MODELLING A CONDITION MONITORING BASED CONTROL USING MATLAB/SIMULINK FOR ROTATING ELECTRICAL MACHINES

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ABSTRACT

This research attempts to model a protection system for rotating electrical machines through online condition monitoring to indentify the problem including the problematic source in the machine and to protect breakdown due to excessive vibration without human intervention. Maintenance of electrical machines is essential so, condition monitoring of machines is gaining importance in industry to reduce the downtime costs and increase machine reliability.In this work a simulation model has been developed using MATLAB/ Simulink for online condition monitoring to detect the problem and to protect the machine without human intervention. If any problem is occurred in any location in the machine then vibration of the whole system increases.It extracts the maximum value of vibration signals coming from different bearing positions of the machine. If the magnitude of vibration is in 'unacceptable' range then it trips the relay to stop the system and creates a buzzer sound to alert everybody. If the magnitude of vibration is in 'unsatisfactory' range then an alert message has been designed to appear on the computer screen with different buzzer sound for caution.In 'unsatisfactory' and 'unacceptable' condition it displays serial no. of defective bearing.This system not only protects the unscheduled shut down of machines but also increases the lifetime of machine components.

KEYWORDS

Condition Monitoring, Vibration Analysis, MATLAB/SIMULINK.

1. INTRODUCTION

Rotating electrical machines are the essential components in industry. The unscheduled shut down caused by a failure of machines can cause enormous costs. Energy loss increases due to unscheduled shut down of machine and it increases total economical losses[1]. More energy losses actually come from the unscheduled downtime caused by the unexpected motor failures, which, can be catastrophic and intolerable for certain industries. The most common types of faults in rotating electrical machines(see Figure. 1) have been found using failure surveys and these have been categorised according to the different components of machines[2,3] -(i) Stator fault (37%), (ii) Rotor fault(10%), (iii) Bearing faults (41%), (iii) Other fault (12%). Application of condition monitoring system for machines is increasing industry due to the need to increase machine reliability and decrease the possible loss of production due to machine breakdown. Nowadays, application of online machine condition monitoring is increasing to reduce both unexpected failures and maintenance costs. Using this technique health of rotating machines can be monitored and machine problems can be detected when it is operating [4].A block diagram of the general approaches shown in figure-2. M.L. Sin, W.L. Soong and N. Ertugrul (2003) surveyed about the current trends in on-line fault detection and diagnosis of induction machines and also indentified future areas for research to diagnose the machine faults[5].K. Vinoth Kumar, S. Suresh Kumar, Badugu Praveena(in 2010) developed a soft computing technique based model using MATLAB/Simulink for online condition monitoring system to detect the faults[6]. O. Uyar, M. Cunkas (in 2011) designed a Simulation model for motor protection system against six different fault parameters, fuzzy logic is used to compute the delay time,If the problem persists at the end of this delay time, the system sends a signal to stop the motor to avoid expensive failure [7].

In this paper a simulation model has been developed using MATLAB/SIMULINK for electrical drives to identify abnormal machine condition and to protect unscheduled shutdown. When vibration range is 'unsatisfactory' it alerts by sending a alert message in the computer screen with a buzzer sound. When vibration range is 'unacceptable' it trips the relay to stop the system creating different buzzer sound.It displays the problematic source (display the serial no. of machine bearing) in "unsatisfactory" and "unacceptable" condition.

