An Overview Of Predictive Maintenance For Industrial Machine Using Vibration Analysis

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***Abstract*—In this paper, an attempt is made to overview different vibration analysis techniques and predictive maintenance for industrial machines. The techniques considered in this paper involves analysis in time-domain, frequency-domain, time-frequency representation (TFR), Wavelet transforms, time synchronous averaging (TSA), and order analysis. Convolution neural networks (CNNs) for feature learning are also discussed. The vibration signal reveals more information about the fault development of industrial machine and the evolution of industrial machine health monitoring methods and its mostly used techniques are reviewed in this paper. The machine lifetime enhancement can be achieved by condition-based monitoring which takes place to keep away from any impulsive failure appearing before the upcoming schedule. The Vibration, Wavelet, Voltage, Acoustic Emission, Temperature, Current, Noise, etc., are some measurements used for industrial machine health monitoring. It is proposed to use wavelet transform along with CNN for vibration-based health monitoring and predictive maintenance.**

***Index Terms*—Condition-based monitoring, Predictive maintenance, Vibration analysis.**

I. INTRODUCTION

Predictive maintenance in industrial machines is done on condition-based monitoringArturo Garcia-Perez et al, (2016). All over the world, the manufacturing industries have to spend a lot on upgrading their system to ensure stable production and to improve product quality. Hence ”manufacturing line - computerized inspection” and ”equipment predictive maintenance” are two predetermined investments for the factories. The Production inspection process has shifted to a fully automated one and Fig.1. shows the general maintenance method for rotating machinery.Predictive machine health monitoring limits the serious change in fault development in the industrial machine. For several decades mechanical wear fault and failure have been detected using vibration analysis technique in predictive maintenance to avoid unwanted breakdowns and downtime as discussed by Kirankumar M V et al, (2018). The machine health monitoring techniques are done by vibration analysis, wavelet analysis, analysis of noise, temperature, voltage &acoustic emission, fourier transform(FT), empirical mode decomposition (EMD), short-time fourier transform (STFT), hilbert-huang transform, etc.

A traditional approach to equipment maintenance is to repair and replace equipment after a certain period. But this cannot prevent downtime due to malfunctions, which will put a halt to the production line and incur massive losses. If the condition monitoring and predictive maintenance system are implemented, parts that are about to break down can be discovered in advance to accurately determine the time for repair, and the risk of unexpected shutdown can be prevented as discussed by Tsypkin et al, (2017). Based on studies and customer’s experience, after implementing the system, Downtime can be reduced by 40%, the repair cost can be reduced by approximately 50% and utilization can be increased by 25%.

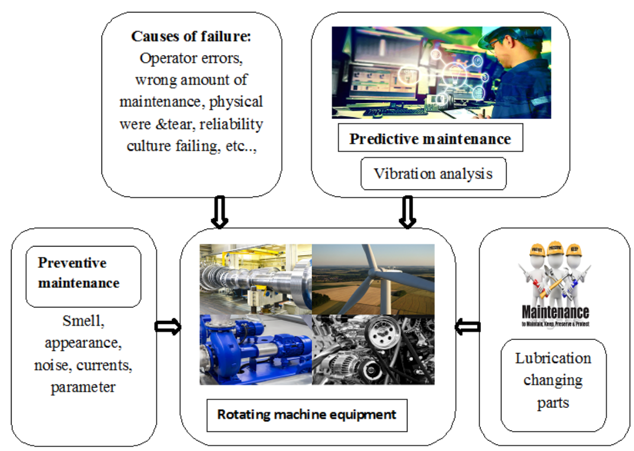

Fig. 1. Maintenance category for rotating machine.

