Lack of Lubrication Condition in Bearings of a 3-phase AC Induction Motor

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***Abstract*— This paper aims to propose a model for identifying the lack of lubrication and its condition in the bearings of a 3-phase AC induction motor both qualitatively and quantitatively through the process of quality indexing. The analysis will be based on the technique of vibration condition monitoring. This work would contribute to the improved maintenance of induction motor bearings in the industry. LabVIEW and data integration techniques are used to develop and implement the model. The Sound and Vibration toolkit is used and signal simulation is performed. The output gives a quality index of the lubrication condition in the bearing.**

Keywords— Vibration, Condition monitoring, Bearing, Lack of Lubrication, 3-phase AC induction motor

I. INTRODUCTION

A 3-phase induction motor is an electro-mechanical energy conversion device that converts 3-phase input electrical power into output mechanical power. It finds its application in almost all aspects of the industry.

Condition monitoring (CM) is the process of monitoring certain aspects of a piece of equipment (such as vibration, temperature, etc) to detect any changes that might indicate a potential issue [10]. It is an important component of predictive maintenance since incorporating condition monitoring allows maintenance to be scheduled and preventative steps to be performed to avoid future failure and unexpected downtime.

Following are some of the guidelines that are suggested by TWI Global [10].

Condition monitoring can be broadly broken down into three steps [10]:

1. Install the Monitoring System
2. Baseline Data Measurement
3. Ongoing Monitoring

Bearing lubricant degrades and friction levels rise over time, which can be detected using accelerometers. As a result, the bearing requires grease replenishment to extend its life and prevent failure. When the bearing is well lubricated, vibrations are low and vice-versa. Hence, by analysing the frequencies of vibrations produced by the machine, it can be identified whether there are any defects in the system or not. This is the primary aim of the project. However, sometimes there are other conditions and factors which may cause the signals to indicate a lack of lubrication whereas, in reality, it would prove otherwise. The reasons could be the presence of contaminants like moisture or sand, loss in viscosity of lubricant and corrosion, or some other reason. Hence, it is also necessary to assess the qualitative aspect of the lubricant.

Machine vibration is a reliable indicator to detect bearing faults and also provides an understanding of the state of the lubricant. Hence, well-accepted standards are available such as ISO 10816 which is the most popular.

Several bearing manufacturers agree that incorrect lubrication conditions can account for more than 60% of bearing failures thereby making lubrication a key indicator of a bearing's life. Hence, techniques to detect and sense lubrication anomalies as well as provide the information are needed to take action [2].

Vibration signals are usually below 20 kHz but far above 1kHz, except for certain vibration resonances that can reach beyond that. The vibrations produced due to lack of lubrication are found to drastically reduce when grease is introduced into the bearing. As residual lubrication reduces the vibration gradually increases [3] thus raising the amplitude of the resonance frequencies. The presence of contaminants also produces signals but they have their particular signal characteristics which give them a distinction.

Lack of lubrication: Lubrication issues are characterised by high-frequency vibration (between 1 kHz and 20 kHz) with bands of peaks spaced apart from one another. This is because these frequency ranges excite the resonance frequencies of the bearings [6].

Vibrations can be expressed in metric units (m/s^2) or units of gravitational constant, g (1g = 9.81 m/s^2). This is the unit of measurement when the vibrations are measured using an accelerometer. All of the measurements made in this paper are in terms of acceleration.

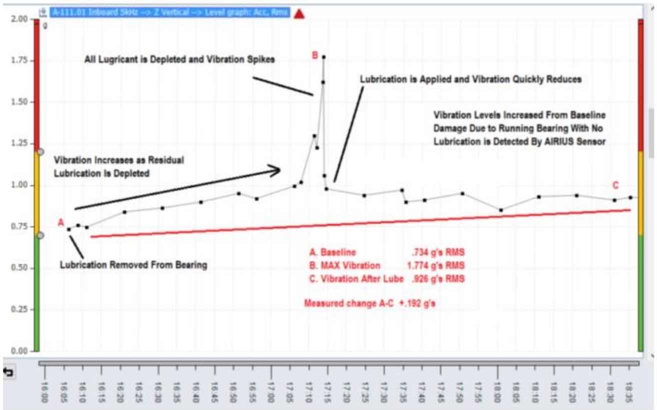


Figure 1: RMS trend graph in terms of g's [3]

Changes in the amount of grease in the bearings can be detected through vibrations produced while running the bearing. Even if the amount of grease is little, the vibration signals increase by a large amount.

