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MACHINE LEARNING THROUGH CONDITION BASED MONITORING & SIGNAL PROCESSING – A REVIEW

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Abstract
This paper explains the crucial advantage of Condition Based Monitoring through Signal Processing for machinery. Techniques like FMECA, fault diagnostics & prognostics, signal processing and Fast Fourier Transformation has been discussed. Also, various real life examples shows the insights of vibrational effect.

Keywords – Condition Based Monitoring (CBM), FFT, RUL.

1. Introduction

Critical component, machinery of system or operating process requires maintenance through the operation without ceased which results in reducing lot of rework cost and lost production caused by failures. In order to meet strong demands from the market- machine in operating conditions, maintenance is to be planned in advance. Planned maintenance reduces rework costs, repair parts inventory and overall maintenance cost. Also, it improves product quality and increases process efficiency. [2]

Maintenance Principles

In general there are three types of Maintenance techniques – Periodic or Preventive maintenance, Predictive maintenance or CBM and Breakdown or Reactive maintenance.
CBM of machinery prefers to detect malfunctions early before failures are growing up serious condition which influence system and results in breakdown. Undesired break down of system especially in industry is excessive costly. According to the monitoring system's benefit, any mechanical system have expected percentage of improvement due to utilizing CBM. In CBM through transducers signals are received and further with signal processing generally done through Artificial Neural Networks (ANN) mapping is done to predict failures. Main components of Preventive Maintenance System (PMS) are user friendly hardware and software, automated data acquisition system, automated data management and trending, flexibility, reliability and Accuracy. Elements of CBM cycle are smart fault tolerant (sensors), data preprocessing & feature extraction, fault classification, prediction of fault evolution and scheduled require maintenance. CBM is used in Power plant, Process industries, Aerospace, Automation & ship manufacturing industries, Earth moving, mining equipment, and paper & cement mills etc.

TABLE I: Economic Analysis of Predictive & Preventive Maintenance.

Budget Head	Predictive Maintenance (Rs)	Preventive Maintenance (Rs)
Capital Maintenance Equipment Cost	5,00,000 (transducers and sensors)	Zero
Machine Downtime, Repair & Labour, cost per shutdown for repair	50,000	50,000
Maintenance cost at the end of 1st Year	5,00,000	2,00,000
Maintenance cost at the end of 10th Year		20,00,000
Maintenance cost at the end of 20th Year	7,50,000	40,00,000

Assuming 4 shutdowns a year
Assuming there are 5 shutdowns between 1st and 20th year.

Techniques for Predictive Maintenance

- Vibration Monitoring (72% industries applied this technique throughout the world)
- Wear, Debris Analysis and Oil Analysis (Used for lubricants analysis)

- Motor current signature analysis
- Thermography (Used for thermal Imaging)
- Non Destructive Techniques (NDT) (Utilizes Infrared rays / eddy current/ x rays/acoustics emissions)

Various transducers used in CBM

Mechanical Parameter	Transducer
Vibrations	Accelerometer
Oil	Particle count meter
Wear Debris	Spectrophotometer
Temperature	IR Detectors
Electric current	Hall effect sensors
Process parameter	Orifice, Pressure gauge

Failure Modes Effects & Criticality Analysis (FMECA)
Analysis of the most critical equipment in the machinery which requires highest maintenance attention is done through FMECA. This analysis technique deals with all potential failure modes for a system under CBM. FMECA is initiated in early design process which results in highest impact in process reliability. FMECA can be categorized under three general category Design, Process & System. One of the parameter in FMECA is Risk Matrix or Risk Priority No. (RPN) which is measured in a scale of 1-10.
RPN = O*S*D
Where O= Occurrence frequency of failure mode.
S = Severity of failure mode.
D = Detectability of failure mode.
Lesser the value of RPN better the condition of Plant/ Equipment.

Fault Diagnostics and Prognostics

Fault diagnosis means detecting, isolating and identifying an impending or incipient failure condition and the affected components of system is still operational even though at a degraded mode. Many times a defect has occurred that does not totally impair the machine it will be still running. Basically there are two techniques for fault diagnosis – Model based (Finite Element Analysis) and Data driven (signal Based).[1]

Data driven fault can be classified as stored fault pattern library (Fault classification), Decision making and Fault classification – Neutral Networks, Fuzzy logic etc, and Diagnosed faults.

Fault Prognostic is the ability to predict accurately and precisely the Remaining Useful Life (RUL) of a failing component or sub system. It is used as a forecasting tool to predict failure.

Types of Signals & Signal Processing
Signal covey's information and transducers measures mechanical quantity. With the transducer connected, signal received. Through low pass filtering certain artifacts are remove from signals and time domain feature extraction of data is done.

