Unbalanced Load Condition Fault Detection and Identification a Condition Monitoring Approach

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Summary
Industrial motors are the backbone of industry and bear harsh environmental and mechanical stress. Unbalanced loading is the major cause of failure in induction motors used extensively for industrial applications. Predicting any unbalanced load condition by measuring the vibration of the motor and its assembly has always remained a successful technique apart from other techniques for predictive maintenance. In this paper, a system of detecting and analyzing the unbalanced load condition is designed using an accelerometer and a temperature sensor. The overall system is designed through LabVIEW programming and both the sensors are interfaced through an Arduino making a data acquisition system. The continuous vibration of load side drive end bearing, the temperature of bearing, and motor winding temperature with balanced and unbalanced load conditions are monitored with the designed system. Hysteresis control to turn off the motor is incorporated when the limits of vibration and winding temperature are observed. Results show that the developed condition monitoring system is fully capable to detect increased levels of vibration and temperatures due to an unbalanced load condition and can prevent the damage of the motor in extreme conditions.
Keywords:
Vibration, Temperature, Unbalanced load, induction motor, winding.

1. Introduction

Induction motors play an important role as driving force of industry and bear harsh environment and are widely used to drive different kinds of loads such as fans, centrifugal pumps, elevators, blowers, compressors, etc. With the passage of time, they start degrading and lead to major failure owing to various types of faults. These faults include supply imbalance, stator winding failures, broken rotor bars, misalignment, static, dynamic air-gap irregularities, rotor imbalance, and bearing failures [1-3]. Vibration analysis provides a great deal of information regarding any fault in a rotating machine. In rotating equipment, vibrations are produced due to faults such as mass unbalance, misalignment, looseness of parts. Misaligned shafts usually produce extra vibration; thus, generating huge forces on bearings and consequently reducing the life span of the machine [3, 4, 5]. Bearings in any machine support the system and the disturbances from the rotor are shifted to the bearings where data is acquired [6, 7]. Vibrations observed at the bearings represent the influence of unbalance on the system. Hence, it is necessary to know the amplitude of the vibration of the shaft from the vibration signals sensed at bearings.

In rotating machines, either they are center-hung or overhung unbalance which is caused by improper distribution of mass around the shaft at center line. Rotation unbalance shaft produce a fluctuation in the force and thus leading to failure if not taken care. Unbalance force can be calculated by the formula (See Eq. 1) and can be seen that radius (r), mass (m), and angular speed (ω) are directly proportional to the unbalance force (F) [8].

$$F = mr\omega^2 \qquad (1)$$

At greater speed even small unbalance mass can produce greater force. Hence, it is necessary to detect the unbalance at early stage and vibration data helps to detect various faults at an early stage. In general, displacement, velocity, and acceleration are the main parameters used to evaluate the vibration characteristics of any dynamic system [9]. Time domain methods are applied directly on vibration signals in order to detect the change in their amplitude and energy distribution in the presence of a bearing failure [10]. In [11], multiple faults of induction motor are diagnosed using fast Fourier transform (FFT) and short time Fourier Transform (STFT) based spectrogram. While, [12] presents a frequency domain method to detect bearing faults in induction motor using current signature analysis via FFT on FPGA board. In [13], a STFT based technique for vibration analysis of a three-phase motor has been applied successfully. The vibration spectrum analysis along with phase analysis has been

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successfully performed for the detection of shaft unbalance in [14, 15].

For vibration analysis, there are many techniques such as FFT, shock pulse analysis, ultrasonic analysis, time waveform analysis, and power spectral density. Condition monitoring by using LabVIEW and Arduino is an online technique for industrial machines. In this technique, Arduino is used to interface the analog output values of different sensors and to perform serial communication. In [16], a portable design of Arduino based prototype has been designed to detect the faults in rotor bars of the induction motor using DFT spectral analysis. Arduino with Zigbee based wireless control and monitoring system is shown feasible for monitoring, starting, and stopping where wired communication becomes costly or physically impossible [17].