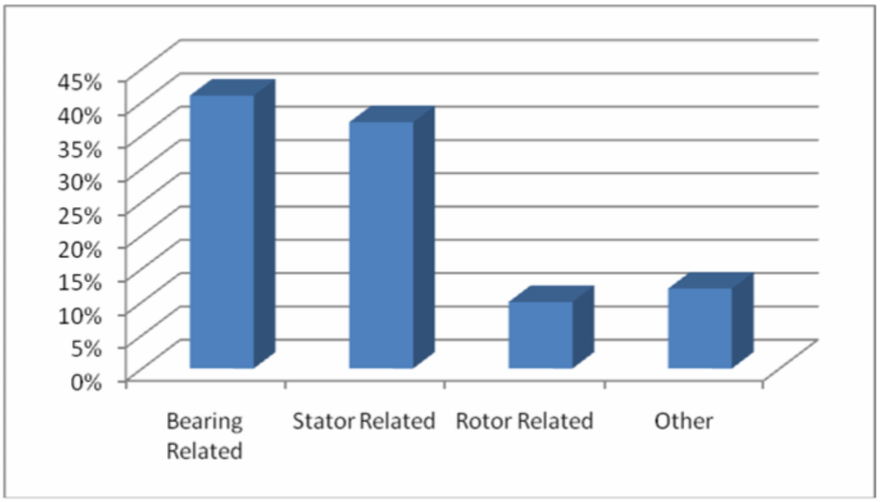


Figure 1. Different types of faults in rotating electrical machines in %.

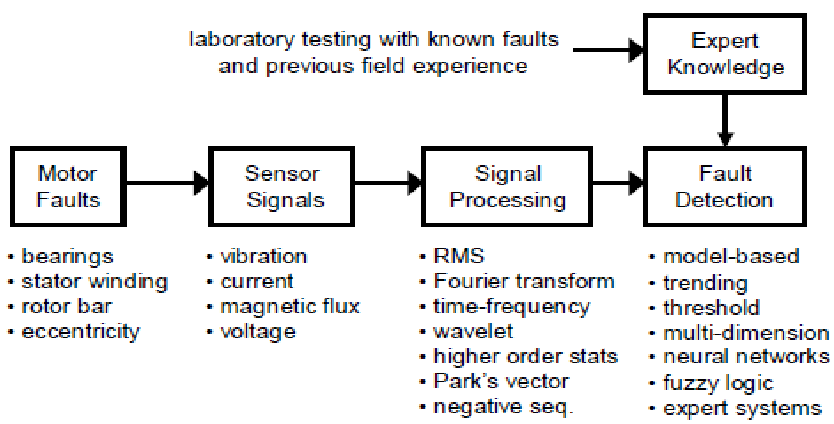


Figure 2. The online condition monitoring process.

1.1. Vibration Analysis

The most commonly used condition monitoring system is the vibration-based condition monitoring. The vibration monitoring technique is based on the principle that in running condition all systems produce vibration. When a machine operates properly, vibration range is small; however, when a fault develops and some of the dynamic processes in the machine change, the vibration also changes.Vibration based condition monitoring is the most reliable method to assess the overall health of a rotating motor drive system. Vibration based condition monitoring system requires storing of a large amount of data. Multiple sensors are mounted often to measure the vibration on different parts of the machine. In abnormal condition the machine vibration will be very high.Cesar da Costa, Mauro Hugo Mathias, Pedro Ramos & Pedro Silva Girão used MATLAB/Simulink to model for the implementation of vibration measurement and analysis instruments in real time based on circuit architecture [8]. Mikhail Tsypkin have shown(2011) that vibration analysis is a efficient and convenient tool for diagnosing different types of mechanical and electromagnetic problems in induction motorsusing case histories from VSC's(Vibration Specialty Corporation) field service files[9].

1.2. Bearing Problems

Ball or rolling type bearings are normally used in rotating electrical machines. 40-50% of machine faults are correlated with bearing related problems. Bearing problems occur due to some mechanical and electrical problems. There are some techniques to find out bearing faults in rotating machines. Using motor current wavelet transform the baring faults in induction motors can be detected [10]. Using stator current based analysis the bearing faults can be detected [11,12]. Frequency response analysis can be useful to detect the outer and inner race faults of rolling bearings [13]. Bearing faults in electrical machines can be detected using high-resolution spectral analysis of the stator current [14].Bearing problem can create rotor eccentricity. If some problem occurs in any of the bearings of the electrical machines then the vibration of the whole system increases. The abnormal vibration causes unscheduled shutdown and it reduces the lifetime of machine components, so continuous monitoring is necessary. The Vibration spectrum analysis of bearing inaccuracies is shown in Figure 4.

