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AKSARAY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCE

DEPARTMENT OF ELECTRICAL ELECTRONIC AND COMPUTER ENGINEERING

VIBRATION ANALYSIS FOR INDUCTION MOTORS WITH AN EXPERT SYSTEM

MASTER OF SCIENCE THESIS

Cuma TIPIRDAMAZ

SUPERVISOR

Prof. Dr. Mehmet Reşit TOLUN

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APPROVAL

CUMA TIPIRDAMAZ, M.Sc. with thesis student No. 142335404, successfully presented the M.Sc. thesis titled **"VIBRATION ANALYSIS FOR INDUCTION MOTORS WITH AN EXPERT SYSTEM"**, prepared after satisfying all the requirements identified in the concerned bylaws, before the jury whose signatures are affixed below.

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DECLARATION

The idea for this present study was taken from the literature regarding the topics. I hereby declare that the whole work presented in this thesis has been composed and originated by myself unless otherwise specified. The study was conducted completely under the supervision of Prof. Dr. Mehmet Reşit TOLUN.

Cuma TIPIRDAMAZ

PREFACE

Induction motors are common in many industrial applications. Due to their simple design, failures can occur and they can be a reason production stops or the operating conditions which is not safe. Many developer focus on analyses to evaluate machine condition for better efficiency.

The applications of induction motor in industrie show that condition monitoring with fault diagnostic is very essential for nonstop production. Fault diagnosis of an induction motor by an expert system is the main goal of this research.

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ABSTRACT

VIBRATION ANALYSIS FOR INDUCTION MOTORS WITH AN EXPERT SYSTEM

This thesis presents an expert system for induction motor fault detection based on vibration analysis by using corvid expert system. Vibration signals of induction motors on four different actuating mechanism are collected with a specific vibration measuring device. The device evaluates the values with three harmonics in frequency domain. Expert system provides the recommendations as maintenance activity or the reason of the vibration by using vibration values. This system is tested and validated on four type of actuating mechanisms. Obtained results show that this system can detect faults in early stages with high accuracy and reliability. Thus, it provides malfunction and failure prevention and improves overall performance and efficiency of industrial systems.

Keywords: Fault Detection, Induction Motor, Vibration Analysis, Data Analyse, Expert Systems

ÖZET

İNDÜKTİF MOTORLARDA UZMAN SİSTEM İLE VİBRASYON ANALİZİ

Bu tez indüktif elektrik motorlarında vibrasyon analizini kullanarak hata analizi yapan bir uzman sistemi sunmaktadır. Vibrasyon sinyalleri özel bir vibrasyon ölçme cihazı ile dört farklı elektrik motoru mekanizmasından alınmıştır. Cihaz frekans ekseninde bulunan üç harmoniği değerlendirmektedir. Uzman sistem bakım faaliyetleri için önerilerde bulunabilmekte ya da vibrasyon değerlerini kullanarak vibrasyon nedenini sağlayabilmektedir. Bu sistem dört farklı mekanizmada test edilip doğrulanmıştır. Elde edilen sonuçlar bu sistemin hataları yüksek güvenirlilik ve hassasiyetle erken safhalarda tespit edebildiğini gösteriyor. Bundan dolayı sistem sorunları ve hataları engelleyip endüstriyel sistemlerin verim ve performanslarını artırabilmektedir.

Anahtar Kelimeler: Hata Tesbiti, İndüksiyon Motor, Vibrasyon Analizi, Bilgi Analizi, Uzman Sistem.

