Influence of Lubricant Starvation on Gearbox Vibration Signatures for Condition Monitoring

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Abstract Different gear failure modes are strongly correlated with lubricant status, for example low oil level or starved lubrication leads to significant gear damages. In order to develop an early detection and accurate diagnosis of gearbox lubricant serving conditions based on online vibration measurements, this study will investigate the effect of lubricant starvation on the gearbox vibration responses. A two-stage helical industrial gearbox was tested under different lubricant shortage conditions. The results show that the gearbox vibration signature changes significantly with lubricant starvation, which includes more consistent increase in the amplitudes of vibration responses at meshing frequency harmonics and their associated sideband components. These changes correspond that vibration signal can be considered to normalise condition indicator of gearbox lubricant starvations.

Keywords: Gearbox, diagnostics, lubricant starvations, vibration response.

1 Introduction

Gears are key components that determine the capability and reliability of many industrial machine products. Gearbox oil lubricant is one of the most important components that protects gears from different failure modes. Insufficient lubrication can increase friction, temperature and material wear, which ultimately leads to a failure of the component materials that are essential to the system function [1]. The limitation of oil dip lubrication availability in the contact of gears and bearings with respect to their scuffing failure performance and flank load carrying capacity was investigated by Höhn B.-R. et al. (2011) in [2, 3]. They indicated that lack of cooling oil leads to high gear bulk temperatures and therefore increases risk of gear failures such as scuffing, pitting, micropitting and low-speed wear. Many works in the gearbox diagnosis have been presented using vibration analysis. They rely mainly on vibration analysis and focus on

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detecting mechanical faults such as a cracked tooth. Conversely, very few works examine the possibility of employing vibration analysis for detecting improper lubricant service levels [4-6]. Gear vibration characteristics are the key indicators in the diagnosis of machine faults, which was used to detect lubrication level of gearboxes with some limitations, as in Refs. [1], [4], [5] and [7]. In the meantime, the variation of tooth friction associated with the oil immersion depth has been presented in several researches. They concluded that less oil leads to higher friction coefficient [8] and more sliding friction between the teeth, which is a potential source of vibration and noise in gears [9-11] and certain amount of work is required to overcome the frictional forces, which can be observed in different ways such as frictional heat generation, noise, vibration [12, 13].

The references indicated that there is a strong relationship between gearbox lubricant volume and its vibration signatures, however, a few works emphasis this relationship for the purpose of condition monitoring and diagnosis. To fill this gap, this study will examine the vibration characteristics to normalise the condition indicator to the variation of gearbox oil capacity for future preventive maintenance.

2 Gearbox Oil Condition Monitoring

Gearboxes are very important and commonly used in different industrial applications. They must be kept in order, available and reliable under a wide range of conditions. However most gearbox failures can be attributed to improper lubricant statues and poor lubrication can increase bulk temperature of the gears and cause higher surface shear stress [2]. Therefore, it is a vital rule to monitor oil quantity in gearbox carefully in terms of system maintenance. Vibration analysis is one of the most effective techniques for monitoring the health of machinery to avoid catastrophic failures of machines [14]. Typically, gearbox oil level condition monitoring and diagnosis process can be achieved through different steps as shown in Fig. 1.

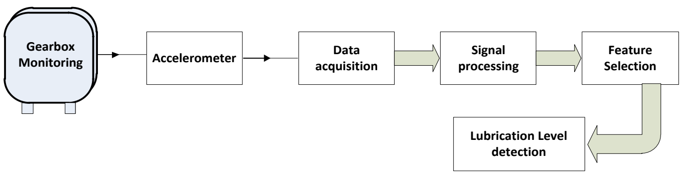

Fig. 1. Step configuration of gearbox oil level condition monitoring.

3 Experimental Setup and Test Procedure

In order to establish a relationship between gearbox oil volume and vibration signature, experimental work was carried out to monitor the oil lubricant conditions of a two-stage helical gearbox using a traditional vibration technique. The test rig comprised a back to back two-stage, 13.1 kW, helical gearbox driven by a three-phase induction motor and connected to a DC generator. The rig was powered by an AC motor with15kW, 1460 rpm while a DC motor/generator was used to represent different load conditions. An electromechanical accelerometer mounting to the gearbox housing was used to measure vibration signals, as illustrated in Fig. 2. Three different quantities were simulated as normal oil volume (BL, 2.6 litres) and two abnormal lube volumes (LV-600 and LV-1100), which are carried out by taking off 600ml &1100ml respectively. In order to simulate a common industrial machine and get reliable comparison data, the test rig was run under different operating conditions with a five times repeated scenario for each oil capacity.

