CONDITION MONITORING FOR ROTATING MACHINES USING VIBRATIONANALYSIS A REVIEW

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Abstract: Rotating machines turbines, compressors, generators, blowers, pumps, alternators, adaptors, launching engines plays very important role in power plants, aerospace, mining, chemical industries.. Etc. Failure of any one of the rotating machine parts will leads to loss of productivity, quality, time, cost of production, and safety against catastrophic failure. Condition based monitoring of a machine helps to retain the effectiveness & performance of a machine to its optimal level. This condition monitoring Diagnosis is effective and it is done by different monitoring techniques. Out of all the condition monitoring through vibration analysis technique will shows 80 percent of failures like misalignment, looseness, unbalance..etc. in the rotating machines.

This paper presents an enlarged survey on the expansion and the recent approaches in the condition monitoring of rotating machines through vibration analysis technique, and also discusses the most recent progress in the mechanical condition Monitoring and fault diagnosis.

Keywords: Condition Monitoring, Vibration Analysis, Fault Diagnosis, Rotating Machine.

I. INTRODUCTION

In power plants, aerospace, mining, chemical industries machines are continuously working for production.For longer life time of operations different types of faults may occur in machine .The common types of machine faults are: (i) Unbalance (ii) Shaft misalignment or bentshaft (iii) Damaged or loose bearings (iv) Damaged gears (v) Faulty of misaligned belt drive(vi) Mechanical looseness (vii) Increased turbulence (viii) Electrical induced vibration.[1] Condition monitoring and diagnosis engineering is a novel concept which enables us to detect in advances any incipient failure with ease& confidence in any part of a dynamic system before such failure triggers – off. Various failure mechanism, which in turn may render the whole system uneconomical, unreliable, unhealthy, unsafe & even lethal [2].Various Condition monitoring techniques followed all three areas of interest namely fault detection, diagnosis and prognosis [3].condition `monitoring follows different types of techniques to identify the root cause of problem in rotating machinery [4,5,6]

1.1Condition Monitoring Techniques

The following are the major techniques of condition monitoring and are commonly used. They are:

- Visual monitoring
- Vibration monitoring using spectrum analyzer.
- Contaminant or debris monitoring
- Performance and behavior monitoring
- Temperature monitoring or IR Thermography
- Acoustic analysis
- Tribology
- Sound monitoring.
- Shock pulse monitoring.
- Other nondestructive testing techniques

The following table shows selection of condition monitoring techniques

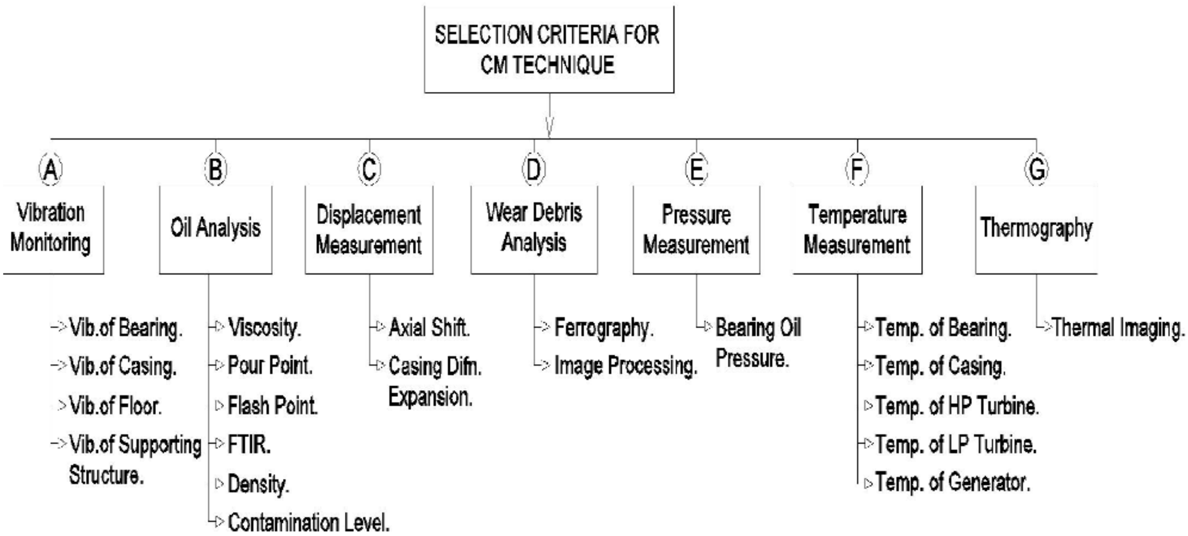

Table1: selection of condition monitoring techniques

As per Analytical Hierarchy process vibration analysis is best technique to identify most typical faults occurs in the rotating machinery [7] Vibration analysis is the most effective techniques for monitoring the health of machinery. They offer complementary strengths in root cause analysis of machine failure, and are natural allies in diagnosing machine condition [8] Some typical faults and defects like shaft misalignment, looseness, unbalance..etc which are frequently occurred in rotating machines can be detected withvibration analysis.