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SYMBOLS AND ABBREVIATIONS

A	Acceleration
ANN	Artificial Neural Network
AI	Artificial Intelligence
BPF	Blade Pass Frequency
C	Celcious
CBR	Case Base Reasoning
CCD	Charged Coupled Device
CPM	Cycle per Minute
CPS	Cycle per Second
D	Displacement
ES	Expert System
F	Force
FFT	Fast Fourier Transfer
FLS	Fuzzy Logic System
GA	Genetic Algorithm
HVAC	Heating Ventilation and Air Conditioning
Hz	Hertz
M	Mass
MM	Milimeter
PC	Personel Computer
PSD	Power Spectral Density
SWM	Support Vector Machine
V	Velocity

1. INTRODUCTION

Induction motors are common for industrial applications with many different actuating mechanism. There is a known fact that 40 – 50% of generated power is consumed by induction motors. Although they have a simple design, failures can occur and may be a reason production stops or unsafe operating conditions. Operational environment and princibles or assembly tasks can affect to increase induction motor failure much earlier the expected component lifetime. Failures can take place in the stator, rotor, bearing, or the actuating mechanism which they directly connect by coupling to the induction motor. Because of this reason, fault diagnosis takes place very important application in many industrial area. Diagnostic is a definition very famous in literature. It is used sensing to different areas such as mechanisms in hospital or car diagnostics in services and there is no need to implement exact definitions, because it is a common knowledge. This researche will be interested on technical diagnostics so it is required to provide a detailed describiton and explanation for this term.
The term diagnostic is a branch of science that identify the experimented state of things through cotegarized into known types with ampirical and usual defination by initiating the present state and also by forward developments. From this very general definition of the term diagnostic that can be emerged that diagnostics present the first state of the releated object and presents us some suggestions regarding its future behaviour.

The history of fault diagnosis stands as the induction motor itself. In early stages induction motors implemented with by own integrated protection systems such as high current and high voltage not to get failure. Even this kind of tools are still very common, many companies could not prevent unexpected system failures and reduced motor lifetime. Through induction motors builted more complex, improvements were also improved by the progreammers in the field of fault diagnosis.Very useful diagnostic strategies and control tools were developed to make a fault control drive. There are many improved techniques for this issue and many commercial progresses to analyse induction motors at high performance production plants. Redundant and nonstop production design methods have been implemented to get high performance and efficient components with induction motor actuating mechanisms against different kind of failures that can occur. Athough these methods are hard to implement, condition monitoring helps to unexpected fault detection and prediction of induction motors failuere actions. It is very essential to have an ability for detection motor faults in early stages. Detection and correction of incipient faults can give an opportunity for preventive maintenance during the performed and provide sufficient time at shutdown periods in many plants. They can reduce financial losses and avoid unexpected results.

1.1 Aims and Objectives

The main goals of this research are to develope an expert system for fault diagnosis of induction motors. The aims of the thesis are declared.

1.1.1 Feature extraction

The vibration monitoring and also processing have an important method for failure analysing. Actually, there are many type for motor failure analysing method, based on vibration and signals. However, the main factor of motor failure analyse is how to analyse the signals to the known reasons for detection the reason of failure. The goal is to clear behaviours which are related to specific motor fault operations.

The motor operating in very different situation which has unusual signals. But more experimental signal processing techniques usually under estimated values of different mechanisms are necessary. Even those nonstable signals, there are many devices that gives results with more stable and ampirical to make easy analyses. By implementing these devices, it is obvious to define signals which cause the failures. The aim of feature operation is to extract the signal features with the based on time and frequency domain. Regarding to collected signals in layered frequencies with illustrated rules will evaluate the faults and recommend the activities not to get faults.

1.1.2 Fault diagnosis method

The Expert System is an information processing method that proceeds the knowledge as input signals with known rules. Expert system has need an expert knowledge for fault diagnosis application. Because of this reason a knowledge engineer should define rules for fault detection and the inputs of expert system usually uses of measured signals which are taken by instruments that have sensitive and accured enough. In this case, the expert system proceed that processed data to the condition reasoning with rules and inference meaningful recommendation features. The main reason of implementing systems which are for fault diagnosis method research is that illustrating a realistic rule based inference and experimental fault diagnosis system for induction motors using an expert system in this thesis. Further implementing and evaluating the proper fault diagnosis system is another goal for induction motors. The research, as described in this thesis, employs a number of vibration data with a professional device and use device results for fault diagnosis of an induction motor.