Based on peak, RMS, crest factor, clearance factor, or kurtosis values, distinction between the lubrication states of the bearings is done [7]. These parameters provide a qualitative assessment of the condition of lubrication in the bearing. They would help in determining whether the condition of the lubricant is good, deteriorating, or critical.

The appearance of vibration signals from the bearings is shown in the following figures.

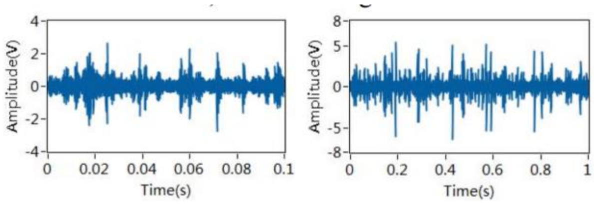


Figure 2: Vibration signal when no lubrication is present [4]

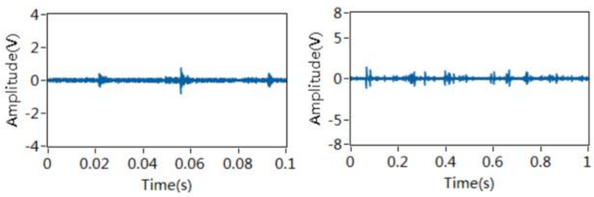


Figure 3: Vibration signal when complete lubrication is present [4]

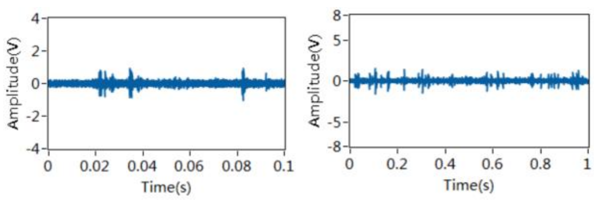


Figure 4: Vibration signal when partial lubrication is present [4]

The vibration level of bearings is related to surface degradation. Improper lubrication is expressed as the increase in spectral components at the bearing cage and ball spin frequency. Vibration signals are analysed in terms of Root Mean Square (RMS) values. Lubrication failures are caused by poor lubricant or viscosity, increase in temperatures, contamination by external substances like moisture and dirt, or even overlubricating [5].

Lack of lubrication influences acceleration RMS values and it is found that the frequency band of 8kHz-10kHz [6] [7] was most sensitive for detecting poor lubrication conditions. Grease conditions of the roller bearing can be defined using the mean and standard deviation values of standard signal estimators such as peak, RMS, crest factor, clearance factor, or kurtosis values, and concluded that the 8-10kHz band gives the best classification of bearing grease condition based on the vibration parameters [7].

A plot is shown in the following diagram.

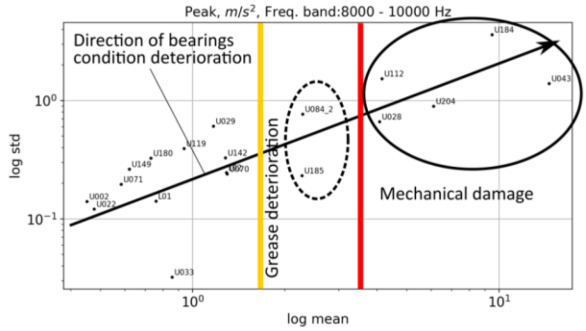


Figure 5: Plot of mean and standard deviation values of Peak accelerations of investigated bearings in band 8000- 10000Hz [7]

Development of this model will allow early detection of a future lack of lubrication in a motor's bearings and also determine the condition of the lubricant. The model will also attempt to identify the presence of contaminants, for example, moisture, if present, and retention of lubricant properties. However, this model would not be advanced enough to predict which type of contamination is present which would require a deeper study into the viscosity of the oil/grease in the bearings. This would be for future work.

II. MATERIALS AND METHODS

A. Motor selection

The developed model will be run on a 50 Hz, 0.78kW (1.04 HP), 3-phase AC induction motor at 1500 rpm which is a class-1 induction motor used in small machines according to ISO-10816 standards and the Bearing utilised – SKF 6205 Deep groove bearings. The motor finds use in industrial impeller aeration blowers. The details of the aforementioned bearing are provided:

DIMENSIONS

d	25 mm	Bore diameter
D	52 mm	Outside diameter
B	15 mm	Width
d_1	≈ 34.35 mm	Shoulder diameter
D_2	≈ 46.21 mm	Recess diameter
$r_{1,2}$	min. 1 mm	Chamfer dimension