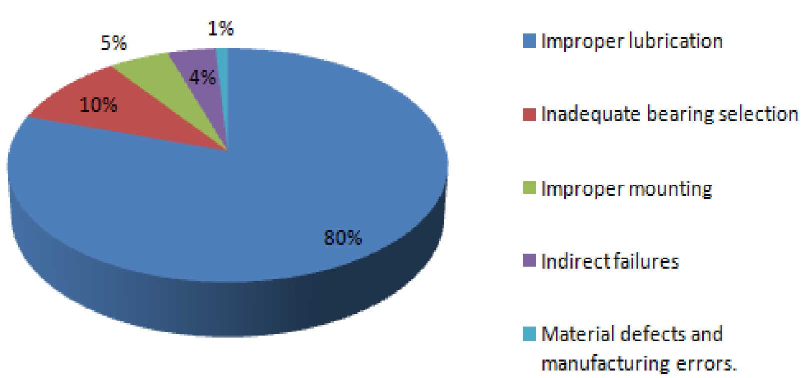


Figure 3. Common bearing failure causes in %

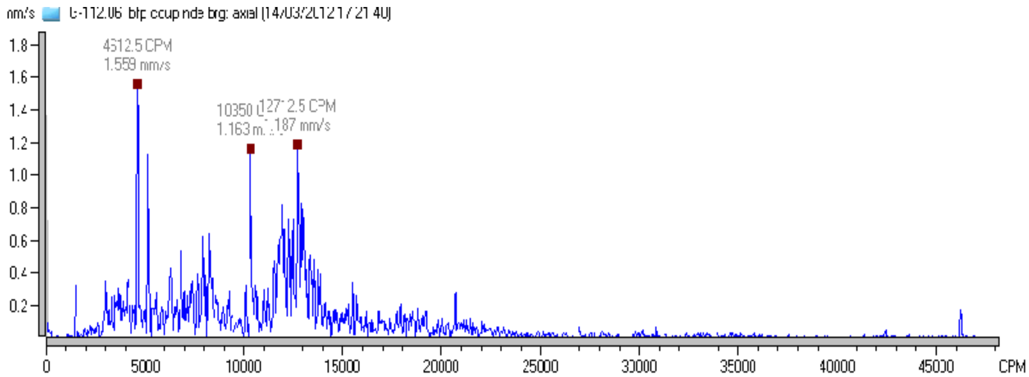


Figure 4. Vibration spectrum of bearing inaccuracies.

1.3. Bearing problem caused by electrical erosion

Electrical motor controlling became very easier with the introduction of variable frequency drives using Pulse Width Modulated (PWM) principles but there was a drawback in using VFDs :the high frequency currents, circulating or shaft grounding(figure 5) ; and some capacitive discharge currents due to high rate rise of voltage and the high switching frequencies, coming from the common mode voltage, indirectly.

The combination of capacitive discharge currents and high frequency currents induces shaft voltages and bearing currents. The voltage reaches to a certain value where it discharges to ground through the bearings. It overcomes the barrier of lubricant film thickness when threshold voltage occurs and a discharge occurs in that time. The voltage charges up again like a capacitor would do and it is not controlled in motors and leads to ‘electrical erosion’.

Electrical motor bearings can suffer from electrical erosion. It leads to bearing damage and consequently premature bearing failure.

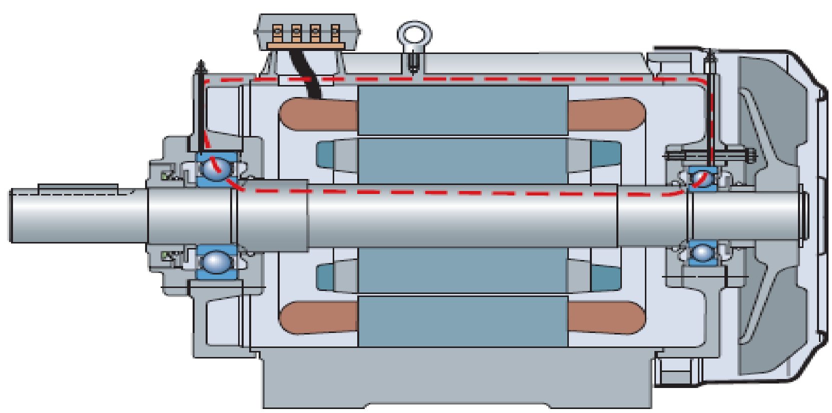


Figure 5. High frequency circulating current in a electrical motor.

