

Time-Domain Dynamic Analysis of Helical Gears with Reduced Housing Model

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ABSTRACT

In this paper we present a time-domain dynamic analysis of a helical gear box with different housing models using a unique finite element-contact mechanics solver. The analysis includes detail contact modeling between gear pairs along with the dynamics of gear bodies, shafts, bearings, etc. Inclusion of the housing in the dynamic analysis not only increases the fidelity of the model but also helps estimate important NVH metrics, such as dynamic load and vibration transmission to the base, sound radiation by the gearbox, etc. Two different housing models are considered. In the first, the housing is represented by a full FE mesh, and in the second, the housing is replaced by a reduced model of condensed stiffness and mass matrices. Component Mode Synthesis (CMS) methods are employed to obtain the reduced housing model. Results from both the models are successfully compared to justify the use of reduced housing model for further studies.

Steady state sound radiation by the gear box housing is then studied in the frequency domain using a boundary element solver. The housing frequency response, which is the boundary condition for the acoustic analysis, is estimated using two different methods. In one method, the response is computed from the generalized coordinates and component modes using modal superposition, in the other the bearing dynamic loads are used to perform forced response analysis on the full FE mesh of the housing. Thus, a template for end-to-end solution to predict radiated noise from a gear box is established.

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INTRODUCTION

Gear noise and vibrations remain key concerns in many transmission applications. The dynamic loads or errors at the gear mesh excite the components in a gear box. Typical transfer path for the noise and vibration includes gears, shafts, bearings, and the housing or the base connected to the housing. Low frequency vibrations propagate through structures as structure-borne noise, and higher frequency vibrations typically manifest as air-borne noise. The housing due to its large surface area acts as a good radiator of sound. Thus, it is imperative that the dynamic analysis of the entire

gearbox, including the housing, is essential in understanding its noise and vibration characteristics.

Lumped parameter models are commonly used to model gear dynamics, where various components of the gear box are represented by lumped inertias and stiffness. The gear mesh excitation, which is the source for the dynamics, has to be provided externally either as time-varying mesh stiffness or as the static transmission error [1]. General purpose finite element software may also be used to solve gear dynamics. But it requires refined meshes near the contact zone for accurate gear tooth contact modeling. Moreover the local refinement needs to keep moving as the gears rotate, thus making it practically infeasible to solve the time domain gear

dynamics problem. In 1991, Vijayakar [2] introduced a combined surface integral and finite element formulation to solve gear contact problems efficiently. The semi-analytical contact formulation along with the superposition of small finite element deflections over large kinematic trajectories of the gears allow one to solve the contact problem in rotating gears fast, thus paving way for solving gear dynamics in reasonable amount of time. Further the need for extremely refined mesh near contact is removed; coarse mesh as shown in Figure (1) would suffice. This formulation has been successfully used to model 2D and 3D gear dynamics by many researchers [3,4,5]. A frequency domain version of this formulation is presented in [7].

The primary focus of this paper is to employ the time-domain FE-contact solver for gear dynamics and use a frequency domain boundary element solver to compute steady state sound radiated by the gear box housing. It might seem more natural to solve a steady state problem in the frequency domain. But, unlike time-domain analysis frequency domain approaches for gear dynamics cannot naturally model the nonlinearities in the system, such as time-varying mesh stiffness, gear tooth contact loss, etc.

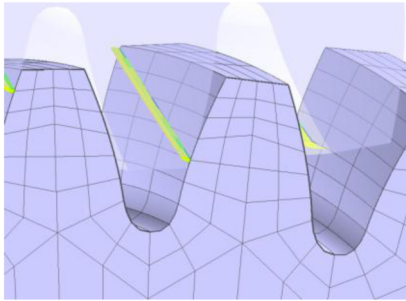


Figure 1. Gear tooth finite element mesh used in the FE-Contact solver. Contact pressure predicted by the solver is also plotted. Note that mesh refinement is not necessary to model contact (in contrast to general purpose FE codes) as the solver uses a combined surface integral and FE formulation [2].