Vibration monitoring is popularly used in rotating equipment for predictive maintenance. The vibration of the machine comes from the sources like Unbalance Bearings, gears, etc. As per Dr. S. J. Lacey, the vibration monitoring systems are classified into two types a) periodic off-line monitoring systems b) Permanent online monitoring systems. In periodic monitoring type, complex measurements are made at many locations on a machine and system vibration is calculated or recorded in the machine and later it will be analyzed in the field. It is usually used when a very early warning of faults is required K N Gupta (1997). In a permanent online monitoring system, the main is to safeguard the equipment by warning and in the meantime shut the machine down when a pre-existing protection limit is exceeded. In this type, vibrations are endlessly measured at a specific point in the machine and the quantification is compared repeatedly with a level of vibration as per the severity chart provided by the standards Jaafaralsalaet et al, (2012).

II. PREDICTIVE MAINTENANCE

The predictive maintenance technique is to predict when the maintenance should be done and also to estimate when the machine failure is likely to occur. G.Gopinath et al, (2012). It is widely used to minimize the risk and cost as we can plan maintenance in advance and thus increased operational efficiency, reduced downtime, better manage inventory. The main aim of predictive maintenance is to halt unpredicted machinery faults. The design is to get the right information at right time. Some benefits of predictive maintenance are shown in Fig.2.

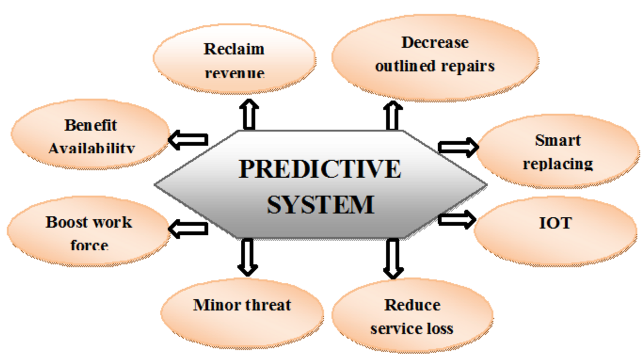

Fig. 2. Predictive maintenance.

A predictive maintenance condition monitoring algorithm can be explained using Fig.3. R.Isermann, (2005). One of the ways to perform predictive maintenance is to analyze the data from the industrial machine in operation.To identify healthy data and faulty data an enormous set of sensor data are obtained in different operating conditions. Hunter Barksdale et al, (2018). The system is built with a mathematical model to estimate its parameter from the data. Then the model is simulated by enforcement of various fault states in various performing conditions to produce faulty informationwith help of both generating data and sensor data. Noise arising from data can be cleared with the help of a filter. Condition indicators are used to distinguish healthy from fault. A well-trained machine learning model can detect anomalies by extracting features. The training classifier detects the different types of faults and with the help of the results; we can easily come to know which part of the machine needs attention.

III. DETECTION, EXTRACTION, AND ISOLATION FOR VIBRATION ANALYSIS

Identification is the main rule of splitting the fault. The characteristics signal from atmosphere vibration and interference is used,therefore. Using appropriate algorithms low amplitude vibration signatures are neglected for further process.

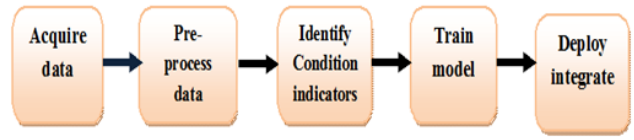

Fig. 3. Algorithm for condition monitoring and predictive maintenance.

Vibrations are the fundamental tool of monitoring. Standard signal processing gives local information about time and frequency Cinun-Siyong et al, (2018). In the methodology,the signal is sensitive to early modification due to impending fault. Some causes of mechanical vibrations are reciprocating space forces,aerodynamic forces,miss alignment, unbalance, critical speed, gearing and coupling inaccuracies,bad drive belts, defective rotor bars, friction or oil whirl, bent rotor shafts, distortion & defective bearings, looseness, various form of resonance, etc.,

Feature extraction involves the process of measurements by extracting the statistical features like standard deviation, mean, skewness, root-mean-square, median, kurtosis, and sum, maximum, minimum to report just in case a bearing fault is progressingYe et al, (2020), V.Gunasegaran et al, (2019). It also compares the enormous amount of vibration signature produced continuously. Gary G. Yen (1999). The fault is classified with fault isolation process. Fault severity estimation involves predicting the exact schedule of the equipment failure. Additionally, it reveals about the fault condition whether emergency procedures are required or not. The most commonly used analysis techniques including time-domain, frequency-domain, time-frequency domain representation (TFR), and wavelet transform (WT), order analysis, etc. are discussed.

