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Mechanical Vibration Analysis Of HVAC system and Its Optimization Techniques

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Abstract: The main aspect of this paper is to discuss capturing and analysis of mechanical vibrations of an HVAC system and optimize its efficiency and performance. This can be done with various methods. In this paper, we are using fuzzy controller for the design optimization. Here the HVAC (Heating, Ventilation and Air Conditioning) system is made use for the analysis. Various analysis are done on mean, variance, standard deviation, kurtosis, maximum and minimum values and histogram of the vibration data from the system along with the frequency mode analysis. In generally, data is captured using the motion sensors or vibration sensors firstly. Then it is analyzed. And on next, the controller decides the solution for the problem. Sometimes it might be a control signal to the controller or a warning pop out in the monitoring system depending up on the characteristics of the vibration. This action is related with the vibration scales, frequency analysis bandwidth and the addition and subtraction of the decibels. The bandwidth of the vibrations is also plays a vital role in the controlling of the system.In this paper, here designed controllers to deal with the analysis of the vibration signals. The simulation of the system is done with MATLAB. The requirement of these controllers is to provide a more stable and reliable performance and helps the system to regain its normal value after any disturbance.

***Key words*:** HVAC, Transducer, Fast fourier transform, mean,variance, standard deviation, kurtosis,histogram, FFT, Fuzzy logic.

I. INTRODUCTION

The mechanical vibration analysis of electrical devices has become a major area in improving the performance and efficiency of the system. There are various techniques used for the same. The basic of these strategies include data capturing, analysis and formation of control signal to the controller. In this paper we will discuss about some of these techniques used currently and try to find some improvement or advanced versions for them.

First of all let us see how any kind of mechanical vibration is processed on any electrical machine. What is a mechanical vibration? In simple words, we can say that mechanical vibrations are oscillatory behavior of mechanical bodies. For this oscillatory motion to exist, a body must possess inertia and elasticity when an external force is applied. In case of electrical devices, this force might be electrical or mechanical. ie, for generators, its mechanical and for motors, its electrical. For a linear system, there is a direct relationship between the cause and effect of the vibrations. If the force input doubles, the effective vibration also doubles. If the current flow is high, the noise can be high and vice versa for electrical motors. The amplitude of these mechanical vibrations will be much smaller, compared with the physical dimensions of the body. The duct vibrations will be larger from case vibrations as case is bolted strongly than duct. There will be normal vibrations due to the excitement of the coil of the device and abnormal vibrations due to some faults in the system on shaft. The aim is to distinguish these vibrations and provide the control signal for optimized performance or give warning signals to the system monitoring equipment for the occurrence of the error. These vibrations can be

(i) Periodic
(ii) Non periodic
(iii) Harmonic
(iv) Random.

The forced vibrations occur at the excitation frequencies, and it is important to note that these frequencies are arbitrary and therefore independent of the natural frequencies of the system. For shaft, it is 200- 250 Hz.

The role of mechanical vibration analysis should be to use mathematical tools for modeling and predicting potential vibration problems and solutions, which are usually not obvious in preliminary engineering designs. If problems can be predicted, then designs can be modified to mitigate vibration problems before systems are manufactured. Vibrations can also be intentionally introduced into designs to take advantage of benefits of relative mechanical motion and to resonate systems. Unfortunately, knowledge of vibrations in preliminary mechanical designs is rarely considered essential. So many vibration studies are carried out only after systems are manufactured. In these cases, vibration problems must be addressed using passive or active design modifications. Sometimes a design modification may be as simple as a thickness change in a vibrating panel; added thickness tends to push the resonant frequencies of a panel higher leading to less vibration in the operating frequency range.

The bandwidth of the vibrations is also plays a vital role in the controlling of the system. The controlling through analysis of these signals allows for fault detection and prediction of any anticipated failure, and has significant benefits including

(i) decreased maintenance costs
(ii) increased availability of machinery
(iii) reduced spare part stock holdings and
(iv) Improved safety

The failure mode analysis technique is commonly used to identify the faults in the system and where the improvement in machinery is available. Reduction in the maintenance costs can be achieved through the continuous monitoring of the system. And also focuses on the optimization of the system by achieving specified objectives.