CALCULATION DATA

Basic dynamic load rating	14.8 kN
Basic static load rating	7.8 kN
Fatigue load limit	0.335 kN
Reference speed	28 000 r/min
Limiting speed	18 000 r/min
Minimum load factor	0.025
Calculation factor	14

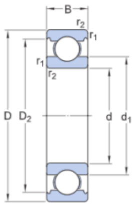


Figure 6: Bearing SKF 6205 Dimensions (Above) & Calculation data (Below)

B. Implementation

The software LabVIEW is used to develop the algorithm and test the model. The datasets for testing the model are obtained from experiments done by past researchers. The model will be able to predict whether the bearing has no lubrication or is partially lubricated or fully lubricated. Additionally, it also assesses the lubricant condition as good, deteriorating, or alarming.

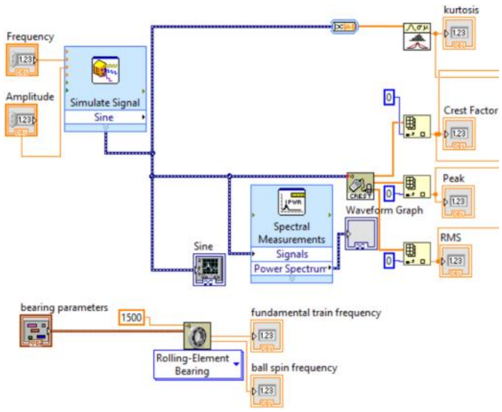


Figure 7: Simulation of obtaining parameter data on LabVIEW. Shown for a simple sine signal; FTF, BSF calculated for a specified bearing.

It is observed that the Peak and clearance values give the best separation for the condition of the bearings. By observation, it was determined that kurtosis values can be majorly used for identifying mechanical damage of the bearings [7].

The following parameter values have been calculated and have been considered for input-

− RMS;
− Peak;
− Crest Factor (CF);
− Kurtosis (KF);
−Clearance factor (CLF);

The method of classification will be based on Peak, RMS, Crest factor, Clearance Factor, Kurtosis and FTF (Fundamental Train Frequency) amplitude. These values are obtained by conducting envelope spectral analysis and the spectral analysis of the vibration signals.

The data from vibration sensors will be collected which will contain noise; after processing the vibration data and plotting the envelope spectra for the same, we can identify and compute the amplitude of the FTF and therefore compare the respective amplitudes. This will enable the classification of the bearing lubrication into different grease amount categories [8]. Further, the peak, RMS, crest factor, clearance factor and kurtosis help in determining the qualitative aspect of the lubricant in the bearing [7]. From these values, the qualitative aspect of the lubricant condition can be determined to some extent. For better analysis of the distribution, the plots of these parameters are made in the logarithmic scale. The best separation between the values of different bearings occurs at 8-10 kHz frequency bandwidth. These plots can show a trend of bearing condition deterioration [7]. These trends can then be divided into sections which can be assigned a class/category of condition.

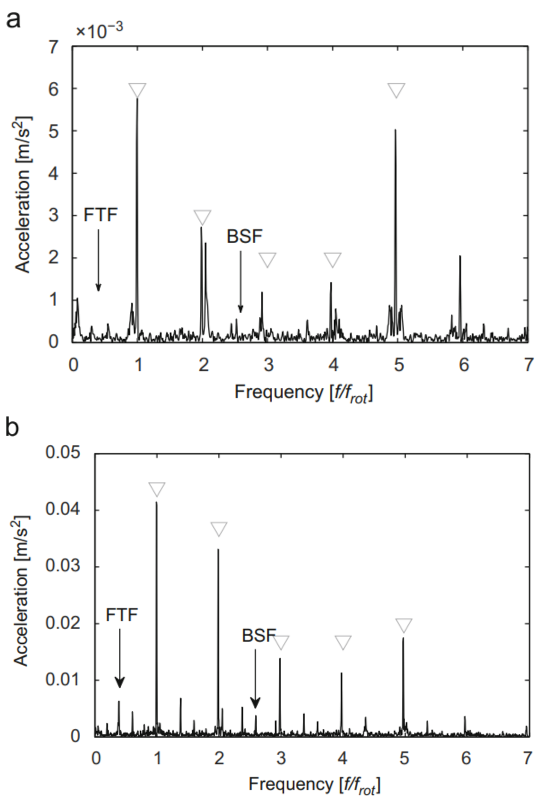


Figure 8: Envelope spectra a) Lubrication starved bearing b) Lubricated bearing [8].