2. LITERATURE REVIEW

2.1 Introduction

The electric motors have an important function in industry. They are common used in many applications such as pumps, fans, the systems with belt etc. However, induction motor faults can be reason of long production stops that means financial loses. Because of this reason many researcher have focused the fault diagnosis of an induction motor. There are a few data to describe faults for electric motors. These are current, temperature and vibration. Current and temperature are classical way for fault diagnosis but the vibration data has further information for analyzes. The vibration data can serve predictive approach for diagnosis. The data that come from vibration analysis can give some idea about trend of the diagnosis.

Artificial Intelligence (AI) techniques are popular for fault diagnosis. These techniques use inference, reasoning by rules and decision making processes as output of progress. There are some AI techniques for fault diagnosis by using vibration analysis in the literature.

2.1.1 Expert system

Expert Systems are common for fault diagnosis. Rule-based systems are widely used because they allow the incorporation of multiple cases. This is an advantage of evaluating the knowledge to reach the direct results. There is some sample fault diagnosises for rotating machines as an expert system in the literature.

Ma etal., (2012) have implemented a rule based expert system for machine fault diagnosis. The system defines rules according to the mechanism and reason of failures and aims to guide maintenance effectively.

Zhinong etal., (2013) have studied an expert system that defines the faults by multi source signal integration for reciprocating compressors. The expert system is an online monitoring system that gives recommendations about inspection and maintenance activities.Ebersbach etal., (2007) generalizes an expert system that execute machine condition monitoring of a gearbox through the vibration, oil and wear particle analysis.

The system analyze the machine condition and tries to find the reason of gearbox faults.

Ngoc-Tu etal., (2007) confirm the machine status by using decision tree with vibration based inputs at a rotating machinery. The main idea behind of this work is to generate a simple way to monitor machine status with the knowledge of experiences and case studies such as looseness case, stator winding fault, rub fault and unbalance motor. Expert system gives comments and suggestions through this case studies.

Željko etal., (2012) determine a system that vibration signals of healthy and faulty induction motors are collected and characteristic features, as indicator of fault presence, are calculated, in both time and frequency domain. Two types of faults were considered, static eccentricity and bearing wear. In this manner, the system has more efficient fault detection based on more comprehensive feature sets, which would improve maintenance procedure and decrease total cost in production processes.

2.1.2 Fuzzy logic system

Fuzzy logic provides an uncertain results but help to describing complex systems by using statements which have no certainity instead of the inference the result exactly true or false. Fuzzy logic is very common in many industrial area with different applications.

Fuzzy logic uses deductive systems to charge the resulting engines to on defined variables and make data bases by using fuzzy if-then rules. Those statements are then revise by a fuzzy logic resulting engine, producing the corresponding output datas, which are then formed to a single overall fuzzy set. Fuzzy sets have an important role while defining to uncertainty. The implementation of fuzzy logic is common in the literature.

Dipti etal., (2015) implemented decisions based on classifying signals into uncertain values is healthier than faulty based values. For instance, the measured amplitude can be examined according to fuzzy logic for a motor then it can be classified as healthy or faulty. Fuzzy logic also allows gathering fuzzy information from different signals together to have a more accurate reasoning regarding the statment of the motor. Those informations define the motor as how much healthy.

Renato etal., (2012) design a reasoning method that perform a waveform through the use of a sensor, implement the signal. The frequency domain has used for analyzing the signal. Fast Fourier Transformer method has to be applied to use frequency domain for signals. Fuzz reasoning is a method that determines any failure of the equipment such as unbalance, misalignment and bearing defects.

Mehmet etal., (2012) used motor stator currents to implement the reasinig data. Those datas are integrated to a PC (Personel Computer) with the software. These datas which are vibration signals are obtained by using software Labview during the analysis of fault condition. After obtaining the dominated signals of the broken rotor bar failure, a fuzzy logic algorithm is implemented to classify the fault.

Arfat etal., (2011) present an induction motor condition monitoring by using fuzzy logic techniques for developing establish maintenance strategies. The AI techniques such as GA (Genetic Algorithm) and SWMs (Support Vector Machine) has combined with fuzzy techniques for efficient and faster condition monitoring purposes.