1.2 Faults Detection in Machine Elements Using Vibration Analysis:

A series of seeded fault tests performed on the double-helical gears in a marine gearbox and presents analyses of the vibration signals measured at two locations on the gearbox for faults [9], Condition monitoring and fault diagnosis of a boiler feed pump unit is done using vibration analysis .causes for excessive vibrations at specified locations are identified in the form of soft rooting and bent rotor [10] Experimental investigations on vibration response of misaligned rotors was done [11] misalignment in rotating shafts are identified in experimental set up through vibration analysis [12] Monitoring of Fatigue Crack Stages in a High Carbon Steel Rotating Shaft was done Using Vibration analysis[13] Experimental investigation of unbalance and misalignment in rotor bearing system using order analysis is done [14] Developed An Expert System For Diagnosis of Bearing Faults of Rotating Components in A Power Plant with the vibration readings [15]Behavior of fatigue crack initiation and propagation in a Pre-cracked high carbon steel shaft which be monitored using a vibration based condition health monitoring method [16] Vibration analysis of intact shaft & cracked shaft was done successfully for different loads [17] Dynamic behavior of a direct coupled rotor-bearing system is investigated. Experimental vibration analyses in the vertical direction of the system are implemented. Vibration monitoring with trend analysis and spectrum graphs are employed to diagnose the excessive vibration source [18] Combined vibration and thermal analysis for the condition monitoring of rotating machinery [19] by using Fast Fourier Transform of the time domain vibration signal to identify the characteristic fault frequency representation corresponding to the calculated fault frequency from the bearing with known fault [20]

2. VIBRATION ANALYSIS TECHNIQUES:

In practice, machine monitoring requires some physically measureable signal to monitor. It might be vibration, sound pressure or a temperature signal. Vibrations are the most commonly used monitoring signals. Basically, vibration monitoring uses signature analysis .Basically, vibration monitoring uses signature analysis Vibrations are not subject to background disturbances to the same extent as acoustic noise. Vibration sensors, accelerometers, can be placed closer to the source than microphones. [21, 22, 23] The vibration signal analysis is one of the most important methods used for condition monitoring and fault diagnostics because they always carry both static and dynamic information of the system. There are several vibration analysis techniques used to analyze the bearing vibration. Their classifications are: time domain, frequency domain, time-frequency domain and other techniques. [24, 25, 26, 27, 28]

2.1 Time domain analysis:

Time domain technique is easiest and simplest technique to analyze the vibration signal waveform. Peak-to-peak amplitude is measure from the top of the positive peak to the bottom of the negative peak. Time domain analysis is the process in which statistical features are computed from the vibration data. By comparing the statistical features, particular faults can be identified. The statistical features that are used for time domain analysis are mean (M), variance (σV),Root Mean Square (RMS), Kurtosis (K), Skewness (S),Normalized central moments.[4,25,29,30,31,32]

2.2 Frequency domain analysis or spectral analysis:

Generally frequency domain features are more capable than time domain features in indicating the faults in rotating machine. This is because the resonance frequency component or the fault frequency component can be detected more easily in frequency domain features as compare to time domain features[24,33,34] The frequency domain analysis involves analyzing bearing vibration data based on the frequency. Methods which are used for this analysis are Discrete Fourier Transform (DFT), Envelope Analysis, Resampling [35]

Frequency-domain techniques convert time-domain vibration signals into discrete frequency components using a fast Fourier transform (FFT). Simply stated, FFT mathematically converts time-domain vibration signals trace into a series of discrete frequency components. The Fast Fourier Transform (FFT) is an algorithm for calculation of the Desecrate Fourier Transform [36,37].FFT Works Well under constant load torque, constant speed and with high power machines, but not for small and medium power motor operating under low speed and low load torque. [38] Unfortunately, the methods based on FT are not suitable for non-stationary signal analysis [39] A modified cepstrum analysis was proposed by Merwe and Hoffman [40]. Envelope analysis or amplitude demodulation is another popular technique used to detecting incipient failure of rolling element bearing. This method is also known by different names such as high frequency resonance technique [41,42,43,44] amplitude demodulation [45] demodulated resonance analysis and narrow band envelope analysis [46,47] Envelope analysis or amplitude demodulation is the technique that can extract the periodic impacts from the modulated random noise produced within a deteriorating rolling element bearing. This process even possible when the signal from the rolling element bearing is relatively low in energy and 'buried' within the other vibrations produced from the machine. For these non-stationary signals, other techniques also have been introduced.