Not only the motors and generators, but the HVAC system also posses vibration. It can cause secondary radiation of noise from walls, ducts, floors, etc. A close monitoring of these vibrations also required for the smooth and improved working of the system. Components of the mechanical system (e.g., fans, dampers, diffusers, duct junctions) are also important because it may produce sound by the nature of the airflow through and around them. As a result, almost all HVAC components must be considered. Because sound travels effectively in the same or opposite direction of airflow, downstream and upstream paths are often equally important.

As per the above comments, we can understand that the vibration analysis of any system is much important as temperature analysis, current – voltage analysis, metallurgical failure analysis and wear debris analysis. Noise or vibration signal analysis can provide the vital and exact running condition of the machine. But sometimes, the signal, which is to be monitored, might be submerged or interfered with other signals. We have to find for an improved method for the analysis of vibration signals.

2. METHODOLOGY

For making or attaining a control strategy, we need to distinguish the vibrations from individual components of the system. In time domain it is not easy to carry out this process. So usually we make use of frequency domain for better results. For that, one of the method used is fourier transform. We have to convert these time domain to frequency domain using Fourier transform technique. Fourier transform gives the frequency domain of the vibration data captured.

In time domain, there is a chance of developing the fault before it affect the overall rms vibration level or peak level. The result of the faults might be causing serious damage to the system. So it is better to make use of frequency domain analysis for the optimized result of the system.

After converting the time domain signals to frequency domain, we are employing a fuzzy controller. It is a better controller used in yes/no conditions. Here make use of this technique for analyzing the vibration signals. On this method, we undergo a predefined algorithm and finds solution for the problem. Fuzzy logic finds applications in variety of domains. It is proven to be much cheaper, stronger and reliable than most of the classification algorithms. Specifically, fuzzy logic is most used when the input data is not crisp in nature and it gives vague information [16].

The other factors used to for the classification of faulty vibration signals are

- Mean
- Standard deviation
- Variance
- Maximum value
- Minimum value

After classifying the error signal, we have to go for the control signal. For an optimized system, we have to choose for the most suitable solution of the problem identified.

The control strategy includes various stages.

- Detection of system mechanical vibration
- Extraction of specific component by Fourier transform
- Analysis of this FFT signal using fuzzy control algorithm
- Generation of control signal from the controller
- Comparison of control signal with the required optimized parameters
- Final control element or actuator to control the equipment at the last stage.

3. OBJECTIVE OF THE STUDY

3.1 Measurement of vibration on vibrating equipment.

Examination of equipment vibration generated by system components, such as bearings, drives, etc. Measurement of the natural frequencies (resonances) of vibrating equipment or connected structure(s) Examination of equipment installation factors, such as equipment alignment, vibration isolator placement, etc and Measurement of the unbalance of reciprocating or rotating equipment components gives the idea about what action to be done to avoid that fault.

3.2 Determining the problem source

Determining the problem source is important as if the problem source is not determined, then optimization of the system is not attained. . Hence identification of problem source is very important for a fast time reaction to the problem.

3.3 Determining problem type

Once the source is identified, then we have to find the characteristics of the noise and have to reach in to a point that what type of problem is occurred. Some of the normal problems showed by the machines are given below.

1 Equipment improperly specified or installed, poorly balanced, misaligned, or operating outside of design conditions
2 Equipment with inadequate or improper vibration isolation
3 Resonances in equipment, vibration isolation system equipment
4 Various faults in any mechanical body part of the system

3.4 Taking action to the determined problem

The signals captured by sensors are given to controllers. Here general purpose accelerometer vibration sensor are used. These signals are analyzed using Fourier transform. An appropriate control signal or warning signal is generated according to what the problem detected. This may be to the controller or to the monitoring system for recording. if the found out problem is something that cannot handle by the controller, i.e. requirement of any mechanical body replacement etc. the warning signal is send to the monitoring system.

