A Brief Review/Survey of Vibration Signal Analysis in Time Domain

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Abstract :

Vibration signal analysis and monitoring is a predictive maintenance technique that can detect the faults in the machines. In this paper, data acquisition system, signal analysis and lab VIEW Tool is used for detecting the faults in machines. Thus, preventive action can be taken in advance. For monitoring and analysis of vibration signal, time domain, frequency domain and time-frequency domain analysis of vibration signal is implemented. Wavelet transform analysis will give more accurate information about the vibration signal type, signal fault region and fault extent as compared to time domain analysis. In this paper, a brief review about the concerned research work is presented & is just a survey / review paper & there is no novelty in it and is only a collection of works done by various authors. This will surf as a base for all the people who wants to pursue their career in the field of control systems.

Keywords — *Data acquisition, Vibration signal analysis, Time domain, Frequency domain method, Lab VIEW.*

I. INTRODUCTION

Vibration signals are generated from the machine in industries, which are the good indicator to monitor the machine. Internal faults of the machine can be easily detected from the vibration signal graph. Thus, preventive action can be taken in advance. The signal nature is measured and the sophistication degree is required in acquisition system. There are number of ways are available in order to send data into a computer.

Data Acquisition Card (DAQ) card is one of the important module that can easily access the data from physical phenomenon in the real world to the digital computer of artificial world. DAQ can be used easily, it performs multifunction and cost is less than any other data transfer device. A computer plays an important role in process, monitoring, analysis and control of vibration signal. For interfacing, GPIB were most popularly used in earlier in order to test and measurement instruments as prior to virtual instrumentation.

This has emerged into a multifunction technique that encompassed the entire computer based instrumentation area. Thus for a large extent hardware can reduced. By these advantages, VI is used as a dominant tool for the expansion and contrivance of instrumentation application and systems. Lab VIEW (laboratory virtual instrument engineering workbench) tool is used as a software driver for interfacing with various instruments. More application like monitoring, analysis and controlling can be done by lab VIEW tool [1].

The flow of the paper is organized as follows. A brief introduction to the research work was presented in the previous paragraphs in the introductory section. Vibration measurement is dealt with in section II followed by the fault detection architecture in section III. In section IV, time domain analysis is presented. The conclusions is presented in section V followed by the references in section VI and the author biographies.

II. VIBRATION MEASUREMENT

Measurement of standard vibration signal starts with collecting a time varying signal using a vibration transducer, such as an accelerometer from a machine component. For simple applications piezo-electric crystals is used as a transducers, where it converts mechanical vibration signal in to corresponding electrical voltage signal. Then this signal is brought into a portable, digital measuring instrument such as data acquisition system through the data cables and the signal can be processed for a variety of user required functions [2].

Based on requirements and the methods of analysing the signal, the user can perform different mathematical operations and processing to convert the raw signals to other vibration measurement units and also by using mathematical operations such as FFT's the user can change the domain of vibration signal. For an accurate output in a required frequency range, the user can modify the intensity of the raw signal, signal conditioning techniques such as averaging, signal sampling, low pass and high pass filter series circuits which are integrated to the measuring system.

The great importance of time domain waveform analysis for a particular condition monitoring technique is, it can fix the number of samples and also sample rate [3]. Most of the portable vibration signal measuring instruments are incorporates an FFT (fast Fourier transform) processing system which helps to convert a time-varying signal to corresponding frequency domain and splitting it into its individual frequency components. Further more advanced signal processing techniques such as spectra analysis, log-spectrum (cepstrum), Short Time Fourier transform (STFT), wavelet transform are also available

III. FAULT DETECTION ARCHITECTURE

The first step is to collect the vibration signal from the machine. Accelerometer transducer is used as sensing element in order to collect these vibration signals. The accelerometer provides a voltage that corresponds to the vibration level. Data acquisition card collects these analog signals from accelerometer and transfer into digital signals for further analysis. Additional measurements can be used such as temperature measurement.

Multiplied measurements using both vibration and temperature analysis is possible to enhance the efficiency of the system, even temperature measurement could be used to make more accurate measurements. Computer software (Lab VIEW) is used to perform the analysis and the analysis methods are explained in brief in the subsequent sections.