1.4. On-line condition monitoring

On-line condition monitoring system is also called permanent monitoring system. From the selected points of the machine the vibration is measured and is constantly compared with acceptable levels of vibration.The principalfunction of a online condition monitoring system is to protect the machines from excessive vibration by providing a warning that the machine is operating improperly. The online monitoring techniques with time domain and frequency-domain approaches can be used in the industry[15].S. H. Chetwani, M. K. Shah & M. Ramamoorty(2005) describes the utility of online monitoring technique to detect various faults (broken bar in the rotor cage of induction motor, bearing faults, eccentricity faults and stator turn to turn short) in running motors without shutting down [16].

2. METHODOLOGY

Vibration is characterised in terms of velocity, displacement, acceleration, frequency and phase. Displacement, velocity & acceleration show how much vibration is present in the machine, the units are micron, mm/sec & mm/sec^2 respectively. Frequency, computationally determined, signifies the causes of vibration. Phase is useful in identifying from where the vibration is coming and also used in field balancing.

Velocity is used as input parameter in this paper.If some problem occurs in any of the bearings then the vibration of entire system increases. The magnitude of vibration is maximum in the problematic position of bearing. If the velocity range is 'unacceptable' range then it automatically stops the system by tripping the relay creating a buzzer sound and it also gives an alert message with different buzzer sound when magnitude of velocity is in 'unsatisfactory' range. It is applicable in online condition monitoring system. In 'unacceptable' and 'unsatisfactory' condition it displays serial no. of defective bearing.

Table1. Vibration ranges of machines according to ISO 2372.

Machine	Good	Unsatisfactory	Unacceptable
Class-I	<2.5 mm/sec	(2.5 - 4.5) mm/sec	>4.5 mm/sec
Class -II	<4.5 mm/sec	(4.5 – 7.2) mm/sec	> 7.2 mm/sec
Class-III	<7.2 mm/sec	(7.2 - 11.2) mm/sec	> 11.2 mm/sec
Class-IV	<11.2 mm/sec	(11.2 – 29.2) mm/sec	>29.2 mm/sec

Raw vibration data is necessary from a faulty machine to verify this model. The data is collected from a motor and a centrifugal pump using vibration meter for the analysis[Figure-6]. Data is collected from different bearing positions of the faulty system in velocity mode.It is collected in 'axial', 'horizontal' and 'vertical' direction on different bearing positions of the system[Table-2].This is a class-III machine.

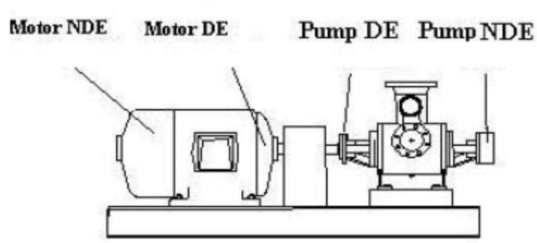


Figure 6. Diagram of motor- pump unit.

Table 2. Measurement of vibration of the machine in velocity mode.

Position	Velocity		
	Horizontal	Vertical	Axial
MNDE(A)	3.46	2.58	2.79
MDE(B)	2.65	2.50	3.35
PDE(C)	8.71	7.83	7.61
PNDE(D)	8.08	5.02	5.22

MNDE(A)- Motor Non Driving End, MDE(B)- Motor Driving End, PDE(C)- Pump Non Driving End,PNDE(D)- Pump Non Driving End.

If any problem is occurred in any position then the vibration increases in entire system. The magnitude of vibration is maximum in that position where the problem is occurred. Data is collected in velocity mode using vibration meter for the analysis.

This is a class III machine and it‘s vibration ranges is explained in table-1. It is seen that velocity in position C(PDE) is maximum and it is in ‘unsatisfactory‘ range. So, it can be understood that some problem is occurred in position C.

This model trips the relay to stop the machine when vibration is in ‘unacceptable’ range. If A,B,C& D four bearing positions are numbered as 1,2,3,4 respectively then the model displays the serial no. of defective bearing position and displays a alert message in the computer screen mentioning the abnormal condition without any human intervention. The model displays ‘3’ if problem is occurred in position C.