IV. VARIOUS VIBRATION MONITORING AND PREDICTIVE ALGORITHMS

G.Gopinath (2012) has discussed using bearing vibration signature for motor fault diagnosis. The approach for motor rolling fault detection with the vibration analysis is by using neural networks and time-domain and frequency-domain analysis. The vibration spectrum is recorded, the peaks are specifying and by implementing the software with the standard limits, each peak is determined. With the help of the vibration velocity root mean square (RMS) value, we can determine the machine service status. Artificial neural networks help to estimate failure times of degrading to make decisions on scheduling the maintenance activities and replacement. L.E.Negrete Navarretea et al, (2012) have provided a study of rotor damage, inter-turn short circuits inside stator coils. The simulation was performed toward extracta waveform of magnetic flux density between air gap and also with in electromagneticcore. For further analysis, the simulation is performed using MATLAB to observe harmonic distribution. The fast fourier transform analysis (FFT) operates flux density signature were scheduledto detection of fault and analyses of the flux density can be done. S.Sendhil Kumar et al, (2013) have discussed the various aspects of predictive maintenance, vibration analysis, condition monitoring, and related sensors are reviewed. This method is to improve productivity and reliability and also reduce maintenance costs in any industry. Fault detection and diagnosis are discussed. The paper concludes that when the velocity value significantly increases the misalignment also increases.

Junda Zhu et al, (2014) have provided elaborate category and mathematical explanations of condition indicators developed for shaft, bearing, and gears. The condition indicator which increases the storage of the signal also provides insight into the component and efficient transmitting at the same time. For feature extraction, a time-synchronous averaging (TSA) algorithm was applied. The time-synchronous resampling algorithm is to stabilize the shaft. K.H.Hui et al, (2015) have presented a survey on the most recent development on condition monitoring techniques such as vibration analysis and artificial intelligence (AI) used for automated decision making. Some other effective analyses are based on FFT, STFT, EMD, HHT, and wavelets. Artificial Intelligence which detects and diagnosis automatically machine faults is used mainly to reduce human error. K.Alameh et al, (2015) aim to study various time-domain and frequency-domain analysis features based vibration analysis after fault diagnosis of permanent magnet synchronous machine (PMSM).The rotor eccentricity fault (REF) and de-magnetization fault (DMF) with various severities among simulated across multiple-physical model to get signature of the machine. The signal under allvariety& level of fault is extracted with time and frequency indicators. By analysing the skewness and the median frequency of the vibration signature, the type of fault existing is identified. The existing fault type and the severity were automatically providing in artificial neural network (ANN).

Vladimir Dekys (2016) deals with fault detection in rotary machines in various industries. It is based on Amplitude spectra and phase lead technology to detect events from the signal measured. The multi-parameter approach is advised to use because symptoms of fault displaying is not easy for this method so important decision is taken based on the different type of measurement. The various measurement of the machine outcome is discussed in the paper. ShyamPatidar (2017) has presented a piece of general information about adequate condition monitoring in the machine. Manufacturing a machine running exactly throughout its life is quite challenging. Machine performance deviation can affect the quality of the product hence well planned and effective maintenance is the only solution that reduces downtime and maintenance cost. To run the precision manufacturing machine in the process both condition monitoring (CM) & maintenance management (MM) plays a wide role to extend the lifetime. Alwadie.A (2017) has presents alternative non-invasive a way of dealing with variable load application and limited capability for low load conditions. The proposed power analysis technique performs on different operating points in the motor. The motor stator current analysis overcomes the drawback of the sensor-based method.Similarity of motor stator current and also the instantaneous power validates the superiority of the technique which is discussed.