3.5 Continuous monitoring

Continuous monitoring of the system is required to make sure whether the analysis were correct or not. It is very important to the continuous evaluation of the parameters to make the quality assurance. Feedback control strategy is employed in monitoring the system. The performance is continuously monitored and signals or pop outs are send to the controller in case of any abnormality is detected.

4. VIBRATION MEASUREMENT

Vibration measurements must specify how the amplitudes are expressed. These can be either peak (the maximum level), peak-to-peak (the range between minima and maxima), or rms (root mean square). Several factors must be considered when making vibration measurements such as reference signal, frequency range of measured signal, transducer to be used, etc. An extremely rigid attachment method is used for transducers, such as dental cement, or a screwed connection with oil between the surfaces, is required for accurate measurement at very high frequency (about 5 kHz).

Sensitivity and scale are two important factors affecting the measured values. Use of not too much sensitive or less sensitive sensors will result in getting the proper signals. If we are using a very high sensitive instrument, then we will be having problem with the increased amount of noise. More effective techniques should be used to get the required data and it consume more time and money too. So selecting a sensor with the correct range of sensitivity is important.

Transducers, pre amplifiers, analyzers are used to detect the vibrations from the system.

5 VIBRATION SIGNAL ANALYSIS

The mechanical vibrations thus obtained are of time domain. We have to convert them in to frequency domain for detailed analysis and detection of any fault. Suppose there is a bearing fault in the motor. It is easy to find out the error in frequency analysis of the vibration, compared to amplitude analysis in time domain.

5.1 Fast Fourier Transform

Fast Fourier Transform method is used for this. Forces and responses in real world systems are usually complicated.We need to understand how to express them in analytical terms. For this focus on deterministic analytical forced vibration response analysis: Assume that we know the excitation or force exactly at any moment in time. In random vibration analysis, the statistical properties of the excitation, which is not a continuous sample of data.

$$G(\omega) = \sum_{n=1}^{k} g(t_n) e^{-j2\pi f t_n}$$

Where t_n is the time domain value and f is the frequency

5.2 Mean

Finding the mean value after a specified set of vibration data from sample and comparing it with the reference data will help us to define the error type and the magnitude of the fault. Find the optimized output by analyzing the change in mean of the vibration data.

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Where x is the instantaneous value n is the total count of values

5.3 Variance

The variance for a sample set of data means how far the samples are spread out over the range. It gives the amount of chance of any error to be occurred in the machine. Variance of vibrations from a motor near to zero indicates that it is working in good condition. Analysis on the vibrational data on its variance gives us the probabilty of running the instrument on good condition.

$$Var(x) = \frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{1}{2}\left(x_i - x_j\right)^2$$

Where x is the sample in data and n is the number of samples

5.4 Standard Deviation

The standard deviation of the sampled vibration data over a time period gives the quantity of the error occurred on field. It is defined as the closeness to the mean value of specific set of sample data.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \mu)^2}$$

Where

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i$$

And x is the sample in data and n is the number of data

5.5 Fuzzy controller

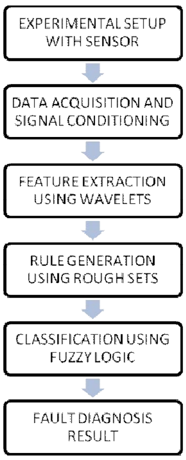


Fig 5.2.1 Flow chart of fault diagnosis system using fuzzy logic

The transformed signal from time domain to frequency domain is then analyzed using a fuzzy controller. The flowchart of the process of diagnosing the system condition using the fuzzy controller is described below.

The primary objective of this work is to find whether the induction motor is in good condition or in faulty condition. This is done by looking at the current status of the framework with references utilizing if-then algorithm. If the pump is found to be in faulty condition, then it has to be segregated into cavitation, bearing fault, impeller fault, and both bearing, impeller fault together. This study focuses on the use of rough set theory for fault diagnosis of induction motor.