3. EXPERIMENTATION

3.1. Model Description

The condition monitoring based simulation model is given in Fig-7 which has been designed using MATLAB/Simulink. The vibration data of class-III machine is used as a case study. If any problem is occurred in any position then the vibration of entire system increases. The magnitude of vibration is maximum in that bearing position where the problem is occurred. The four ‘Max’ blocks are used in this model. Four ‘max’ blocks are used to extract the maximum magnitude of vibration from four bearing positions of the system. The last ‘max’ block is used to extract the one maximum value from the five. The ‘Embedded MATLAB function 1’ block is used to check the maximum value. If the vibration is in ‘unacceptable’ range (> 11.2 mm/sec) then it stops the system by tripping the relay creating different buzzer sound and zero value is displayed in the display box. If the value is less than 11.2 then the data goes to second ‘Embedded MATLAB function 2’ block for condition checking. If vibration is in ‘unsatisfactory’range then a message is displayed in the computer screen with a computerised buzzer sound to alert everybody otherwise the system is on . The alert message is shown in Fig-8. In ‘unsatisfactory’ and ‘unacceptable’ condition it displays the serial no. of defective bearing to find out the problematic source. The ‘Sound Generator’ is used to create the sound. A ‘light bulb’ is used to indicate that the vibration range is high.

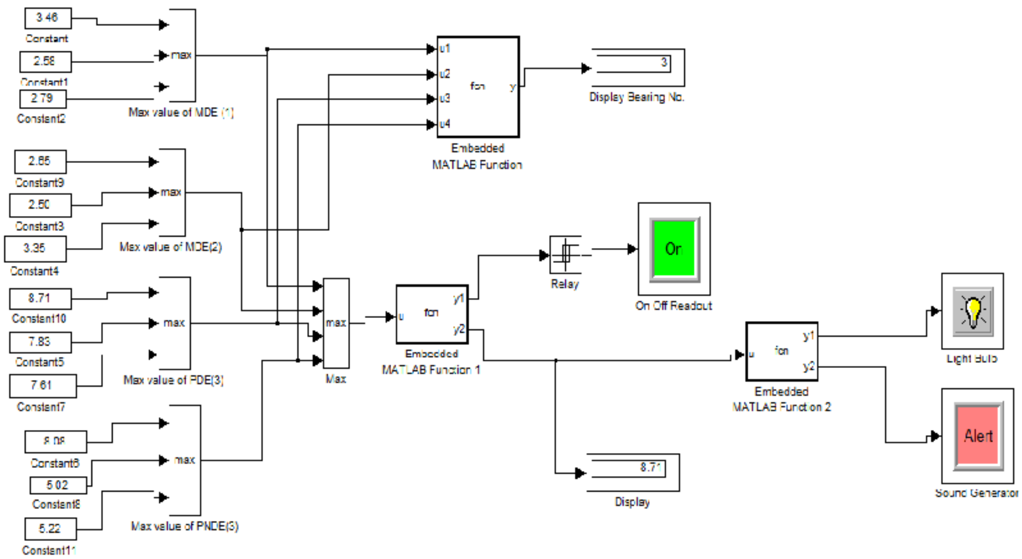


Figure 7. Simulink model of condition monitoring system for rotating electrical machines.