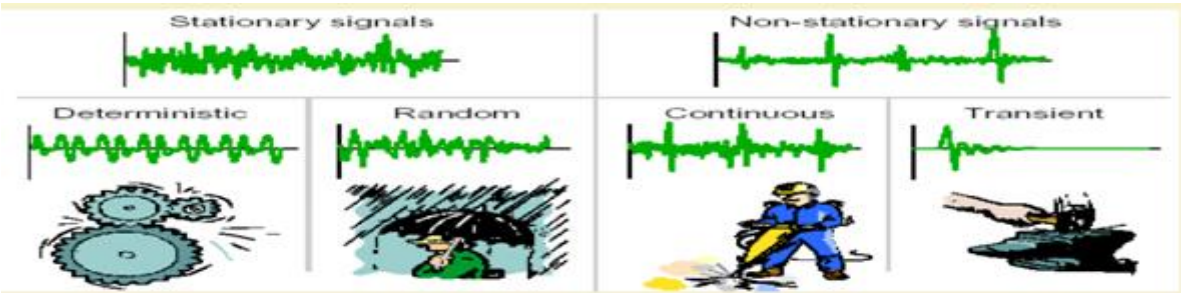


Figure 1. Types of Signals

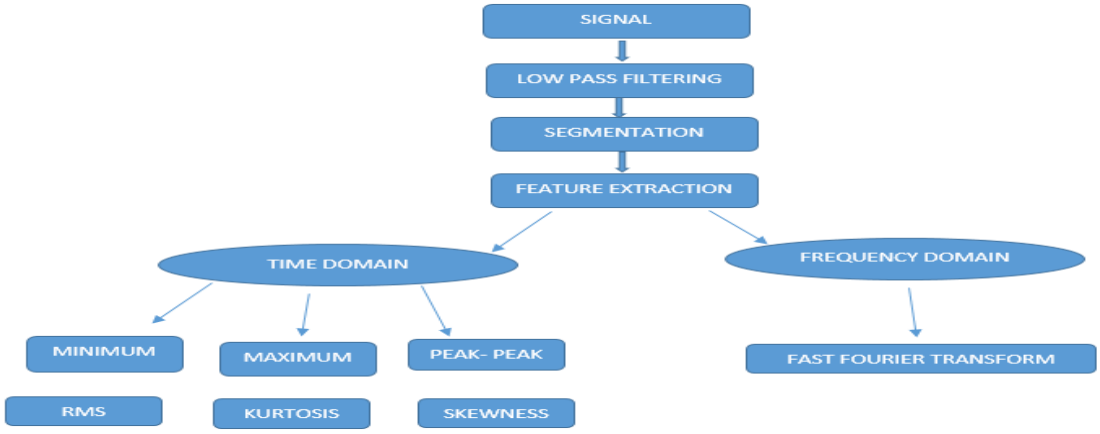


Figure 2 Signal Processing Flowchart

Time Domain Analysis and Frequency Domain Analysis

Signal analysis is defined as the determination of the response of vibration system due to unknown excitation. Signals obtained through transducer can be analyzed on Oscilloscope as analogue signal. Analysis of amplitude of vibration with time is known as Time Domain Analysis. If many signals are need to be analyzed then Frequency Domain Analysis is used as each component have unique frequency and machine signature.

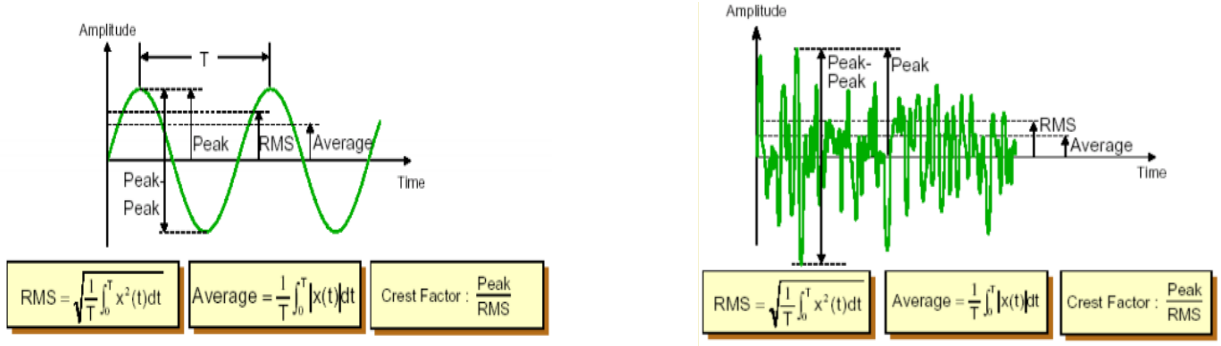


Figure 3 Time Domain Analysis

Rotodynamics

Vibrations and sound are the main area of concern for all rotating machines which can be analyzed through "Rotating Speed/". Order analysis is done to calculate the rotating speed of rotary machines. Various methods for order analysis are - FFT Based Order analysis , Time Signal Recording and Short-Time Fourier Transform and Vold-Kalman Order Tracking Filter Technique. Moreover to avoid undesirable vibrations dampers, vibration and shock isolators are used.