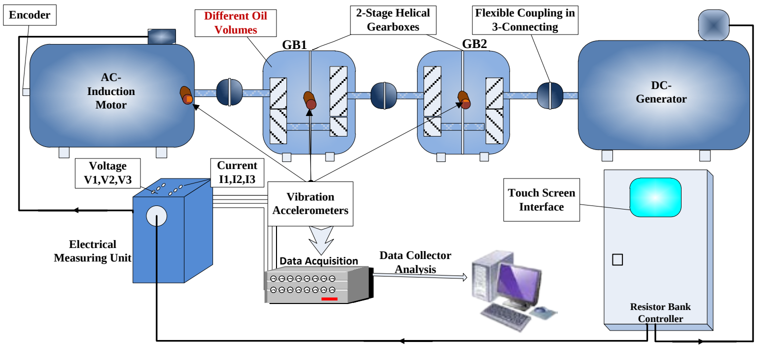

Fig. 2. Schematic diagram of the test rig system.

4 Results and Discussion

The main objective of this study is to investigate the effect of oil starvation on the vibration characteristics of gearboxes. The data sets were processed by necessary schemes including spectrum analysis and time synchronous average (TSA). The TSA is an effective technique used in vibration monitoring and fault diagnosis to suppress the components which are asynchronous with that of interesting [15].

4.1 Effect of Oil Starvation on Vibration Level

The most reliable parameter in condition monitoring is the root mean squared values (RMS) value which is a measure of the power content in a vibration signal [16]. Fig. 3 shows the RMS values of the TSA vibration signals under different conditions, whereas each test set was repeated five times for gaining more reliable results. It can be seen that the vibration levels of the tested gearbox (GB1) are generally increased with the reduction of oil quantity as compared with the normal gearbox (GB2), which shows approximately unchanged in the vibration level. The vibration changes are consistent with the results that presented in [1], which is owing to more friction between the surfaces of the meshing teeth. However, RMS is often not sensitive enough to detecting incipient faults in particular.

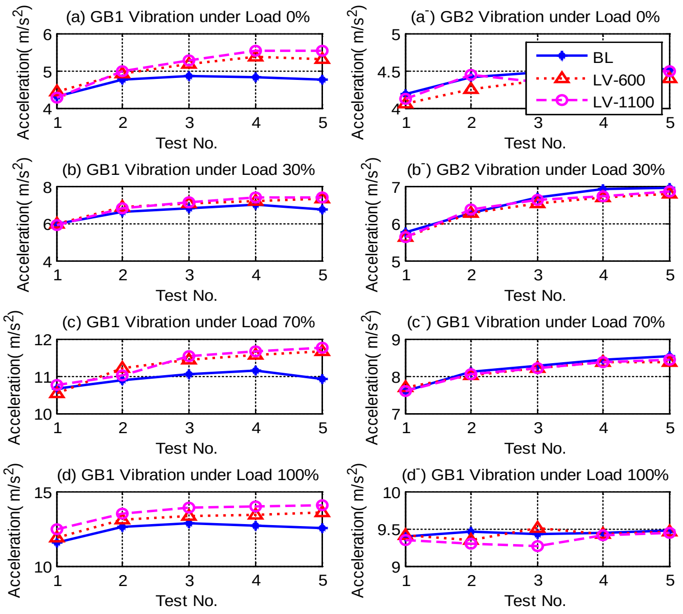

Fig. 3. RMS vibration signals of the two gearboxes

4.2 Vibration Response at Mesh Frequency

For further understanding of vibration change and hence to obtain a more detailed and accurate diagnosis of oil capacity variations, the change of spectral amplitudes at meshing frequency components is investigated, which usually indicates the gearbox conditions. Fig. 4 shows the amplitudes of vibration response at the first meshing frequency components. It can be seen that the second harmonic shows a very clear and consistent increase by more than 8% especially under high load operation.

