of the results obtained at the previous time step and a series of expansions and reductions of the degrees of freedom to simulate the motion of the gears and the travelling load as the teeth enter and leave contact with a time dependent nonlinear contact mesh stiffness. A couple of models with different conditions is analyzed with this method and the results obtained are discussed for different web and shaft designs and tooth profile modifications. Finally, the strengths and weaknesses of the proposed method are discussed, and the possibility of further improvement is commented upon.