Condition monitoring of rotating machines can save costs occurred on maintenance as well as saves crucial time. Data analyzed for the condition of the equipment is used for predictive maintenance [18]. Several condition monitoring techniques are being used nowadays [19]. In this paper, we have developed an overall system comprising motor with shaft detecting healthy and unhealthy bearing vibration using an Arduino, an accelerometer and temperature sensor. The designed system is tested with induction motor faults and analyzed with the healthy and unhealthy condition. The overall system detects and provides unhealthy condition measures as well as shutdowns the system in case of unhealthy conditions.

The remainder of this paper proceeds as follows. In section 2, the system methodology is discussed that is followed by the system design and implementation in section 3. In section 4, the results and analysis are presented that is followed by the conclusion in Section 5.

2. Methodology

To develop the experimental setup for this investigation a 0.5hp single-phase induction motor is used to drive a cylindrical load mass of 4.2 inches coupled through a straight coupling. The ADXL335 accelerometer and LM35temperature sensor are used to monitor the vibration and temperature of the motor. The mass as a load resides on the derive end (DE) and non-derive end (NDE) bearings of the two pedestals making a center-hung system. The motor current winding is continuously measured and displayed in a LabVIEW panel which indicates status of unbalanced load, unhealthy bearing, and winding temperature. A hysteresis based control turns off the motor when the winding temperature rises to a reference value. The upper trigger point UTP is already fixed and makes ready the motor to be turned ON when the winding temperature reduces below the lower trigger point (LTP). The block diagram of the experimental system is shown in 오류! 참조 원본을 찾을 수 없습니다..

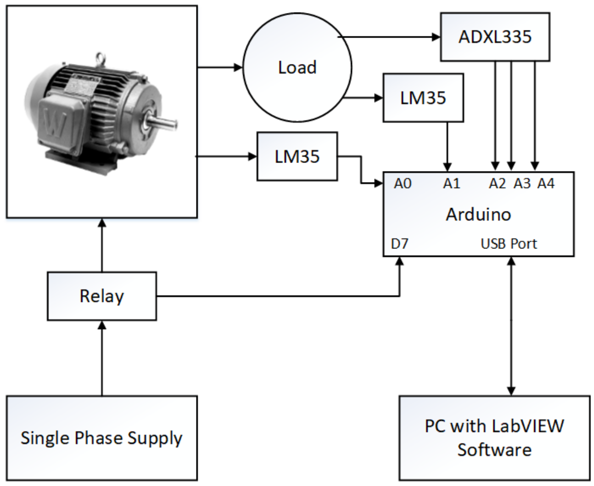

Fig. 1 Block diagram of the condition monitoring system

The three-axis output(x, y, and z) of an accelerometer measures the DE bearing vibration which is connected to A_2, A_3, and A_4 analog input pins of Arduino. The temperature sensors outputs measuring DE bearing temperature and winding temperature of the induction motor and these sensors are connected to analog inputs of Arduino A_1 and A_0, respectively.

Arduino is connected to the computer through a USB port for the two-way communication between Arduino and LabVIEW. Continuous display of parameters, balanced and unbalanced load conditions are performed in LabVIEW panel. The LabVIEW software sends the control signal to Arduino board to turn off the motor through digital output D_7 that is connected to the relay board, which ultimately turns on and turn off the motor by a hysteresis control.

3. System Implementation and Analysis

The implementation flow diagram of the algorithm is given in Fig. 2. It is evident that analog values of voltages representing bearing vibration, bearing temperature, and the winding temperature is measured and compared with reference set-point values in the LabVIEW panel. In the first place, the acquisition of continuous vibration and temperature signals is compared with the acquired DE bearing vibration, DE bearing temperature, and winding temperature with reference values. In the second stage, then, process the vibration and temperature signals in the time domain and display it in the LabVIEW panel continuously. Continuously, it is determined whether the load is balanced or unbalanced. In case, the load is unbalanced then turns on the Red indicator of over vibration on the LabVIEW panel. If bearing and winding temperatures are greater than reference values then indicate in red on the LabVIEW panel as over-temperature and turn off the motor by a hysteresis control. If bearing and winding temperatures are below a LTP then enable the motor to be turned ON again through the LabVIEW panel.

