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Analytical and Experimental Vibration Analysis of a Damaged Gear

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American Gear Manufacturers Association



TECHNICAL PAPER

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

ABSTRACT:

A comprehensive analytical procedure was developed for predicting faults in gear transmission systems under normal operating conditions. A gear tooth fault model is developed to simulate the effects of pitting and wear on the vibration signal under normal operating conditions. The model uses changes in the gear mesh stiffness to simulate the effects of gear tooth faults. The overall dynamics of the gear transmission system is evaluated by coupling the dynamics of each individual gear-rotor system through gear mesh forces generated between each gear-rotor system and the bearing forces generated between the rotor and the gearbox structure. The predicted results were compared with experimental results obtained from a spiral bevel gear fatigue test rig at NASA Lewis Research Center. The Wigner-Ville Distribution (WVD) was used to give a comprehensive comparison of the predicted and experimental results. The WVD method applied to the experimental results were also compared to other fault detection techniques to verify the WVD's ability to detect the pitting damage, and to determine its relative performance. Overall results show good correlation between the experimental vibration data of the damaged test gear and the predicted vibration from the model with simulated gear tooth pitting damage. Results also verified that the WVD method can successfully detect and locate gear tooth wear and pitting damage.

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ANALYTICAL AND EXPERIMENTAL VIBRATION ANALYSIS OF A DAMAGED GEAR

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I. INTRODUCTION

In the last two decades, the use of gear transmissions in both defense and commercial applications has substantially increased. With the demand for higher power and performance, premature failures in transmissions often result in financial losses, and sometimes even lead to catastrophic consequences. In the aerospace industry, one of the major concerns is with gear fatigue failures in rotorcraft transmission systems. Large vibrations in gear transmission systems usually result in excessive gear tooth wear and possible tooth crack formation which, in turn, leads to premature gear failure. Thus, it is important to understand the dynamics of a transmission system over a variety of fault conditions, as well as under nominal conditions. With this, methods can be explored to detect and assess the magnitude of the gear damage present. Due to limitations in the number and types of experiments that can be performed, the only practical means of obtaining this type of data is through analytical simulations.

The major objective of the research reported herein is to develop and verify a model to predict the vibration of a transmission system with the effects of gear surface pitting and wear. To simulate the vibration of the transmission system, the equations of motion were established individually for each rotor-gear-bearing system. The effects of tooth wear or surface pitting are simulated by changes in the magnitude and phase of the mesh stiffness. These localized changes in the gear mesh are incorporated into each gear-rotor model for dynamic simulation[1-3]. The dynamics of each gear-rotor system are coupled with each other through the gear mesh interacting forces and the bearing support forces. The global vibrations of the system are evaluated by solving the transient dynamics of each rotor system simultaneously with the vibration of the casing. In order to minimize the computational effort, the number of degrees-of-freedom of the system are reduced by using a modal synthesis procedure[1,2].

To verify the analytical model with experimental data, the dynamics of a single spiral bevel pinion with various degrees of gear tooth damage was simulated. Results from the model were compared to experimental results using a joint time-frequency analysis method. This approach was chosen because of the large amount of information represented in the joint time-frequency results which can not be represented separately in either the time domain or the frequency domain. The joint time-frequency analysis will provide an instantaneous frequency spectrum of the system at every instant of the revolution of the pinion while a Fourier Transform can only provide the average vibration spectrum of the signal obtained during one complete revolution. In other words, the time-changing spectral density from the joint time-frequency spectra will provide information concerning the frequency distribution concentrated at that instant around the excited instantaneous frequency which cannot be obtained in a regular vibration frequency spectrum. The joint time-frequency analysis approach applies the Wigner-Ville Distribution (WVD) [4-6] on the time vibration signal of the system. Some success has been achieved in applying the WVD to gear transmission systems [7,8] to recognize faults at various locations of the gear. Other fault detection techniques, including frequency domain analysis[9,10] and several time discriminant methods such as: FM4[11], NA4*, and NB4*[12-14] are also used to compare with and verify with the WVD approach.

Based on results of this study, some conclusions are made on the ability of the developed model to simulate gear tooth surface damage, and the ability of the WVD method to detect damage sufficient to verify with the model.

II. ANALYTICAL PROCEDURE

The dynamics of the *i*th individual gear-shaft system can be evaluated through the equations of motion for the vibrations of a individual rotor-bearing-gear system as shown in Figure 1[1,2], given in matrix form, as