VIBRATION IDENTIFICATION

CAUSE	AMPLITUDE	FREQUENCY	PHASE	REMARKS
Unbalance	Proportional to unbalance. Largest in radial direction.	1 x RPM	Single reference mark.	Most common cause of vibration.
Misalignment couplings or bearings and bent shaft.	Large in axial direction 50% or more of radial vibration	1 x RPM usual 2 & 3 x RPM sometimes	Single double or triple	Best found by appearance of large axial vibration. Use dial indicators or other method for positive diagnosis. If sleeve bearing machine and no coupling misalignment balance the rotor.
Bad bearings anti-friction type	Unsteady - use velocity measurement if possible	Very high several times RPM	Erratic	Bearing responsible most likely the one nearest point of largest high-frequency vibration.
Eccentric journals	Usually not large	1 x RPM	Single mark	If on gears largest vibration in line with gear centers. If on motor or generator vibration disappears when power is turned off. If on pump or blower attempt to balance.
Bad gears or gear noise	Low - use velocity measure if possible	Very high gear teeth times RPM	Erratic	
Mechanical looseness		2 x RPM	Two reference marks. Slightly erratic.	Usually accompanied by unbalance and/or misalignment.
Bad drive belts	Erratic or pulsing	1, 2, 3 & 4 x RPM of belts	One or two depending on frequency. Usually unsteady.	Strob light best tool to freeze faulty belt.
Electrical	Disappears when power is turned off.	1 x RPM or 1 or 2 x synchronous frequency.	Single or rotating double mark.	If vibration amplitude drops off instantly when power is turned off cause is electrical.
Aerodynamic hydraulic forces		1 x RPM or number of blades on fan or impeller x RPM		Rare as a cause of trouble except in cases of resonance.
Reciprocating forces		1, 2 & higher orders x RPM		Inherent in reciprocating machines can only be reduced by design changes or isolation.

Table2: Problem Identification at Different Vibration Amplitudes

2.3 Time -Frequency Domain Techniques:

Time-frequency domain techniques have capability to handle both, stationary and non- stationary vibration signals. Time–frequency analysis can show the signal frequency components, reveals their time variant features.

A number of time-frequency analysis methods, such as the Short-Time Fourier Transform (STFT), Wigner-Ville Distribution (WVD), and Wavelet Transform (WT), have been introduced.

STFT method is used to diagnosis of rolling element bearing faults [48]. Due to its low computational complexity and definite physical meaning, STFT is often used as an initial pre-processing tool to analyze non-stationary vibration signals. The STFT maps the vibration signal into a two-dimensional (2D) function of time and frequency [49]. The basic idea of the STFT is to divide the initial signal into segments with short-time window and then apply the Fourier transform to each time segment to ascertain the frequencies that existed in that segment.

The Wigner distribution (WD) is derived from the relationship between the power spectrums and the autocorrelation function for time-variant and non-stationary processes [50]. The WVD has been used for gear fault detection [50, 51] and it is used for rolling element bearing to represent the time-frequency features of vibration signals [52]. The Winger distribution [53] and spectrogram [54] are the well known quadric time frequency representations which are used for diagnosing gear faults. The directional Choi-Williams distribution (dCWD) was proposed for rotating machinery fault diagnosis [55]. Directional Winger distribution (DWD) has been applied in analyzing the order of rotating machine [56]. The third and fourth order Winger moment spectra also called Winger bi-spectra and Winger tri-spectra were also used for rotating machine vibration signals [57]. The fourth order Winger moment spectra have been applied for diagnosis of valves system faults in an engine [58].

The advantage of wavelet transform (WT) over the STFT is that it can achieve high frequency resolutions with sharper time resolutions. The wavelet transform (WT) is the most popular method to diagnosis bearing faults [59, 60] the continuous wavelet transform (CWT) is developed base on Short Time Fourier Transform (STFT) with better time frequency resolution. The Discrete wavelet transform (DWT) was used to fault diagnosis spalling in ball bearings [61], Rolling element bearing fault diagnosis using wavelet packets [62], Intelligent on-line quality control of washing machines using discrete wavelet analysis [63] compared the effectiveness and reliability of wavelet transform method to other vibration analysis techniques[64] the discrete wavelet transform can be used as an effective tool for detecting single and multiple faults in the ball bearing [65] method of combination of kurtosis and wavelet analysis to diagnosis of rolling bearing fault [66] An efficient approach to machine health diagnosis based on harmonic wavelet packet transform [67]