Figure 8. Alert message

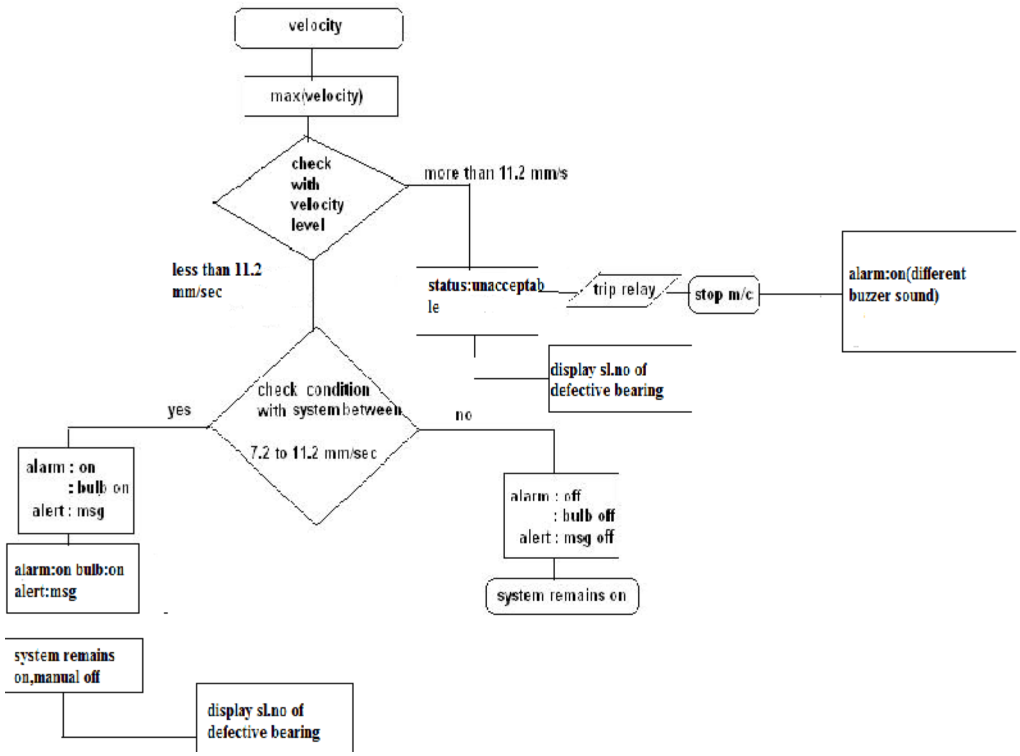
3.2. Tracking Problematic Source

Our proposed simulation approach also manages to track the problematic source with abnormal velocity range due to some problem. This feature makes the system safe and identifiable with the problem domain. Once the source with ‘unsatisfactory’ or ‘unacceptable’ velocity is identified, then it is easier to solve to the user to normalise the problem physically and manually. We had the put this logic in the pseudo code (3.4) section 3.4.5(“Source identification‘).

Table 3. Experimental Result

Vibration range [velocity(maximum)]	**Condition**	**Machine**	**Alert**	**Alarm**	**Light Bulb**	**Display serial no. of defective Bearing**
Less than 7.2 mm/sec	Good	On	Off	Off	Off	No(display '0')
7.2-11.2 mm/sec	Unsatisfactory	On (manual off)	Message	Buzzer Sound	On	Yes
>11.2	Unacceptable	Off	Off	Different Buzzer Sound	Off	Yes

3.3. Flow Chart



3.4. Pseudo Code:

3.4. 1. Bank up all the velocities

3.4. 2. //Find the max velocity

Input : velocity
calculate max(velocity)

3.4. 3. //Check max(velocity) for a certain assigned level

if max(velocity) < 11.2mm/sec
system: running on

```
        Go to Step: 4
   else
      max(velocity) > 11.2mm/sec
        system: stops
   end
```

3.4. 4. Condition checking:

```
if max(velocity) lies between 7.2 to 11.2mm/sec
        alarm: ON
              : bulb ON
        alert :messag
 else
        alarm: Off
              : bulb Off
alert : no  message
end
```

3.4. 5. Source identification:

```
// we tracked with a key called "source",
// if the target value comes with one
// u1, u2, u3 and u4 are four velocity ranges.
source = max([u1, u2, u3, u4]);
if u1<7.2 && u2<7.2 && u3<7.2 && u4<7.2
source = 0;
// when velocity ranges from all machines will less than 7.2
else if u1>u2 && u1>u3 && u1>u4
source = 1;
// when velocity range of u1 is greater than all rest
else if u2>u1 && u2>u3 && u2>u4
source = 2;
// when velocity range of u2 is greater than all rest
else if u3>u1 && u3>u2 && u3>u4
source = 3;
// when velocity range of u3 is greater than all rest
else  source = 4 ;
// when velocity range of u4 is greater than all rest
end
end
end
end
```

4. CONCLUSION

This simulation model is useful for all classes of machines in online condition monitoring system. The vibration data of class-III machine is used as a case study.It is not only useful to predict problems but also protects machine from permanent breakdown. It also identifies and displays the problematic location in the machine without any human intervention. Excessive vibration can damage the machine components. So, this system will increase the machine lifetime.

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