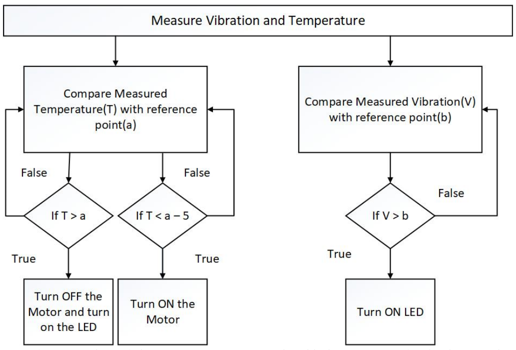

Fig. 2 Algorithm to turn on and off the motor in balanced and unbalanced condition based on hysteresis control

In Fig. 3, the realized hardware of the condition monitoring system in which a single-phase induction motor of 0.5hp is used and operated at a fixed speed of 1450 rpm. The motor shaft is connected with a balanced cylindrical mass having a size of 4.2" as load supported by two ball bearings. An accelerometer and a temperature sensor are installed on DE bearing. A temperature sensor mounted in winding of motor also to measure the stator winding temperature of the test motor is shown in Fig. 4.

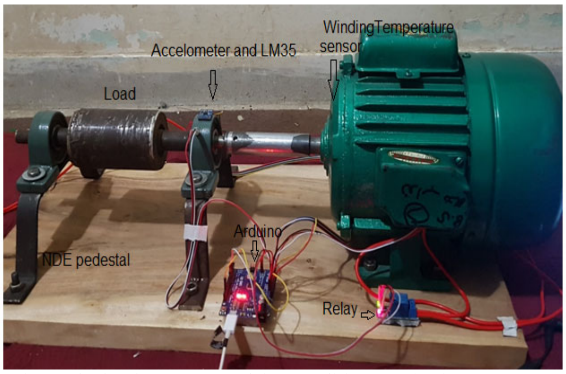

Fig. 3 The hardware setup of the Condition monitoring system

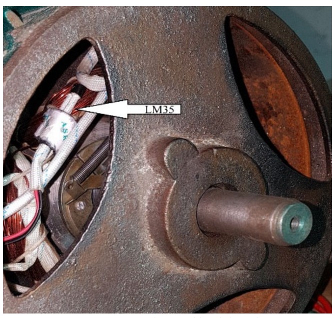

Fig. 4 Temperature sensor installed in the motor winding

4. System Testing and Results

This test and analysis of the system is performed on the two conditions as balanced and unbalanced load. The load configuration is shown in the Fig. 5 and Fig. 10. Implementation and results obtained in both the scenarios are discussed as under:

4.1 Balanced Load Condition

The center-hung mass as balanced circular rotor is rotated at a fixed speed of 1450 rpm shown in Fig. 5. Resulting measurements of the healthy condition of bearing vibration for 3 axes with bearing and winding temperature is shown in Figs. 6-9. Observed values of vibration are x=0.1g, y=0.36g and z=1.277g. Observed values of bearing temperature are ranging from 20-28°C. Observed values of winding temperature are 28-30°C.