2.1.3 Artificial neural network

Artificial Neural Network (ANN) includes simple empirical units connected to complex layer architecture. An ANN has many artificial neurons that are switched to each other according to implemented neural bound sequence. The main goal of the bound relation is to convert the inputs into arithmetic outputs that can be understand.

The ANN is a kind of famous artificial intelligence technique which has been implemented for analyses faults in induction motors in the literature.

Khatami etal., (2011) are implemented an artificial neural network simulator to carry out fault diagnosis based on predictive maintenance. They have used vibration data as input and handled unbalance, misalignement and bearing fault as an output. The neural network has been trained with variety of inputs of motor condition as the expert training information.

Mohammadehsan etal., (2010) analyze the fault diagnostic of an electric motor based on artificial neural network by using vibration monitoring. The vibration monitoring results are input for the neural networks and the reason of the vibration is the output. These results effect to better predictive maintenance operations and decrease the possible failures in operating system.

Rajul etal., (2009) corporate the reasons of the faults in electric motors by using motor current signature analysis based on Neural Networks. Fault indicators, testing and monitoring methods and fault detection techniques has been presented. The presented results detect rotor health of the motor and proceed the maintenance activities.

Sanmgita etal., (2013) produce a condition monitoring program that aims to detect incipient faults with vibration data acquisition by using artificial neural network constructed expert system on a plastic extrusion machine.
Tran etal., (2009) have performed a machine fault diagnosis method regarding to the evaluation of real monitored data according to a rule based reasoning which is determined by expert knowledge. The Expert System (ES) integrates adaptive order tracking method and artificial neural networks (ANNs) for fault diagnosis. Data mining is another common technic is also applied to knowledge based system which is extracted diagnosis knowledge from data base as input and output process values.
Bo-Suk etal., (2004) present an intelligent fault diagnosis system with ART-Kohenen neural network for integration case-based reasoning (CBR). Mainly, the neural network is used to make hypothesis for a new problem and to guide CBR module for getting further information from previous case.
Jafar (2012) proceeds a pattern recognition method for fault diagnosis of induction motor bearings by using the artificial neural networks. The ANNs are trained with experimental data for known machine condition.

2.1.4 Other AI techniques

The other AI techniques are also common in the literature. These are mainly based on software or methods. The methods are similitude with existing ones.
Changfeng and his friends used a software named Clips. Clips is a multi-paradigm programing language and simultaneously supports rule based and procedure oriented programming method.
The system mainly aims to predict faults for bearing and improve the diagnostic efficiency of rolling element bearing.
Jawadekar etal., (2012) propose the wavelet approach for fault detection of induction motor by signal processing. The frequency domain is used with wavelet transform and artificial neural network algorithm. Multiple fault detection technique has been also used in this study.
Jacob etal., (2015) developed an intelligent vibration monitoring and fault diagnostic for induction motors by using virtual instrumentation technique. Labview software has been used for building intelligent system and PIC Micro controller has been used for testing and diagnoses the faults. Both software serve the results and recommendations for electrical machine.

Shahriar etal., (2011) present a research for fault detection of an induction motor. Vibration signals in time domain has been integrated to two dimensional gray scale images. Then features are extracted from gray scale images as local binary patterns. These patterns proceed the diagnosis for the induction motor.

Moosavian etal., (2012) present a fault detection technique regarding to power spectral density (PSD) of vibration signals with K-Nearest Neighbor and Support Vector Machine (SVM) methods. The frequency domain vibration signals of an internal combustion engine is collected on three journal-bearing. Three states of journal-bearing was analysed that namely, normal, corrosion and excessive wear situations.

3. VIBRATION ANALYSIS

3.1 What is the vibration?

Vibration is the periodic or oscillating movement of a machine or machine component from its position to a certain point. Vibration is a repeated action and it is continuous. Most vibrations are not required in machines and component of the machine because they can be reason of increased stresses, energy losses, wear, decreasing of bearing life, induce fatigue, and absorb energy from the mechanism.

Vibration can be measured by three different magnitude. These are velocity (v), displacement (d) and acceleration (a). A simple harmonic oscillation can determine these measurement units.

