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Detection of Fatigue Cracks in Gears with the Continuous Wavelet Transform

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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

Under ideal operating conditions, gearboxes generate vibration signals with frequency components that are pure harmonics of the gear meshing frequency. Developing tooth fatigue cracks introduce short-time amplitude and phase modulations of the gear meshing vibration signal. Traditional techniques for gear fault detection have focused on either the time domain or the frequency domain. The newly developed wavelet transform enables one to look at the evolution in time of a signal's frequency content. This property is very well suited for the analysis of localized transients that are generated by the operation of faulty gears. In this study, magnitude wavelet maps of the vibration signal are calculated and used to assess the condition of an instrumented gear test rig. A key finding is that the wavelet map of the residual vibration signal offers a better indicator to the presence of cracks than the map of the actual signal. The results obtained are also compared against those of the well-accepted phase demodulation approach.

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1500 King Street, Suite 201
Alexandria, Virginia, 22314

November, 1997

ISBN: 1-55589-697-9

INTRODUCTION

There are significant financial rewards to industrial plants which can minimize equipment downtime as well as maintenance expenditure. Predictive condition monitoring can effectively contribute towards both of these objectives. Among the many tools currently in use to achieve these goals are those based on processing of the machine's vibration signal. These have gained a much wider acceptance because of the advantages they offer.

The vibration and noise generated by a machine are directly related to its "health" condition. However, extracting from amongst all components of the vibration signal that which is due to a specific fault is often not a trivial task. The complications arise because several faults generate similar vibration patterns. The task is then to properly process the vibration signal and display it in a form very suitable for reliable assessment of a machine's condition. At the heart of vibration based machinery diagnostics are the ideas and methods of discrete-time signal processing, where one is often confronted with the task of deciding on which method to use to reveal each specific machine fault or malfunction. This issue is still the subject of intensive analytical as well as experimental research activities.

Gears are widely used in many mechanical systems. Their required accuracy spans a wide spectrum, from low accuracy in simple power transmission, to high accuracy in motion transmission. This paper is mainly concerned with precision gears. Amongst the most dangerous failures observed in gears are fatigue induced teeth cracks. The appearance of cracks is often accompanied by changes in the gear meshing conditions and vibration patterns.

GEAR VIBRATION

The major source of vibration in a gearbox is the meshing action between gears. For a mathematically perfect set of gears, operating under constant load and speed conditions, the vibration energy will be concentrated at the gear meshing frequency and its harmonics. Localized gear faults introduce short-time modulations of both the amplitude and phase of the vibration signal. Monitoring and processing of this vibration signal is thus the key to identifying developing faults in the gear train. It is certainly true that imperfections in the gear train due to the geometry

and surface finish, will also introduce some amount of modulation in both the amplitude and phase of the vibration signal. These modulations are however "uniform" for all teeth, and they will show up as "slow" modulations of the vibration signal. In contrast, localized faults introduce abrupt changes in the vibration signal.

CURRENT DIAGNOSTIC TECHNIQUES

There are several techniques currently available for vibration based diagnostics of gear faults in general and fatigue cracks in particular. The techniques can be divided into those based on analysis of the signal in the frequency domain, and those based in the time domain. Undoubtedly, each approach has its own merits and limitations, and where one technique has difficulties, another could shed better light.

While experience has shown that spectral analysis is very successful in pin-pointing "distributed" faults in geared systems, localized faults such as cracked and spalled teeth are extremely difficult to extract from the average spectrum of the vibration signal. For these localized faults, time domain based techniques often offer a better alternative. The time domain techniques range from the calculation of statistical indicators such as the kurtosis and crest factor, which assess the condition of a machine from the "peakiness" of its vibration signal, to those based on the synchronous time averaging and its extensions, such as amplitude and phase demodulation via Hilbert transform.

Synchronous Time Averaging was introduced by Weichbrodt and Smith (1970), but however did not gain much acceptance because it required the use of expensive hardware, such as phase-locked frequency multipliers and tracking filters. Nevertheless, the technique allows one to zero in on the vibration caused by a specific gear and enhance it while attenuating other frequency components that are not synchronous with the rotation of the gear of interest. The synchronous average signal $x(t)$ is calculated from the raw vibration signal $y(t)$ according to

$$x(t) = \frac{1}{N} \sum_{k=0}^{N-1} y(t - kT) \quad (1)$$