The distinction between the lubrication starved and well-lubricated bearings based on the FTF and the Ball Spin Frequency (BSF) amplitude is most significant in the frequency range of 8 to 10 kHz range. Using the spectral coherence and the spectral kurtosis method, the frequency band can be obtained. This is specific to each bearing type.

In the 8.2–9 kHz interval the spectral coherence of lubrication starved bearing shows a significant increase compared to the one calculated for the properly lubricated bearing. Although there is a similarity in both the spectra, the spectrum of the lubrication starved bearing shows a significant increase in the amplitudes of the spectral components at FTF and BSF which are absent from the spectrum of properly lubricated bearing. The amplitude of the FTF spectral component was recorded as the relevant feature [8].

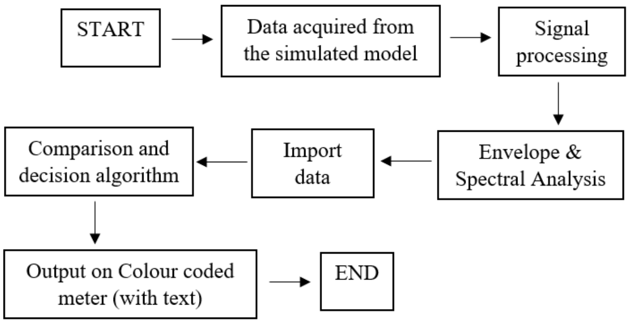


Figure 9: Flow chart of the implementation procedure

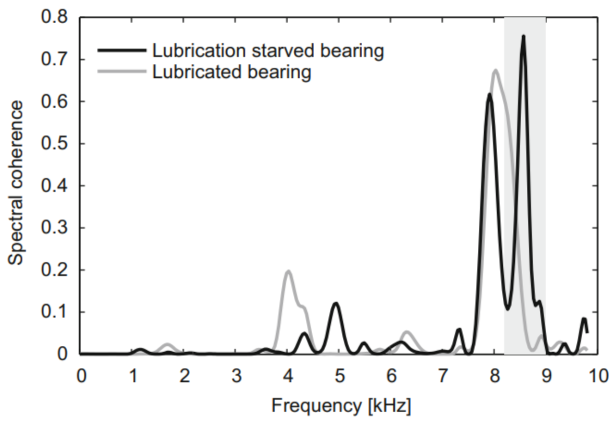


Figure 10: Spectral coherence plot for lack of lubrication [8]

The following table is the imported inputs from the CSV file into LabVIEW. It contains data on motor bearings in different conditions. It is displayed in array format.

Bearing No.	0	1	2	3	4	5	6	7
Mean Peak value	0.25	0.36	0.42	0.13	4.56	2.3	5.54	0.88
Mean RMS	0.1	0.098	0.11	0.056	0.314	0.164	0.31	0.088
Mean Crest Factor	2.5	3.673	3.818	2.321	14.522	14.024	17.871	10
Mean Clearance Factor	10.25	10.36	11.54	9.86	31.24	22.34	35.56	12.69
Mean Kurtosis	2.35	3.65	4.58	2.36	10.49	9.1	10.58	6.98
FTF Amplitude	2.45	2.94	4.52	1.65	4.12	3.25	1.57	2.39

Figure 11: Table of the Input parameters of the bearings obtained from motor

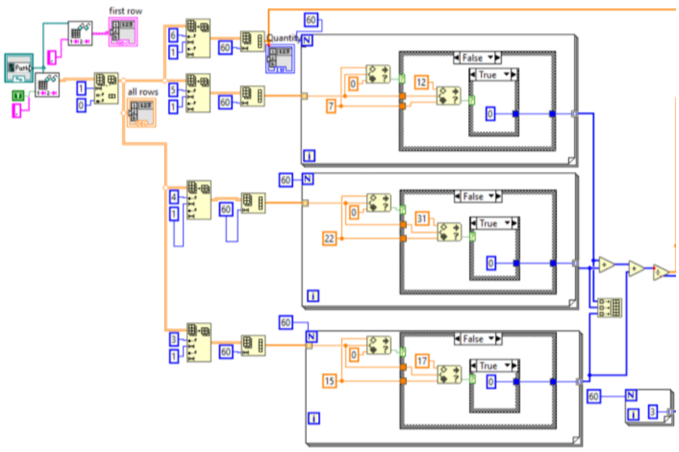


Figure 12: Data Import and Comparison and decision program on LabVIEW.