Rajani. J et al, (2018) have presented vibration analysis-based gearbox monitoring methodologies to diagnose the fault. The features are captured with discrete wavelet transform and the fault type is identified using a support vector machine. The features for gearbox fault detection have been given this condition monitoring algorithm is simply used for real-time application. E.A.Nabby et al, (2018) have presented a paper in a study of condition-based machine monitoring achievement and goals are done with the help of different techniques in vibration analysis.Applying various methodologies such as spectrum, waveform, and impact demodulation which detect and diagnosis fault and decision making. The impact demodulation technique which specifies the fault bearing, and source location it improves machine health and availability, and also avoids any unplanned stoppage, while time and spectrum can only detect but won't show the exact fault that occurred. In demodulation, the peak value is higher on the drive than on the non-drive side. K.Ravi Prakash Babu et al, (2018) have present fault detection in turbine generators are analyzed by horizontal, vertical, and axial direction vibration signal in the form of velocity. As per the ISO standards, the misalignment of the rotor was predicted and diagnosed. The turbo machinery condition is maintained.

SagarSutar et al, (2018) have presented a study of common causes as produce vibration in machines. The problem of the machine is identified using phase and amplitude of the vibration signature and also discussed the data collection equipment as well as elaborated the phase analysis and frequency analysis, unbalancing, and procedure of balancing. The industrial machine fault location can be identified with help of vibration analysis. KawtharAlameh et al, (2018) have proposed a model that focuses on the rotor smaller domains and air gap faults. By changing some of the parameters various severities were simulated. The value of various thresholds is been computed to achieve a less false rate. D.Ganga et al, (2018) have presented an internet of things (IoT) machine monitoring for real-time. Motor shaft vibration data are collected using vibration sensors through a serial drive interface. The IoT- cloud gets the data from multiple machines. The data were analyzed with the proposed classification-based signature decomposition algorithm and also with time-frequency domain analysis compute the thresholds value of all the machines intricately to the internet of things (IoT) autonomous system.

Yong Chen et al, (2019) have presented a related work of failure detection methods of permanent magnet synchronous motors (PMSM). Some common faults like electrical, mechanical, and magnetic are detected with data-driven diagnostic algorithms, model-based fault diagnosis, and various signal processing methods are enumerated. Deep learning is a hot topic due to its high intelligence but the requirement of hardware is higher even though data are correctly classified. Sparse representation classification (SRC) and support vector machine (SVM) and also some methods are shortly described in this paper. Pinjia Zhang et al, (2019) have presented a survey of wind turbine breakdown and existing condition monitoring and fault diagnosis (CMFD) method operation and maintenance. The breakdown leads to drastic repair expense due to complex structure and difficulty to access some time many threaten the stability of the whole power grid. The energy flow, information flow, and integrated operation and maintenance system based on electrical signal is been proposed that improves the signal to noise ratio SNR of information. The sensor less condition monitoring and fault diagnosis (CMFD) of wind turbine (WT) is the future implementation. Umesh carpenter et al, (2019) have presented a survey of recent developments in bearing failure, vibration estimation procedures, and wellsprings that have been completed for increasing the exactness and capacity of monitoring bearing. With time-domain we can only identify only the fault in bearing it won't show the location of the fault and in frequency domain distinguish the fault area in bearing.

Wedajo T. Abdisa et al, (2019) aim to diagnose bearing fault using a vibration dataset by testing the signature easily by programmable logic controller in artificial neural network. These data are recorded for normal bearing, outer and inner raceway, and ball defect of bearing. All the three-layer otherwise called multi-layer back propagation neural networks was proposed. Both time and frequency provide a good detection. A programmable logic controller (PLC) on an artificial neural network (ANN) bearing-based identification produces feasible in-time domain features. This is the cheapest software approach and guarantees its flexibility and also a major approach for carry out the bearing fault on existent and upcoming new projects. M.Fabricio et al (2020) have presented monitoring of industrial electrical equipment using the Internet of Things. The system measures the equipment using sensors that are connected to the data module, stores the data for preliminary processing. The data are analyzed to detect the operating state and this information is transmitted to the Internet of Things for storage and real-time visualization, processing detects a potential failure, the system alert, and provides minimal automation. GyungminToh et al, (2020) have provided a study of fault monitoring by applying machine learning algorithms that have rapidly improved in vibration-based structural application.