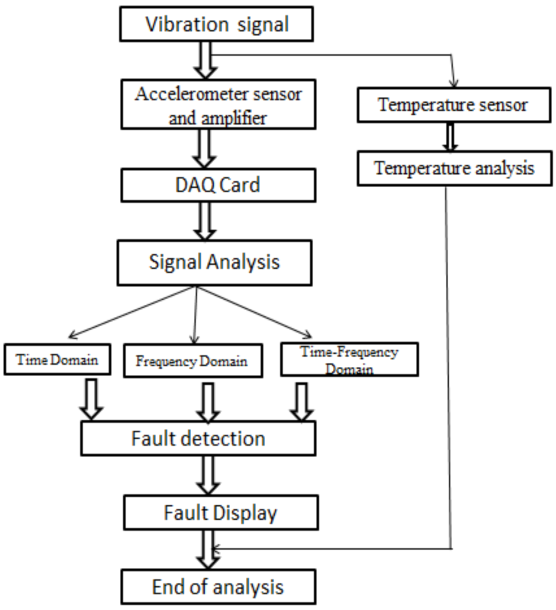

Fig 1 : Fault Detection Architecture

IV. TIME DOMAIN ANALYSIS

In time domain analysis vibration signals will be collected as digital values which indicate the proximity, velocity or acceleration in the time varying plot. This helps to analyses or displays the vibration data as a function of time.

The advantage of time domain signal format is that no or little data are lost prior to inspection of vibration signal. The vibration signal from good machines and faulty machines shows the different vibration signature even after the normalization, energy elimination and filtering of time domain data [4].

The time domain is used to analyze the failure and fault, by analyzing the acoustic data or vibration signal obtained from machine component, signal processing techniques and feature extraction are mainly used to find the random characteristics of a vibration signal generated from machines.

Feature extraction is the mathematical parameters which represent the peaks, shapes, and randomness of a time varying signal and this can be calculated using higher derivatives of time domain signal. Some of the parameters of the vibration signal analysis techniques that are used to analyses the time domain signal plots are classified into following groups:

- Statistical parameters that include standard deviation, Root Mean Square (RMS) value, peak value, crest factor, kurtosis, skewness, clearance factor, and impulse factor, shape factor, upper wound value of histogram and lower bound value of histogram.
- Filter based methods include adaptive noise cancelling (ANC), prony model & de modulation, etc.
- Time based synchronous averaging methods which includes Residual signal (RES), Difference signal (DIFS), Time synchronous Averaged (TSA) signal etc.

A. Standard Deviation

Standard deviation represents the amount of dispersion or variation from the average. A low standard deviation represents the data point is very close to the mean, whereas high standard deviation represents the data points are spread over a large range of values.

$$\text{Standard Deviation} = \sqrt{\frac{1}{n}\sum_{i=0}^{N}\left[X(i) - X\right]}$$

where X represents the mean value of the time series of X(i) & i is the sample number and N is the total number of samples.

B. Root Mean Square Value

RMS feature is good for tracking the overall noise value and indicates that the amount of energy in the vibration signal is proportional to its RMS value. It is very effective in detecting major out of balance in random signal. The RMS value of the discrete time signal is given by

$$\Psi_x = \sqrt{\frac{1}{n}\sum_{i=0}^{n-1}\left[X(i)\right]^2}$$

where i is the sample number and N is the total number of samples.

C. Peak Value

Due to occurrence of local impacts, variations in peak value of a vibration signal are indicated. Thus the peak value of the signal is used to identify such occurrence. The peak value of time signal is given by

Peak Value = max (Xi)

D. Crest Factor

The crest factor can be defined as the ratio of the peak value to the RMS value, it yields the information about the spikiness of the measured signal. It is a pure number without any dimensions. Crest factor indicates the existence of sharp peaks in signal and its value is very sensitive towards signal properties and is given by

$$\text{Crest factor} = \frac{\text{peak value}}{\text{rms value}}$$

E. Kurtosis

It is a statistical measure which indicates the property of signal, whether the signal data are peaked or flat relative to a normal distribution of signal. In other words, kurtosis can be defined as the standardized 4th central moment of a distribution. Data sets with distinct peak near mean value, heavy tail and decline rather rapidly with respect to mean shows high kurtosis index. But signal data with flat top near the mean shows low kurtosis index and this kind of signal bears less number of sharp peaks.