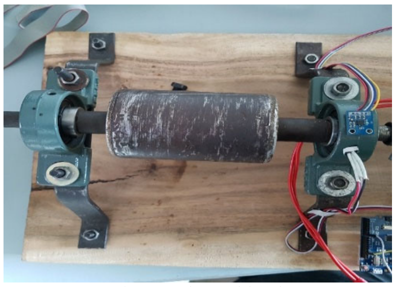

Fig. 5 Balanced load

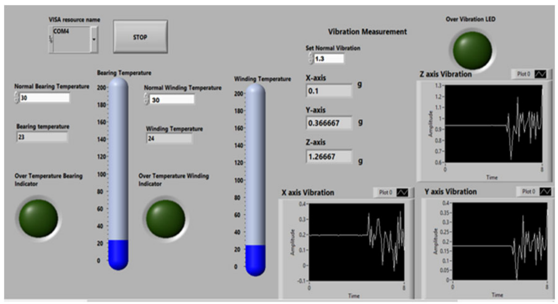

Fig. 6 Combined LabVIEW panel

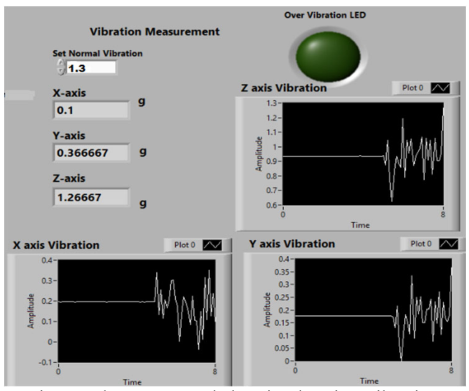

Fig. 7 LabVIEW panel showing bearing vibration

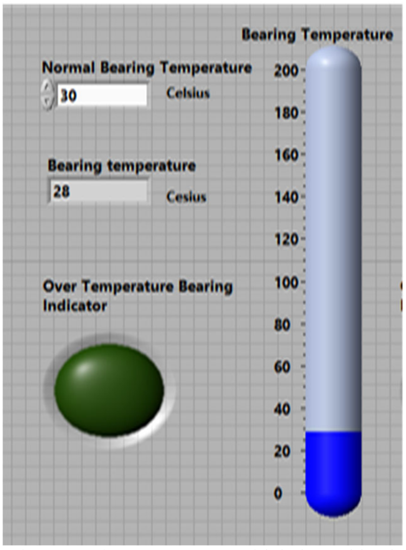

Fig. 8 Bearing temperature with balanced load

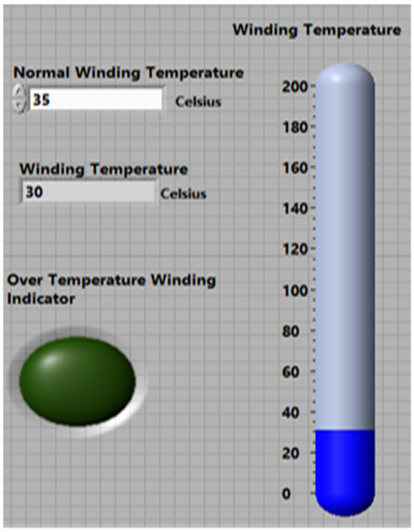

Fig. 9 Winding temperature with balanced load

4.2 Unbalanced Load Condition

Before measuring the unbalanced condition, the reference values were adjusted in the LabVIEW panel based on the previous readings in healthyconditions. For the unbalanced load, two holes drilled in rotor mass shown in Fig. 13 in which a metal strip of the extra weight of 200 grams fixed at one side of the rotor and motor was operated at 1450 rpm resulted in an unbalanced rotor shaft. Unhealthy parameters are measured continuously and the red indicator is turned on as an emergency alarm when the measured value becomes equal to the reference value as Set Normal value in the LabVIEW, then this signal is sent to Arduino digital pin, and the motor is turned off by relay. At every alarm, of temperature, the motor was turned off by hysteresis control. The adjusted values for alarms, measured values in balanced and unbalanced are summarized in Table 1.

Table 1 Summary of reference and measured

S. No.	*Measurements and Set-points*			
	Parameter	*Reference*	*Balanced*	*Unbalanced*
1.	DE Vibration z-axis	1.3g	1.2g	1.38g
2.	DE b Temperature	32°C	20-25°C	25-32°C
3.	Winding temperature	37°C	28-30°C	Above 37°C

DE bearing vibration was observed up to 0.22 g, 0.43g, and 1.38g on the x, y, and z-axis respectively that is shown in Fig. 11. Vibration on the z-axis was required to be observed and results show a small burst with healthy and a huge burst with unhealthy bearing z-axis vibration in Fig.12. A plot of measured vibration in both conditions is also given in Fig. 13. The rise in bearing temperature from less than 25°C and indicator at 32°C in red is shown in Fig. 14 and Fig. 15, respectively. The motor winding temperature rises from less than 20°C to greater than 37°C which resulted in the motor turned off at 37°C by hysteresis control is shown in Fig.16 and Fig.17.