But, the limitations of wavelet analysis like energy leakage, interference and distortion at the ends made way for a relatively new technique Hilbert-Huang transform (HHT) [68,69],independent component analysis, advanced statistical analysis, nonlinear signal analysis and so on [68].Hilbert-Huang transform [68,70] is based on the principles of empirical mode decomposition (EMD) and Hilbert transform. It extracts the signal characteristics viz- amplitude, instantaneous phase and frequency of vibrations resulting from the intrinsic mode functions (IMFs) of the signal being analyzed. Using this method, any complicated signal can be decomposed into a collection of based on the local time scale features of the signal [70, 71]

Empirical mode decomposition (EMD) has been proved an innovative and powerful approach for dealing with nonlinear and non-stationary signal [72, 73, 74, 75]. In order to solve the mode mixing problem that the EMD method may encounter, the ensemble EMD (EEMD) was proposed to improve the drawbacks [76] EEMD is a noise-assisted data analysis method, and to restrain the mode mixing problem of EMD by adding white noise to the initial data. Admittedly, EEMD method is a great breakthrough in the development of EMD algorithm evidently [77, 78].

2.4 Other Techniques

Artificial Intelligence diagnostic method has been used to diagnosis a machine condition. And it is based on learning algorithms: examples include artificial neural nets (ANN), fuzzy logic (FL), neuro-fuzzy techniques, and genetic algorithms (GA) rotation forest (RF), support vector machine (SVM) [79, 80, 81, 82]

Neural network is a soft computing approach which is largely used in condition monitoring techniques because of its effectiveness as it can produce near optimum solutions [82,83]. In artificial neural network, numerous artificial nodes known as neurons are interconnected to form the network. It is an adaptive system that can change its configuration allowing the information to flow through the network, without losing the information.

Comparison of effectiveness of Artificial Intelligence (AI) techniques in fault diagnosis [84] Artificial neural network design for fault identification in a rotor-bearing system [85] identification of unbalance and looseness in rotor bearing system using artificial neural networks (ANN) by two different methods; one is by statistical features and the second by amplitude in frequency domain [86] experimental study of the expert system for diagnosing unbalances by ANN and acoustic signals [87] Unbalance localization through machine nonlinearities using an artificial neural network approach [88] Investigation of engine fault diagnosis using discrete wavelet transform and neural network [89] motor rolling bearing fault diagnosis was done using neural networks [90] Artificial Neural Network technique is applied for stator fault detection in induction motor [91]

Fuzzy logic is an approach to computing based on "degrees of truth" rather than the usual "true or false .A new method Fuzzy Track Monitoring System (FTMS) for estimating the irregularities present in the railway track at running time [92] fuzzy logic approach may help to diagnose induction motor faults. In fact, fuzzy logic is reminiscent of human thinking processes and natural language enabling decisions to be made based on vague information. Therefore, here H.Nijaari applies a fuzzy logic to induction motors fault detection and diagnosis [93] Condition Monitoring and Fault Detection in Wind Turbine Based on DFIG by the Fuzzy Logic [94] induction motor condition monitoring was done by fuzzy logic [95] Model-based and fuzzy logic approaches to condition monitoring of operational wind turbines [96] Analysis of the Tool Condition Monitoring System Using Fuzzy Logic and Signal Processing [97] Rotor fault diagnosis system based on GA-based individual neural networks. (98)

By using different kernels, SVM can make linear or non-linear classifications according to the features of the data. Although SVM is initially for the binary classification problem but through building a set of SVMs based on one class versus all or one class versus one rules, the multiclass problems can be solved. SVM has high accuracy and nice theoretical guarantees regarding over fitting. It can perform well even if the data is not well separable in the original feature space with appropriate kernel and carefully tuned parameters. However, it is hard to interpret the model and tune the parameters. If the users do not have a lot of experience, it might be difficult to work efficiently with SVM. A review is on support vector machine by Achmad Widodo for fault diagnosis [99] .SVM is a supervised learning model which constructs one or a set of high or infinite dimensional hyper plane(s) to separate the data into different classes [100]. .Gear box fault diagnosis was done by SVM [101].so much of research is going to be done based on artificial intelligence techniques

3. CONCLUSION

Condition monitoring and fault diagnosis technique are used to prevent early fault in a mechanical system .In this review paper an attempt has made to epitomize different techniques used in condition monitoring, the importance of vibration monitoring technique.

Different vibration analysis techniques are explained like time domain, frequency domain, time-frequency domain and other techniques. This study reveals that the time domain techniques and frequency domain techniques can indicate the faults in the machine but time domain technique can’t identify the location. Frequency domain techniques have ability to identify the location of fault(s) in rotor. Time-frequency domain techniques have capability to handle both, stationary and non- stationary vibration signals this paper also explain some of the recently used new techniques like artificial neural nets (ANN), fuzzy logic (FL), neuro-fuzzy techniques, genetic algorithms (GA) rotation forest(RF) and support vector machine(SVM). By Artificial Neural Network (ANN) automatic fault diagnosis can be achieved. It also gives better classification of various faults in the machine components

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