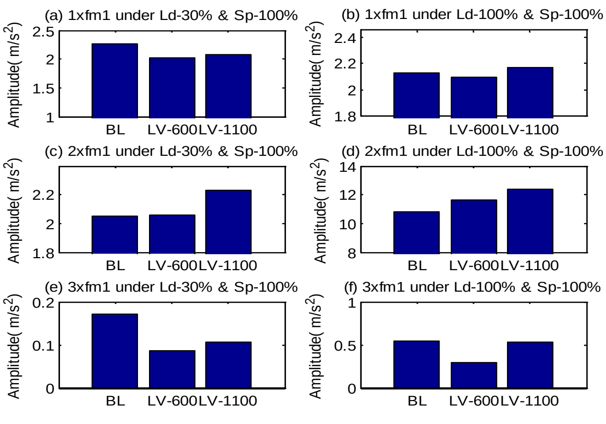

Fig. 4. Spectral peaks of 1st meshing frequency components

Fig. 5 shows the average amplitudes of vibration up to the tenth high order harmonics of two meshing frequencies. The vibration at the first mesh frequency which is the high speed stage with low load shows higher amplitude changes relating to the oil level variations. It is enhanced by more than 8% with the change of oil capacity, which can be considered as an effective feature to perform the instant diagnosis of gearbox lubrication levels. However, the vibration at the second mesh frequency which is the low speed stage with high load shows unclear behaviour, this is possibly because its meshing teeth are still fully submerged in oil.

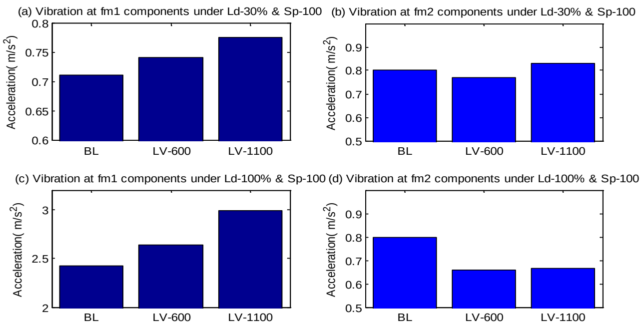

Fig. 5. Average vibrations at mesh frequency components

4.3 Vibration Response at Sideband Frequency

The analysis of sidebands around meshing frequencies is also often based for the detection and diagnosis of gear surface statues as it relates more to gear asymmetric faults such as broken tooth and investable manufacturing errors. The average spectral peaks at the lower and higher sidebands ($f_{sb} = f_m \mp f_r$) around the first three harmonics of the meshing frequency under full load are shown in Fig. 6.

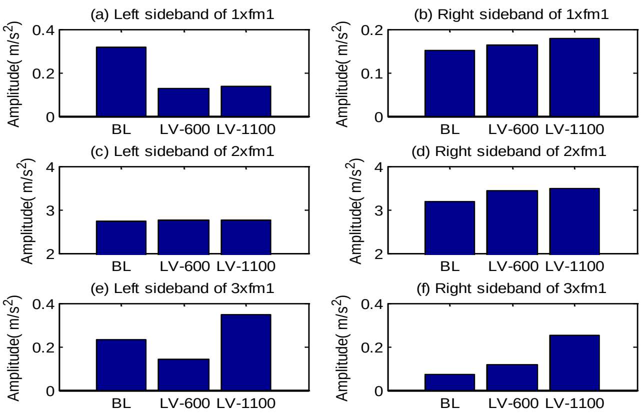

Fig. 6. Spectral peaks of sideband frequency components

It can be seen that the sideband amplitudes are generally increased with the reduction of oil capacity. In addition, more significant increase is demonstrated at the higher sideband frequencies which are enhanced by more than 6%. As a result these features can be also considered as effective indictors to poor lubrications. In conjunction with the change patterns of meshing components and TSA kurtosis, it is possible to make difference between tooth breakages and oil shortage.

Conclusion

Based on fault detection and diagnosis techniques, this study examines vibration signature of two stage helical gearboxes under different oil lubricant conditions in time and frequency domains. It investigates any measurable changes in the vibration signals that can be correlated with the gearbox lubricant starvations. The results obtained show that:

1. The vibration signal of the tested gearbox was changed significantly with the oil condition, which can be used to normalise condition indicator levels of serving oil.

2. An increase in the vibration level was demonstrated with the reduction of lubricant capacity which is a result of higher sliding friction between meshing teeth.

3. The result resolution of both meshing frequency and sideband components can be considered as effective measurements to recognize and perform the instant diagnosis of gearbox lubrication capacity.

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