EXPERIMENTAL AND NUMERICAL INVESTIGATIONS OF VIBRATION SIGNATURES IN DAMAGED GEAR SYSTEMS

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ABSTRACT
Current on-board condition monitoring systems for transmission systems often fail to provide sufficient time between warning and failure in order to implement the safety procedures. On the other hand, inaccurate interpretation of operational conditions may result in false alarms leading to unnecessary repairs and downtime. The early detection of incipient failure in a transmission system is of great practical importance as it permits scheduled inspections without costly shutdowns and indicates urgency and location for repair before any catastrophic failure occurred.

The major objective of this paper is the numerical and experimental investigations of vibration signatures due to localized multiple teeth damages in a gear transmission system. Experimental results from a gear set with controllable damage are compared with those based on numerical simulations. General and specific conclusions are drawn based on the comparisons of the results.

INTRODUCTION
In the aerospace industry, where both weight-to-load factor and efficiency are pushed to their design limits, one of the major concerns is the fatigue failures in rotorcraft gear transmission systems. Such failures are often result from excessive gear tooth wear or tooth crack formation, leading to premature equipment failure. Presently, the prevention and management of premature gear failures has become a vital part of the maintenance program.

Recently, a considerable amount of work in gear life prediction has been carried out using machine reliability and design life approaches. A number of research works concerning gear failures have been reported using vibration signatures in rotorcraft transmissions. The acquired machine vibration/acoustic signatures are compared with a data bank of the healthy machine signatures allowing the detection of abnormalities in the input signals. This procedure does not require a shut down of the rotating machinery, and can be used as an on-line diagnostic and trend monitoring tool. However, most of these works reported are limited to single gear tooth damage and very little work has been carried out on the detection and quantification of multi-gear tooth damages in a gear transmission system.

In this paper, vibration results from cases of an undamaged gear set and gear sets with single tooth damage, 2 consecutive teeth damage, and 3 consecutive teeth damage are acquired. A numerical model developed by the authors [1-3] to simulated vibrations in a damaged gear transmission system is also used. Effects of gear teeth damage are modeled numerically by the change in the geometric profile of the gear tooth. A computer code developed by NASA is use to evaluate the changes in gear mesh stiffness resulted from various types of gear tooth damage/wear. These changes in mesh stiffness are numerically incorporated into the global dynamic simulations of the gear transmission system for vibration signature analysis [1–3].

DISCUSSION OF RESULTS
Experimental Results
The vibration signature changes substantially when damage is introduced in one of the gear tooth as shown in Figure 1a. The amplitude of the time signals has increase substantially and a large number of side-band (non-synchronous) components can also be observed in the frequency spectrum. These side-band components excited include the one that is about the first natural frequency of the system at 105 Hz. In the WVD [4], one can notice that, in addition to the cross pattern due misalignment at 80°, another cross pattern can be found at around 240° at the mesh frequency of 650 Hz. This additional cross pattern is resulted from the dynamics generated by the damaged gear tooth with is located about 240° from the triggering/reference mark for data acquisition. One may also notice that another cross-pattern exists at the 240° location at the system natural frequency of 105 Hz. However, the dark straight line pattern at 350 Hz is due
to the echoing of the two frequencies at 105 Hz and 650 Hz which is a typical shortcoming of the WVD procedure.

Note also that this distinction and vertical elongation of the cross pattern at the frequency of 105 Hz increase substantially for the case with three consecutive gear teeth damage as shown in Figure 1b. The changes in time and frequency vibration signatures remain quite undetectable in this case. Based on these results, one may be able to conclude that the joint time-frequency analysis of the vibration signals using WVD may provide an efficient approach in identifying multi-gear teeth damage in a transmission system.

Numerical Simulations

The model used in this numerical experiment included a driver shaft/gear and a driven shaft/gear both supported by two ball bearings similar to the experimental test rig. Gear loading torque is assumed to be generated by the driving electric motor and the resisting torque is produced by the water-cooled braking system. The overall dynamics of the system is generated by solving the global equations of motion of the transmission system. The gear mesh stiffness are simulated by assuming all the gear teeth are in ideal perfect conditions except for those given controllable damage/wear.

For the cases with different number of gear tooth damage, Figures 2a to 2b, the cross pattern in the WVD at the natural frequency of 105 Hz is substantially more distinct than those from experimental results. The extension of the cross pattern in the vertical time direction due to the increase in the number of gear tooth damage can easily be identified (single tooth damage in Figure 2a and triple tooth damage in Figure 2c). Based on this study, one may also conclude that both the frequency spectrum and WVD using numerical simulations produces the same dynamic characteristics as those from experimental study. However, the numerical simulation will provide a much cleaner/easier identification of the damage in gear tooth surface profile.

CONCLUSIONS

1. This paper provides comparisons and correlations of experimental results obtained from a damage gear transmission with those generated from numerical modeling.
2. The vibration signature analysis using a joint time-frequency procedure, the Wigner-Ville Distribution (WVD) [4], seems to be effective in identifying single and multiple gear teeth damage.
3. The experimental results confirm that the numerically simulated model developed can provide an accurate dynamic correlation with the results obtained from the experimental gear test rig.

REFERENCES