Ting Hu et al, (2021) have presented, the instantaneous shaft speed is extracted by tracking the vibration. Along with shaft speed, directly they get instantaneous phase by numerical integration. The vibration resampling is carried out in the digital domain and the subsequent synchronous analysis increases the signal to noise ratio. Using bandpass filter vibration mode is isolated using phase demodulation on the analytical function to achieve phase isolation. This proposed method will be useful only for gear meshing such as parallel gear meshing. Dileep Kumar soother et al, (2021) have presented the review of deep learning DL-based condition monitoring of motors with itis expression about on feature processing input method. Advanced DL models, DL-based diagnostic, and hybrid fault diagnostic techniques are described.Feature processing techniques have raised the efficiency and also reduce hardware dependency which deletes extra information while during faster execution.Convolution neural networks (CNNs) and recurrent neural networks (RNN) are successful in implementation and imbalance problems in data solved using generative adversarial neural networks (GANs). The work focuses on mechanical fault diagnosis with DL models and a modified task was been carried out regarding electrical failure discovery and also to predict.

V. VIBRATION ANALYSIS

Vibration analysis lets a specialist monitor a machine's vibration by using a real-time (or) handheld analyzer manufacture into equipment IlhanAsilturk et al, (2017). This is a process of anomalies to be looked at. During peak conditions, the machine exhibits a particular vibration pattern. If the machine components like shaft bearing begin to get wear and tears different vibration patterns are generated in the machine. The vibration of any device in movement is distinguished by variation of frequency, amplitude, intensity GoutamSenapaty et al, (2018). Though the vibration signature can be correlated to physical phenomena and the vibration data help to monitor the machine's health. G Diwakar et al, (2012).

A. *Time-domain analysis*

It refers to the analysis of physical signals concerning time. The time domain is an easy and early signal processing technique to analyze the waveform but it's not a successful result K.Umapathy et al, (2010). The time-domain operation such as signal averaging, convolution, inner product, correlation provides information about the signal. This approach analyzes the amplitude and phase of the vibration information in time representation signal to spot the failure of theequipment. Which is adequate during regular vibration obtained and generate the fault based on periodical impulse. With help of time-domain analysis, it's hard to find the source of the fault. The calculation on descriptive statistic broadband analysis method, the parameter being monitored is a root mean square, peak to peak, crest factor, root, standard deviation, skewness, kurtosis, peak & interval ShyamPatidar et al, (2013)

B. *Frequency-domain*

It refers to the analysis of mathematical functions concerning frequency. This technique which as fast fourier transform (FFT), hilbert transform Method and power cepstrum Analysis, etc Amit Aherwar et al, (2012). The "spectrum" represents the frequency domain of the signal. It detects harmonics and sideband patterns in the power spectrum. Xiao et al, (2020). The inverse fourier transform of the frequency-domain function converts into the time-domain function. A frequency-domain includes data on the phase shift that must be appeal to each sinusoid to able to look upon the frequency components to recover the indigenous time signal. Meng et al, (2004). The signal can be alteredamong the time-domain & frequency-domain by transform to get accurate results Azeez et al, (2014).

C. Time-frequency representation TFR

This method has been introduced to handle non-stationary signals in machine faults all methods have restrictions at some point. In time-frequency analysis, the energy is represented in both frequency and time dimension is achieved by using a formulation known as time-frequency distribution. SaleemRiaz et al, (2017) Short-time fourier transform (STFT), wigner-ville distribution, wavelet transform (WT), fourier transform (FT) has restrictions on its result. Time and frequency field values are complex in TFR. modulus of the field indicates amplitude and the argument phase.

