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Gear parameter identification in a wind turbine gearbox using vibration signals

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ABSTRACT

When carrying out vibration-based diagnosis of gearboxes it is desirable to know the numbers of teeth on all gears, so as to be able to calculate toothmesh frequencies and rotational speeds of all shafts. If the speed varies, this information must be obtained in the form of "shaft orders" related to the input and/or output speed. This paper describes how it was possible to extract most of this information from the vibration signal itself in the case of a wind turbine gearbox with one planetary and two helical parallel stages. Using a spectrogram, a section of signal was first found with minimal speed variation (about 4%) after which the instantaneous speed information was extracted by frequency demodulation of dominant speed related components. After order tracking based on this it was found possible to determine the numbers of teeth in the two parallel stages, using very accurate harmonic cursors applied to each of the shafts of pairs of gears in mesh (with common mesh frequency). This was successful for the two parallel stages, but the proposed estimates of the tooth numbers in the planetary section are subject to some doubt. Allowable combinations are quite restricted using the normally applied rules, but there can be exceptions. Even so, the presented approach is confirmed as a viable method.

Contents

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1. Introduction

Monitoring the health of gears in a gearbox, using vibration signals, requires a knowledge of the input or the output rotational speed, the number of stages as well as their arrangement and the number of teeth for each gear. Often, this information is available to the vibration analyst by means of a speed reference signal and the manufacturer's details of the gearbox. Typically, a tachometer/encoder is installed at the high speed shaft to enable estimation of the shaft speed and order tracking of the signal [1] to remove speed fluctuations.

In cases where more limited information is available to the analyst, a harmonic cursor approach has been recommended for the blind determination of the numbers of teeth on a gear pair [2]. The use of a harmonic cursor in such occasions is possible if the gear pair represents a 'hunting tooth' design [2]. The 'hunting tooth design', which is considered as good practice, means that there is no common factor between the pinion and the gear and consequently their harmonics are completely separable except at the gear mesh frequencies (the closest the other harmonics can reach is $1/(m \times n)$, where m and n are the numbers of teeth on the two gears. In order to use a harmonic cursor, the machine speed is required to be stable to about 1:20000 [2]. If this is not the case, order tracking can be used to increase the degree of stability. The harmonic cursor approach also requires the presence of a reasonable number of harmonics of both shafts in the spectrum (logarithmic/decibel scale) including sidebands around the gear mesh frequency. The harmonic cursor approach as described in [2] starts by setting up a harmonic cursor on each shaft in succession, first on the low orders and then progressively adjusting it by zooming in higher frequency bands. This will eventually determine the fundamental frequency to the required accuracy. If lists of the two harmonic series are then compared, the gear mesh frequency corresponds to where they match to better than 1:10000 [2]. Even if the design is not hunting tooth, the approach can often still be used. The most likely common factor is 2 or 3, in which case the first correspondence will be at 1/2 or 1/3 of the actual mesh frequency. For the pinion, this will often lead to an unlikely minimum number of teeth, and in any case if there is an inspection port, the tooth pitch can be measured sufficiently accurately with a tape measure to exclude incorrect possibilities.

The situation presented in this paper discusses the case where knowledge about the characteristics of the gearbox, of a wind turbine, was very limited and there was no speed signal. The challenge imposed in such a situation requires an accurate estimate of the different shaft speeds (or at least their ratios) and the numbers of teeth for each of the gears to calculate the gear mesh frequencies. The case is complicated by the fact that the wind turbine does not run at constant speed and in fact the measurements analyzed are actual signals from a full size wind turbine running under normal conditions and being subject to varying wind conditions and with no tachometer/speed reference signal available. In order to tackle these issues a signal processing approach has been introduced. The aim of this processing is to arrive at an order tracked signal suitable for the harmonic/sideband cursor tuning. The processing approach, which is detailed in Section 3 starts by down sampling (decimating) the original signal so that analysis is made in the low frequency region up to 2500 Hz (dominated by gearmesh frequencies) instead of the full 20 kHz range. The decimated signal was then examined using the spectrogram to observe speed variation and decide on a typical section with small speed fluctuations for further processing. Order tracking was then used on the selected section to remove speed fluctuations. This has to be carried out by extracting a pseudo tachometer from the signal itself. Finally a very accurate harmonic/sideband cursor was employed in an attempt to predict the number of teeth on each gear.

The paper is organized as follows: after this introduction, the experimental data collected is described in Section 2. This is followed by an illustration of the data handling and processing in Section 3. Results are presented and discussed in Section 4. Finally the paper is concluded in Section 5.

2. Experimental data

The case presented in this paper was taken from an actual wind turbine gearbox. The gearbox has three stages (two helical parallel stages and one planetary). A typical schematic presentation to show the layout of the gearbox is presented in

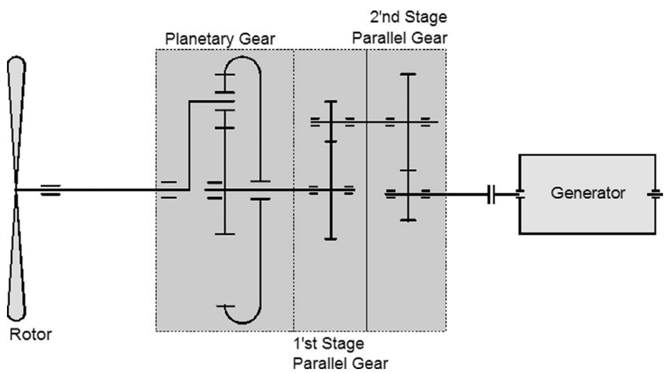

Fig. 1. Typical Layout of a wind turbine gearbox [3] for illustration purpose only.