FFT Analyser

The Fast Fourier Transform (FFT) and the power spectrum are powerful tools for analyzing and measuring signals from plug-in data acquisition (DAQ) devices. Also, effectively acquire time-domain signals, measure the frequency content, and convert the results to real-world units and displays on analyzers. FFTs is useful for measuring the frequency content of stationary or transient signals. It produce the average frequency content of a signal over the entire time that the signal was acquired. The power spectrum shows power as the mean squared amplitude at each frequency line but includes no phase information. Because the power spectrum loses phase information, one can opt for use the FFT to view both the frequency and the phase information of a signal

Various real life examples and analysis done to avoid Vibration

Tractor footrest isolation to avoid vibration where in a tractor the driver puts his foot on this platform and his underbody is rigidly connected to the engine or to the frame of the tractor. So, all the unbalanced forces which occur in the engine during combustion is going to excite the structure and there will be a large amount of vibrations.[5]

Figure 3 1. Tractor footrest

Gas turbine and turbine compressor are operating with a very high speed range of 3000 rpm a small amount of unbalance because of high the speed is enough for destruction and losses. Vibration isolators are used for perfect balance of forces.[5]

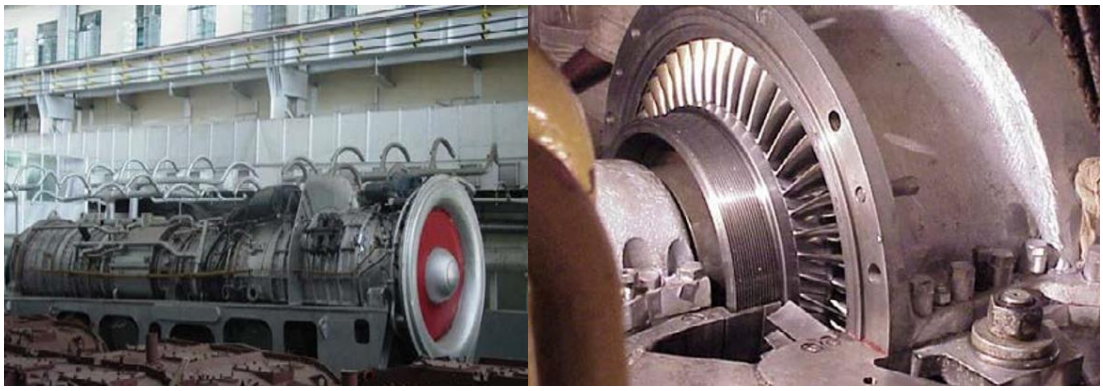


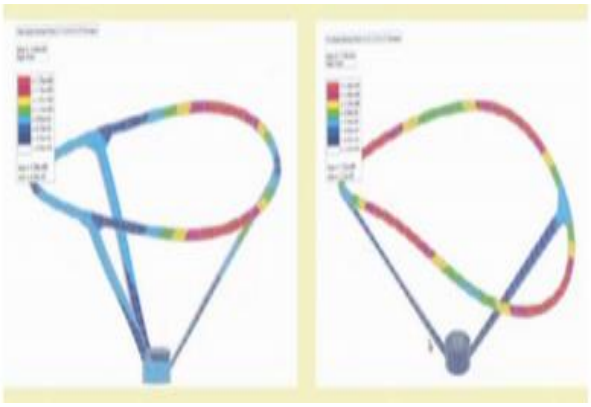
Figure 4 Gas turbine and Compressor

Another application of resonance (when excitation frequency matches with highest frequency in vibration) human body composed of internal organs are supported in a fluid in the chest cavity. So, basically the internal organs have mass and they have certain stiffness also natural frequency and the human organs have natural frequencies around 6 Hertz. Now if a man going on a boat and if there is a large rocking motion and these are because of a choppy wave and the sea, rough seas, so there is a lot of rocking motion. So, a person who is standing on the deck, will have this forcing frequency coming around 6 Hertz and then because there is a resonance you will have large motions in your internal organs you will nauseate and vomit and this is known as motion sickness.[5]

Figure 5 Man Driving Boat

Steering wheel vibration reduction

This is a tractor steering wheel and the problem with this kind of tractor wheel was as long as soon as the engine starts, this steering wheel had an excessive vibration. So, efforts were taken by author at IIT was how to reduce these vibration levels. And then studied is done through a finite element model and found out the natural frequencies of the steering wheel, and out that the natural frequencies of the steering wheel was equal to the engine firing frequency.[5]



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