D. Wavelet transform

The mathematical notation feature of a wavelet transform separate a continuous-time signal within various scale component then analysis every parameter later matched to its scale and also advantages through Fourier methods in analyzing the physical situation. The Wavelet Transformation extracts both local spectra and temporal information Lee et al, (1998). Yassminseid Ahmed et al, (2020).

E. Time synchronous averaging TSA

Time synchronous averaging (TSA) which records data in time-domain this methodextracts waveform in clash data E.A.Nabby et al,(2018). From the vibration source signal clash data and other data are separated and also to decrease the framework noise from signature various techniques have been implemented. Fast fourier transform (FFT) is used to remove the clash data in the vibration signal and which is computed and informed by trigger pulse to the analyzer. TSA is classified into two methods they are time simultaneous linear average & time simultaneous exponential average.

F. Order analysis

The order analysis technique is to analyze the noise and vibration signal of rotating machines like a shaft, bearing, engines, turbines, pump, gearbox, and compressors IlhanAsilturk et al, (2017). The rotating machine speed indicates first-order similarly for multiple of rotational with speed is multiple orders are frequency. It collects the reference RPM signal been correlates with the measured vibration on the rotational equipment. The harmonics orders are identified concerning reference RPM. Spectral analysis is inconvenient to identify the fault early in the machine, particularly local failures. It is hard to interpret the sideband relations and spacing in the spectrum.

G. CNN's for feature learning

Convolution neural networks (CNNs) includes the convolution layers, the pooling layers, the fully connected layers, where CONV layers extract feature maps by conduct convolution operation to the input data; the feature maps is down sampled by pooling layer to highlight the extracted feature to achieve the data dimensionality reduction which is classified by the fully connected layers. Oscar Serradilla et al, (2020) Finally, the fully connected layers which connect all the previous layer to generate global semantic information. By connecting several layers of the convolution layers, the pooling layers, and the fully connected layers we get structural hierarchy so that higher-level features are the composition of the lower level.Which perform high-level and carry out the required task successfully. Both one dimension and 2D are successful in processing it helps to detect fault patterns in vibration coming from the rotating machine Sharma et al, (2020). CNN is the leading exponent of the deep learning technique. Y. Hou et al, (2020).

VI. CONCLUSION AND FUTURE WORK

Condition monitoring gives information about the equipment. The main objective of condition monitoring is to gather information about the fault diagnostic. The data is collected using vibration analysis monitoring of the rotating machine. This review paper describes the vibration analysis and its classification on predictive machine condition monitoring. The vibration analysis technique is used due to its low cost and it is better compared to others. It provides a highly selective, sensitive, and co-effective means for online monitoring of an industrial heavy machine. The study has given some knowledge about the identification of fault in the industrial machine using vibration analysis.Thenovel research work in condition-based monitoring was summarized focusing on upgrading non-linear, non-stationary feature extraction and fault classification algorithms to improve fault detection. The traditional stationary signal processing techniques are inefficient for recognizing machine faults in time-varying conditions. The features with higher dimensions that have higher information should operate in a different condition for robustness. WT analyses have been accepted as a suitable signal processing technique for machine condition monitoring and failure diagnosis. By modelling time series into time-frequency space, it is possible to determine not only the existing frequencies in the signal but also the duration of each frequency in time. WTs possess multiple resolutions for localization of short time components enabling all possible types of gear fault to be displayed by a signal time-scale distribution resulting from the transform. CNN in deep learning identifies the fault. By comparing traditional methods, CNN has the advantage of high accuracy in machine fault diagnoses. Which automatically extracts the feature of input signal & no need for humans in features extraction and other data pre-processing is required hence the feature separable is moderately increased. By combining both CNN and WT we can reduce the false alarm rate with higher efficiency.

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