III. DISCUSSIONS

The following figures are a display of all the possible output that the program produces corresponding to a given bearing condition.

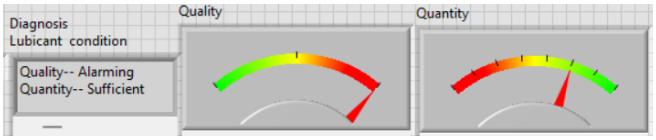


Figure 13: a

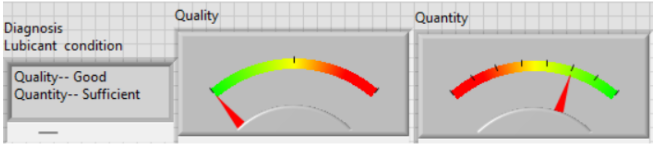
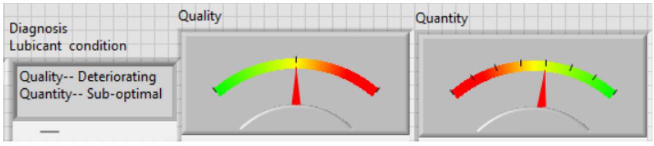


Figure 13: b



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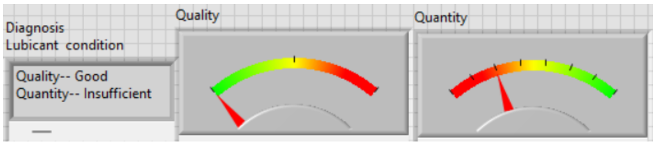
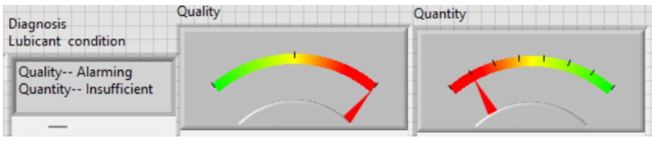


Figure 13: d



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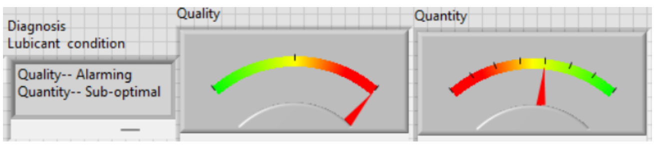

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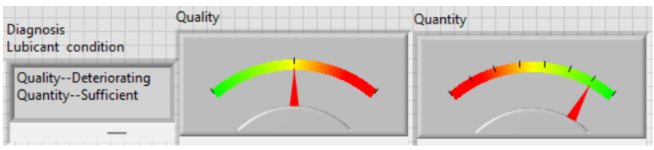

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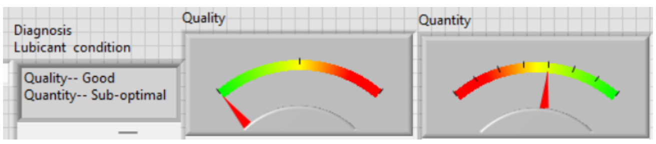

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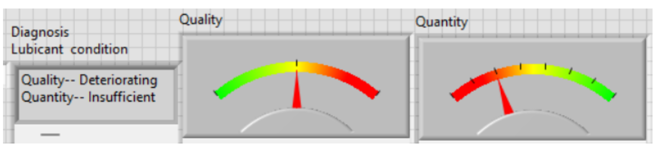

Figure 13: i

The algorithm has been proven to detect and past attempts on similar algorithms show that even small changes in the amount of grease/lubricant present in the bearing can cause significant changes in the frequency and time domain plots and important conclusions can be made and the model can also take right decisions with high accuracy.

The frequency amplitudes are indicative of the lubrication amount present in the bearing.

IV. Conclusion and future work

A. Conclusion

The program is successfully able to identify the lack of lubrication in bearing by using the chosen parameters. It identifies and assesses the condition of lubrication in the bearing and provides a quality index for the same.

B. Future work

The program certainly has limitations. Since the data points were lower in number, the accuracy of the system is low. Hence, efforts could be made to increase the number of data points and thus generate more accurate parameter ranges for more dynamic grading and indexing. This system is not completely automated. It just works as a quality indexing tool for classifying and grading the lubrication condition in the bearing when the parameter value ranges are pre-fed into the program. Signal processing and quality indexing are 2 independent processes here. Efforts could be put to integrate the 2 systems. A Machine Learning algorithm could be used to pinpoint the type of fault in the bearing to help make better decisions.

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