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Application of Acoustic Emission in Diagnostic of Bearing Faults within a Helicopter gearbox

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Abstract

Acoustics Emissions (AE) technology has emerged as a promising diagnostic approach. AE was originally developed for non-destructive testing of static structures, however, in recent times its application has been extended to health monitoring of rotating machines. This paper introduces a novel method for application of AE in monitoring of helicopter gearboxes. In addition this paper investigates the application of signal separation techniques in detection of bearing faults within the epicyclic module of a large helicopter (CS-29) main gearbox using Acoustic Emissions (AE). The results showed successful of AE in detection bearing fault within the helicopter gearbox. Detection of the small bearing defect gives the AE an indisputable diagnosis advantage and prove ability of application of AE in helicopter gearboxes.

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Keywords: Condition Monitoring, Helicopters, Gearbox, Fault Diagnosis;

1. Introduction

Helicopter transmission integrity is critical for safe operation. Approximately 16% of mechanical failures, resulting in the loss of helicopter operation, can be attributed to the main gearbox (MGB)[1]. In addition, 30% of the total maintenance cost of helicopters can be attributed to the transmission system [1]. The need to employ advanced fault warning systems for such transmission systems cannot be understated [2, 3]. Health and Usage Monitoring Systems (HUMS) are commonly used for fault detection of helicopter transmissions in which detection is based on extraction of predefined features of the measured vibration such as FM4, NA4, etc. [2, 4, 5]. HUMS was developed in North Sea operations, motivated in part by the crash to a Boeing Vertol 234 in 1986 which was caused by disintegration of the forward main gearbox. After development in the 1990s, the UK's Civil Aviation Authority CAA mandated fitment of HUMS to certain helicopters. One article suggests that HUMS "successes" are found at a frequency of 22 per 100,000 flight hours [6]. A HUM system consists of two complimentary subsystems: health monitoring and usage monitoring. Health monitoring is a process of diagnosing incipient damage or degradation that could ultimately lead to a system failure. Usage monitoring is a process by which the remaining life of different gearbox components and auxiliary systems is determined by assessing operation hours, current components condition and load history [7, 8]. Several vibration signature analysis methods are developed and applied in the commercial HUMS to detect faults in bearings, gears and shafts. Condition Indicators (CI) refer to the vibration characteristics extracted from these signatures and are used to reflect the health of the component [9]. Numerous condition indicators are calculated from vibration data to characterize component health and these indicators are often determined based on statistical measurement of the energy of the vibration signal, such as rms, kurtosis and crest factors.

The majority of helicopters utilises epicyclic reduction modules gears as transmission systems due to their high transmission ratio, higher torque to weight ratio and high efficiency [10]. As such this type of gearbox is widely used in

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many industries such as aerospace, wind turbines, mining and heavy trucks [11-15]. Different planetary gearbox configurations and designs allow for a range of gear ratios, torque transmission and shaft rotational characteristics. The planetary gearbox generally operates under severe conditions, thus the gearbox components are subject to different kinds of fault conditions such as gear pitting, cracks, etc. [16-19]. Recent investigations on applications of planetary gearboxes have shown that failures initiate at a number of specific bearing locations, which then progress into the gear teeth. In addition bearing debris and the resultant excess clearances cause gear surface wear and misalignment [19]. More recently the accident to the helicopter registered G-REDL [20], resulting in the loss of 16 lives, was caused by the degradation of a planet gear bearing, interestingly, the HUM system condition indicators showed no failure evidence before this accident.

2. Planetary gearbox diagnostics

The use of Acoustics Emissions (AE) technology has emerged as a promising diagnostic approach. AE was originally developed for non-destructive testing of static structures, however, in recent times its application has been extended to health monitoring of rotating machines and bearings [21-24]. In machinery monitoring applications, AE are defined as transient elastic waves produced by the interface of two components or more in relative motion [25-27] . AE sources include impacting, cyclic fatigue, friction, turbulence, material loss, cavitation, leakage, etc. It provides the benefit of early fault detection in comparison to vibration analysis and oil analysis due to the high sensitivity to friction offered by AE [28]. Nevertheless, successful applications of AE for health monitoring of a wide range of rotating machinery have been partly limited due to the difficulty in signal processing, interpreting and manipulating the acquired data [29-31]. In addition, AE signal processing is challenged by the attenuation of the signal and as such the AE sensor has to be close to its source. However, it is often only practical to place the AE sensor on the non-rotating member of the machine, such as the bearing housing or gearbox casing. Therefore, the AE signal originating from the defective component will suffer severe attenuation and reflections, before reaching the sensor. Challenges and opportunities of applying AE to machine monitoring have been discussed by Sikorska et. al and Mba et. al. [27, 32]. To date, most applications of machine health monitoring with AE have targeted single components such as a pair of meshing gears [33], a particular bearing or valve [34, 35]. This targeted approach to application of AE has on the whole demonstrated success. However the ability to monitor components that are secondary to the main component of interest such as a bearing supporting a gear, as is the case with planetary gears in an epicyclical gearbox, has not been well-explored. This is the first known publication to explore the ability to identify a fault condition where the AE signature of interest is severely masked by the presence of gear meshing AE noise. Also notably it is the first known application on a commercial helicopter main gearbox. The application of AE to this field is still in its early stages [28, 36, 37]. Moreover, there are limited publications on application of AE to bearing fault diagnosis within gearboxes [30]. This paper discusses the analysis of vibration and AE data collected from a CS-29 category ‘A’ helicopters industrial test facility and compares their effectiveness in diagnosing a bearing defect in the epicyclic module of helicopter main gearbox. The data was collected for various bearing fault conditions and processed using an adaptive filter algorithm to separate the non-deterministic part of the signal and enhance the signal-to-noise ratio for both AE. The resultant signatures were then further processed using envelope analysis to extract the fault signature.

3. Signal processing and data analysis

Bearing and gear fault identification involves the use of various signal processing algorithms to extract useful diagnostic information from measured vibration or AE signals. Traditionally, analysis has been grouped into three classes; time domain, frequency domain and time-frequency domain. The statistical analysis techniques are commonly applied for time domain signal analysis, in which descriptive statistics such as rms, skewness, and kurtosis are used to detect the faults [38, 39]. A fast Fourier transform (FFT) is commonly used to obtain the frequency spectra of the signals. The detection of faults in the frequency domain is based on identification of certain frequencies which are known to be typical symptoms associated with bearing or gear faults. The time-frequency domain methods are composed of the short-time Fourier transform (STFT) [40], Wigner-Ville [38], and wavelet analysis [41, 42]. The use of these detection techniques are feasible for applications where a single component is being monitored however for applications that include several components, such as gearboxes, it is essential to employ separation algorithms.

Signal separation was achieved using adaptive filter technique; methodology of using such technique is described by authors in [43-45]

4. Experimental Setup

Experimental data was obtained from tests performed on CS-29 Category ‘A’ helicopter gearbox which was seeded with defects in one of the planetary gears bearing of the second epicyclic stage. The test rig was of back-to-back rig configured and powered by two motors simulating dual power input.

4.1. CS-29 ‘Category A’ helicopter main gearbox

The transmission system of a CS-29 ‘Category A’ helicopter gearbox is connected to two shafts, one from each of the two free turbines engines, which drive the main and tail rotors through the MGB. The input speed to the MGB is typically in the order of 23,000 rpm which is reduced to the nominal main rotor speed of 265 rpm.