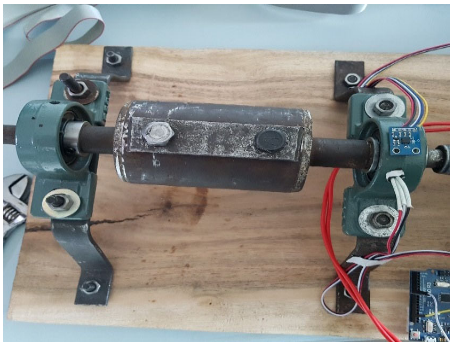

Fig.10 Unbalanced load installed

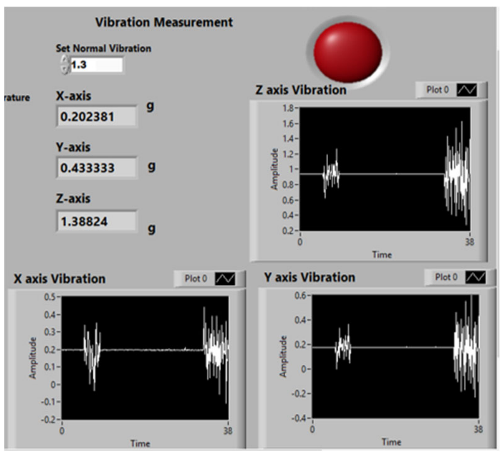

Fig. 11 Lab VIEW panel showing rise in vibration

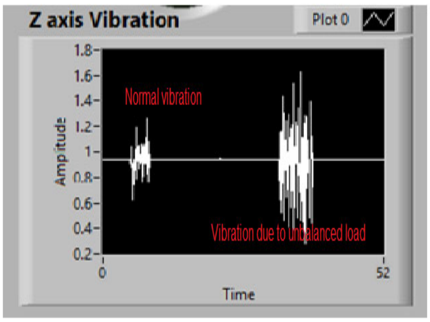

Fig. 12 LabVIEW panel showing vibration in normal and unbalanced load condition

Fig. 13 Vibration graph in balanced and unbalanced load

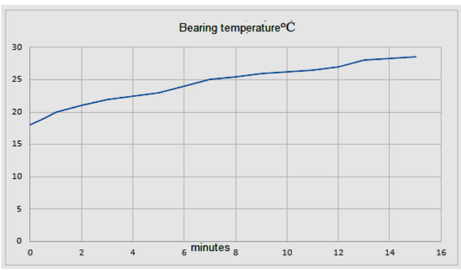

Fig. 14 Graph of bearing temperature rise

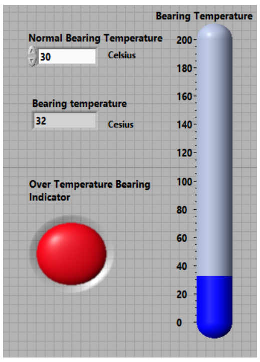

Fig. 15 Over temperature indication for bearing temperature

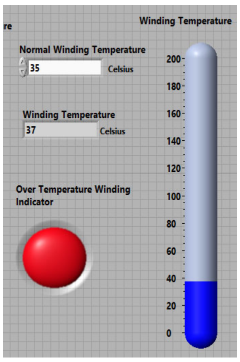

Fig. 16 Over temperature indicator of stator winding temperature

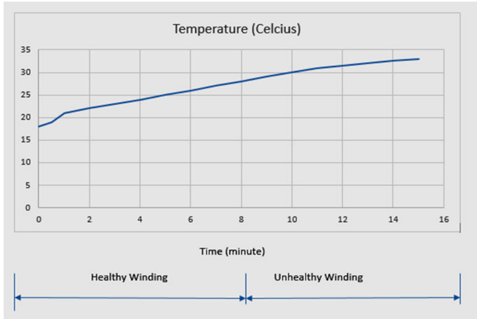

Fig. 17 Graph of rise in winding temperature

5. Conclusions

In this paper, a test bench is developed for condition monitoring of the induction motor. The performance parameters such as vibration and winding temperature are observed through Arduino and LabView. These parameters are monitored in balanced and unbalanced load conditions. It is observed that a temperature and bearing vibration are raised in unbalanced load condition as compared to balanced load condition. Additionally, a hysteresis based motor control mechanism is also implemented to turn OFF the motor at the detection of unbalanced load condition. This Arduino based system can be utilized for predictive maintenance of motor as well as assembly. In future, the system can be upgraded to an IoT by connecting a Wi-Fi module-based platform with Arduino.

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