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Pitting detection in worm gearboxes with vibration analysis

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ABSTRACT

Diagnostics of worm gear defects with vibration analysis is challenging and this is reflected in the limited number of publications. However, these gears are commonly used in many applications such as escalators, mills, and conveyors, and significant cost may arise from their down time due to unidentified defects. This paper aims to apply various vibration analysis techniques to diagnose the presence of naturally developed faults within worm gearboxes.

The condition of three different worm gearboxes were assessed using various vibration signal analysis techniques including a few statistical measures, Spectral Kurtosis and enveloping. This was undertaken in an attempt to identify the presence of defects within the worm gearboxes. It is shown that irrespective of the predominantly sliding motion of the gears, diagnosis of faults is feasible as long as the appropriate analysis technique is employed. In addition the results show sensitivity to the direction of vibration measurement.

1. Introduction

In a worm gearbox the worm meshes with a wheel to transmit motion between crossed shafts, usually perpendicular to each other. Worm gearboxes are generally used for applications requiring large gear reduction ratios; they have the advantage of taking up little space and are simpler in configuration compared to the other gears types of the same reduction ratio. Other advantages of worm gears include the self-locking effect, low backlash, damage tolerance as well as quiet operation. However, worm gearboxes have some disadvantages; they generate high friction compared to the other gears types due to their sliding action (as opposed to rolling) which results in heat generation and hence lower efficiency. Also the sliding motion gives rise to inevitable abrasive wear and scuffing, therefore worm gearbox wheels are usually made of a softer material (usually bronze) and worms are most commonly made of a harder steel [1]. Due to their unique properties, worm gearboxes have found their niche in a variety of industrial applications such as rolling and saw mills, mining machinery and escalators.

With a gradual shift towards condition-based maintenance for greater operational effectiveness, condition assessment via vibration analysis is common practice. However, it is seldom employed for the condition assessment of worm gears due to the inherent challenges involved in the analysis of worm gear vibration. Compared to other gears types where defects manifest as periodic impacts in the form of side-bands around the gear mesh frequencies [2,3], such distinctive defect symptoms

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Nomenclature

Bw	Band Width
D	difference signal
DE	Drive End
Fc	central frequency
K	Kurtosis
K_{max}	maximum Kurtosis
N	number of the points in the signal
NDE	Non-Drive End
r.m.s.	root mean square
SK	Spectral Kurtosis

are not obvious for worm gear sets due to their continuous sliding interactions [4]. Consequently, the literature on this topic is relatively scarce.

Peng et al. [5,6] combined the use of oil and vibration analysis to establish detection methods in a worm gearbox; they concluded that wear analysis remains a useful tool for the detection of gear wear while the vibration analysis was more suited to identifying bearing failures. Vahaoja et al. [4] also reiterated the need to combine vibration and oil analysis to effectively diagnose defects in worm gearboxes. Other technologies that have been employed to diagnosis worm gearbox defects include Acoustic emission (AE), this has been used for fault detection in worm gearboxes where parameters such as r.m.s. and AE energy were found to be reliable indicators of the presence of defects [7]. The number of successful applications of vibration analysis to worm gearboxes is very limited as reflected in the available literature. Furthermore, to date there have been no applications of Spectral Kurtosis and FM4* to worm gearbox diagnosis. This paper aims to examine the effectiveness of such vibration analysis techniques, amongst others, in detection of faults in operational worm gearboxes employed for escalators.

2. Vibration analysis techniques

Whilst there are varied vibration diagnostic techniques available to the user this paper focuses on three techniques: Spectral Kurtosis, envelop analysis and a few statistical measures such as Kurtosis, r.m.s. and FM4*. The techniques selected for this investigation employed a very established diagnostic technique (enveloping), a relative modern diagnostic technique (Spectral Kurtosis) and a few traditional statistical measures. In relation to the latter, the r.m.s. and Kurtosis were selected because they are commonly used vibration diagnostic techniques, in addition the statistical measure FM4* is known to be effective in diagnosing gears pitting [8].

2.1. Statistical metrics

2.1.1. Root mean square (r.m.s.)

One commonly used statistical measure for analysis of vibration is the root mean square (r.m.s.). This parameter tends to provide measurement of the effective energy of the vibration signal with the damaged component expected to produce high vibration energy and hence higher r.m.s. [3]. The r.m.s. is expressed mathematically by:

$$\text{r.m.s.} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i^2)} \tag{1}$$

where N is the total number of samples in the waveforms, x_i is waveform samples.

2.1.2. Kurtosis

Kurtosis is defined as the degree of peakness of a probability density function $p(x)$ and mathematically it is defined as the normalized fourth moment of a probability density function [9]:

$$\mathrm{K} = \frac{\int_{-\infty}^{\infty}[x-\mu]^4 p(x)dx}{\sigma^4} \tag{2}$$

where x is the signal of interest with average μ and standard deviation σ.

Kurtosis is one of the widely used condition indicators principally due to its correlation with impulsive type signatures which can occur with bearing defects [10–12].