6. EXPERIMENTAL WORK DONE

The system taken here for the analysis is HVAC (Heating, Ventilation and Air Conditioning). In present, no vibration data from the field plays a vital role for controlling the system. It is used for only monitoring of the system. In traditional HVAC system, temperature, humidity, air flow rate, etc are taken for the design of the controller. Here, we are analyzing the vibration data and trying to put the results on optimizing the design of the controller.

The main problems that faced by HVAC system are given below. They are

1. Low heating/cooling capacity
2. Return air flow stuck
3. Valve leakage
4. Bearing fault of motor

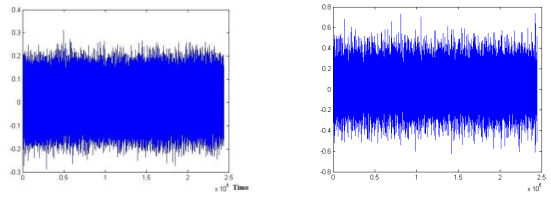
By analyzing the vibration data from the field, we can find what is the current status of the system. For this, we are using mainly two vibrations to the fuzzy controller. One is from the shaft (shaft vibration) and second from duct(duct vibration).

The motor used for the case study is a “Y2 series 3- phase induction motor” manufactured by Toptek private Ltd. And the vibration sensor used for the shaft vibration data is Model 622B01 - Platinum Precision Industrial ICP® Accelerometer manufactured by IMI sensors. For duct vibration data, ACC 320 general purpose accelerometer is used.

Fig. 6.1Installation of accelerometer on duct

7. RESULT AND ANALYSIS

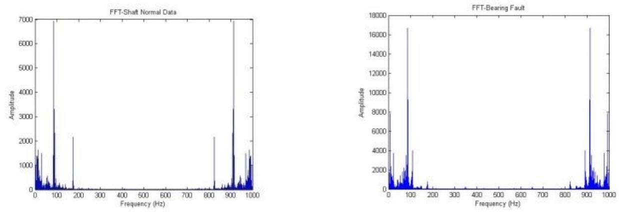
The analysis of the vibration signal are done using MATLAB software. The normal vibration and the vibration on bearing fault from the motor shaft is shown below .



(a) (b)

Fig. 7.1(a) Normal data (b)Bearing fault vibrations from motor shaft

On time domain, it is difficult to analyze the data. Hence we are converting this to frequency mode.



(a) (b)

Fig. 7.2 (a)FFT of normal data (b)FFT of bearing fault data

From the figure, we can see that the amplitude of FFT of bearing fault vibration goes to much higher than that of normal signal.

A detailed analysis of both signals on time domain is also conducted over statistical properties of the signals. The following figure shows the difference in their mean and standard deviation for every 1000 samples.