The end-to-end solution to predict noise radiated by the gear box explored in this paper is described in Figure (2). First, we perform the time-domain dynamic analysis of a helical gear box, including the housing, using the same FE-Contact solver discussed above [3,4,5]. Then we estimate the steady state sound radiated by the housing using a boundary element solver presented in [8, 9]. To reduce the solution time the full finite element (FE) mesh of the housing is replaced by a reduced model of condensed stiffness and mass matrices. Component Mode Synthesis (CMS) techniques are used to obtain the reduced housing model. Dynamic analysis is performed for the two housing models. The results are compared to examine the accuracy of the model with the reduced housing.

SIMULATION WORKFLOW

Here we will introduce the simulation workflow followed to predict the noise radiation by a gearbox. Figure (2) shows the summary of the steps involved. Greater details about each step will be covered as we introduce these topics later on in this paper.

Multi-body dynamics model for gear dynamics is built using the unique finite element-contact solver described in [3,4,5]. The inputs for the model include the finite element models of the gears, shafts, bearings and the housing. Full FE mesh of the housing will be replaced by reduced housing model. The time-domain analysis at the operating speed produces many outputs including dynamic loads, deflections, dynamic transmission error (DTE), etc. Among the outputs, the bearing loads or the generalized coordinates of the reduced housing model are used for the acoustic analysis.

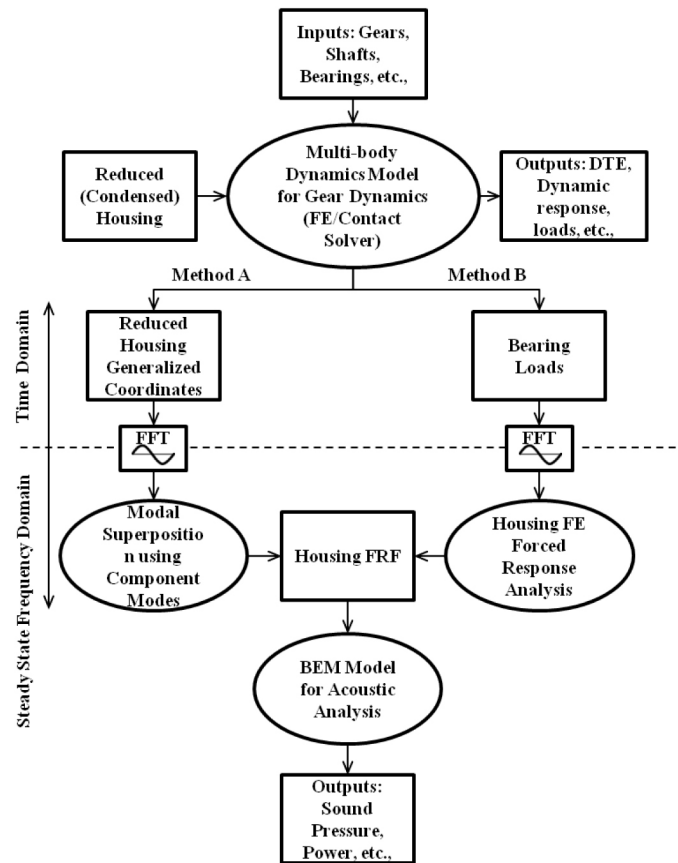


Figure 2. Gear box noise radiation prediction workflow.

Steady state sound radiation by the housing is simulated using a boundary element solver [8] in the frequency domain. The primary input for the acoustic analysis is the housing frequency response function (FRF). This may be obtained by two different methods. In Method A, we utilize the generalized coordinates of the reduced housing model and the component modes to compute housing FRF. In Method B, we use bearing loads to perform forced response analysis on the full FE mesh of the housing. Note that both the generalized