$$\text{Kurtosis} = \sqrt{\frac{\frac{1}{N}\sum_{i=0}^{N}\left[\overline{X(i)-X}\right]^4}{(\text{RMS value})^4}}$$

F. Skewness

Skewness is a measure of symmetry in a distribution, in other words the lack of symmetry. Skewness for a normal distribution is zero since it is highly symmetric and data with Skewness near to zero shows higher degree of symmetry. Skewness of vibration signal indicates the position an orientation of defect. The skewness of a distribution is given by

$$\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[X(i)-\frac{X}{\text{RMS Value}}\right]}$$

G. Clearance Factor

It is the ratio of peak value of the signal to the square of the average of square root of the absolute value signal. If X, is the ith sample value and N is total number of sample, then clearance factor is given by

$$\text{Clearance factor} = \sqrt{\frac{\text{Peak value}}{\frac{1}{N}\sum_{i=1}^{N}[X(i)]^2}}$$

H. Impulse Factor

It is ratio of peak value of the signal to average of the absolute value of the signal, If X_i is the i^{th} sample value, i = 1, 2, 3 , ... and N is total number of sample then it is given by

$$\text{Peak value impact factor} = \sqrt{\frac{\text{Peak value}}{\frac{1}{N}\sum_{i=1}^{N}[X(i)]^2}}$$

I. Shape Factor

It is ratio of root mean square value of the signal to the absolute value of the signal and if X_i is the i^{th} sample value and N is total number of sample, then shape factor is given by

$$\text{Shape factor} = \sqrt{\frac{\text{RMS value}}{\frac{1}{N}\sum_{i=1}^{N}[X(i)]}}$$

J. Upper and Lower Bound Value of Histogram

The histogram can measure the discrete probability density function of sample data. Two values namely upper bound and lower bound values are used as fault classification.

The Upper Bound Value of Histogram (UB) can be obtained by,

$$UB = \max(X_i) + \frac{0.5[\max(X_i) - \min(X_i)]}{N-1}$$

The Lower Bound Value of Histogram (LB) can be obtained by

$$LB = \min(X_i) + \frac{0.5[\max(X_i) - \min(X_i)]}{N-1}$$

A feature to analysis a time domain signal is selected on the basis of its ability to generate meaningful and useful plots and summarize the collected data. Overall root-mean-square (RMS) level and crest factor (ratio of peak value to RMS) are the popular as well as the simplest methods adapted to analysis time domain signal plots. But in the case of detection of localized defects, RMS method provides limited success. So Statistical tools like kurtosis, symmetry, correlation factor, Skewness and probability density properties are also adopted along with RMS method for fault detection [5].

The idea suggested by Tahsin Doguer and Jens Strackeljan [6] was that the time domain signal analysis can be done by feature extraction of time varying signal by concentrating on the properties of a particular part of the time signal in such a way that the selected part should exhibit close relation to possible defects. This iteration is done by selecting a peak in the time varying signal which represents the presents of local extreme in the measured acceleration signal collected from desired rolling element bearing.

After the selection of local extreme peaks from the time domain signal which fulfill the requirements of the peak definition and closely related to defects, significant information like peak position, adjacent data points and amplitude are found then stored as a time domain vibration signal. For the calculation of time domain features the above iterated data sets can be used as inputs and this will increase the accuracy index of the fault analysis, the specialty of this method is that the fundamental properties of the time domain signal will not change even after the normalization of signal data.

V. CONCLUSIONS

The review of this paper presents vibration signal monitoring and analysis in terms of time domain. The vibration signal acquired from accelerometers mounted on the machines is compared with the standard signal to determine the health of the machine. Time domain techniques includes raw signal, statistical parameters, filter based signals and time based synchronous signal.

The statistical parameters such as RMS, standard deviation and kurtosis can be calculated and compared with a threshold to detect machinery faults. Filter based methods such as demodulation are being used to effectively separate “fault” vibrations from other irrelevant signals such as noise. In time domain it is difficult find the fault type and fault region. The vibration signal fault is not clearly obtained. In this paper, a brief review about the same is presented, this will be the base for our future works.

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