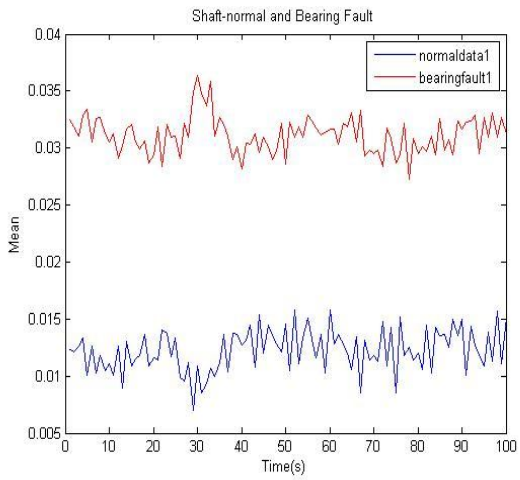


Fig. 7.3 Mean of normal data and bearing fault data

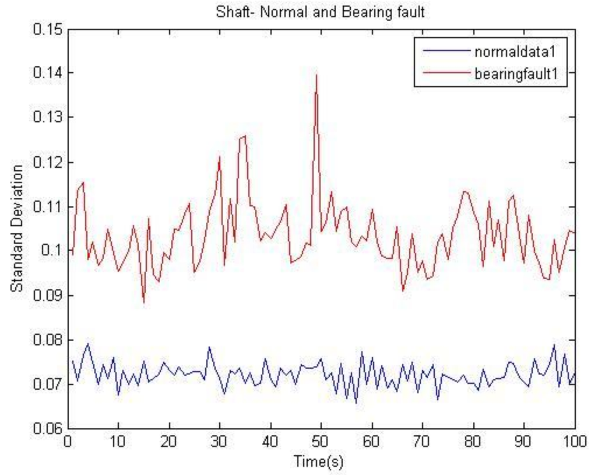


Fig. 7.4 Standard deviation of the normal data and bearing fault data

A fuzzy controller is designed according to the analysis of a number of data and that is connected to a conventional PI controller used for speed variation of the motor in the system.

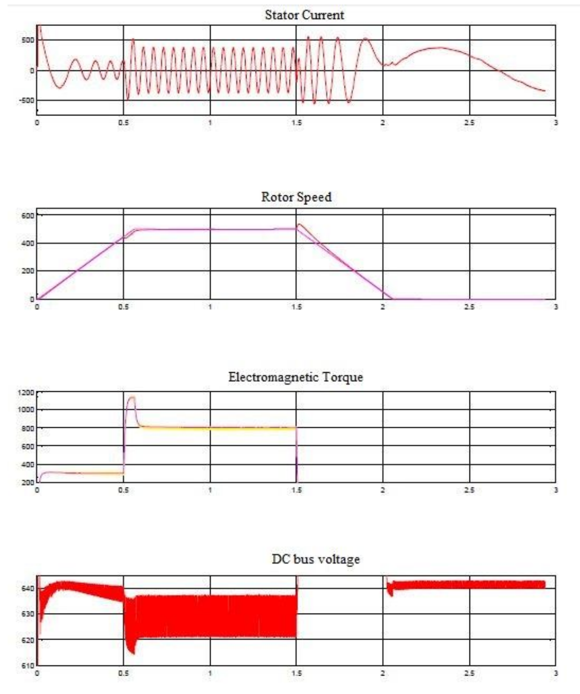


Fig. 7.5 Result on normal condition of the system

Here we can see that the rotor speed is set at a value 500 rpm on normal condition. On bearing fault condition, due to the controller action, the rotor speed changes to lower values. On the reduced capacity condition, the rotor speed shoots to higher values than 500 rpm. The result of the simulations are given below in figure 7.6 and figure 7.7

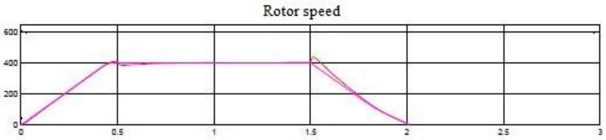


Fig. 7.5 Result on bearing fault condition of the system

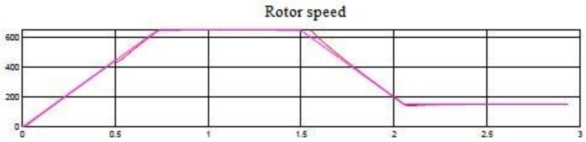


Fig. 7.5 Result on reduced capacity condition of the system

From the graph, we can see that the HVAC system is optimized on the controller action.

8. CONCLUSIONS

Thus the vibration signals from the HVAC system are measured, analyzed and a fuzzy controller is designed using the analytical data. A beginning has been made to provide an integrated environment for analyzing vibration signals of various frequency bands. The following conclusions were made from the experience.

- Spectral ordinate method of distinguishing signal from noise
- Prediction error method of distinguishing signal from noise. This will lead to detection of fault on an earlier state and further improved performance.
- Estimation of magnitude of the vibrating signal.
- Distinction between different kind of vibrations.
- Online detection and estimation of the magnitude of vibrations.
- The characteristics of the electrical machines can be improved further more if a more accurate vibration analyzing methodology is employed.
- The vibration monitoring can be interfaced with SCADA or any other monitoring system and that can help for further improvement of the system.

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