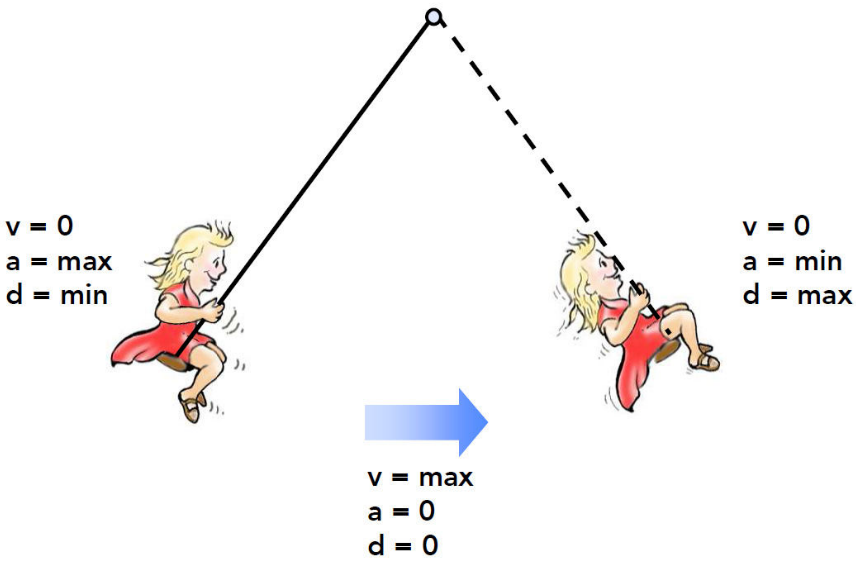

Figure 3.1: Vibration magnitudes.

The girl at the left side is standing and there is no motion so the velocity is zero. When the motion is started and the girl is located through the right side acceleration goes through from max. to min. and also through the this movement displacement occurs.

3.2 Vibration severity

Vibration has a frequency which is the total number of harmonic in one second during the ossicilation of signal.

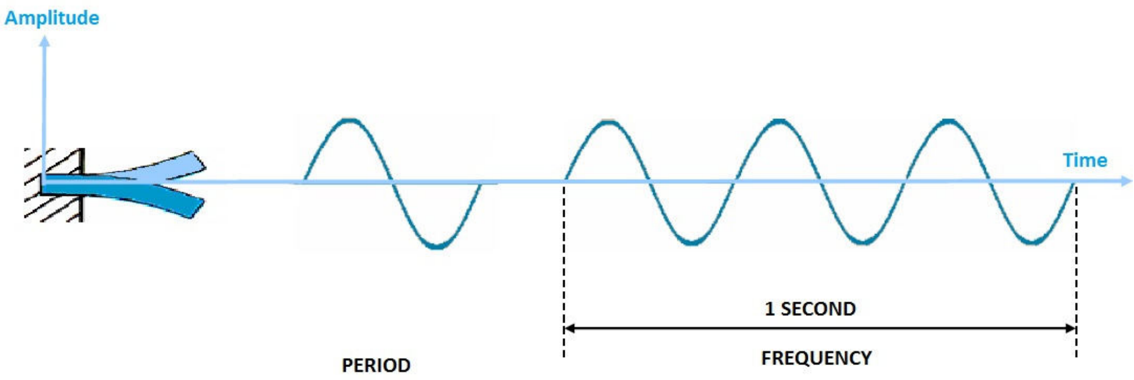

Figure 3.2: Vibration severity.

Induction motors has certain rotating speed. It means that it has main rotating frequency (FE. 1500 rpm = 25 Hz).

The magnitude of the vibration can be measured as displacement, acceleration or velocity. Displacement is a distance for moved object. Its measurent unit is mm (millimeter). Acceleration is a difference the rate of the velocity and its unit is mm/s^2. The velocity of movement is generally variable so the average (rms value) or peak velocity is used during vibration analysis. At this point we can define the severity of vibratin as the avarage value of vibration velocity with a certain range of frequency.

All those clarifications explain the graphical expression of vibration is as following:

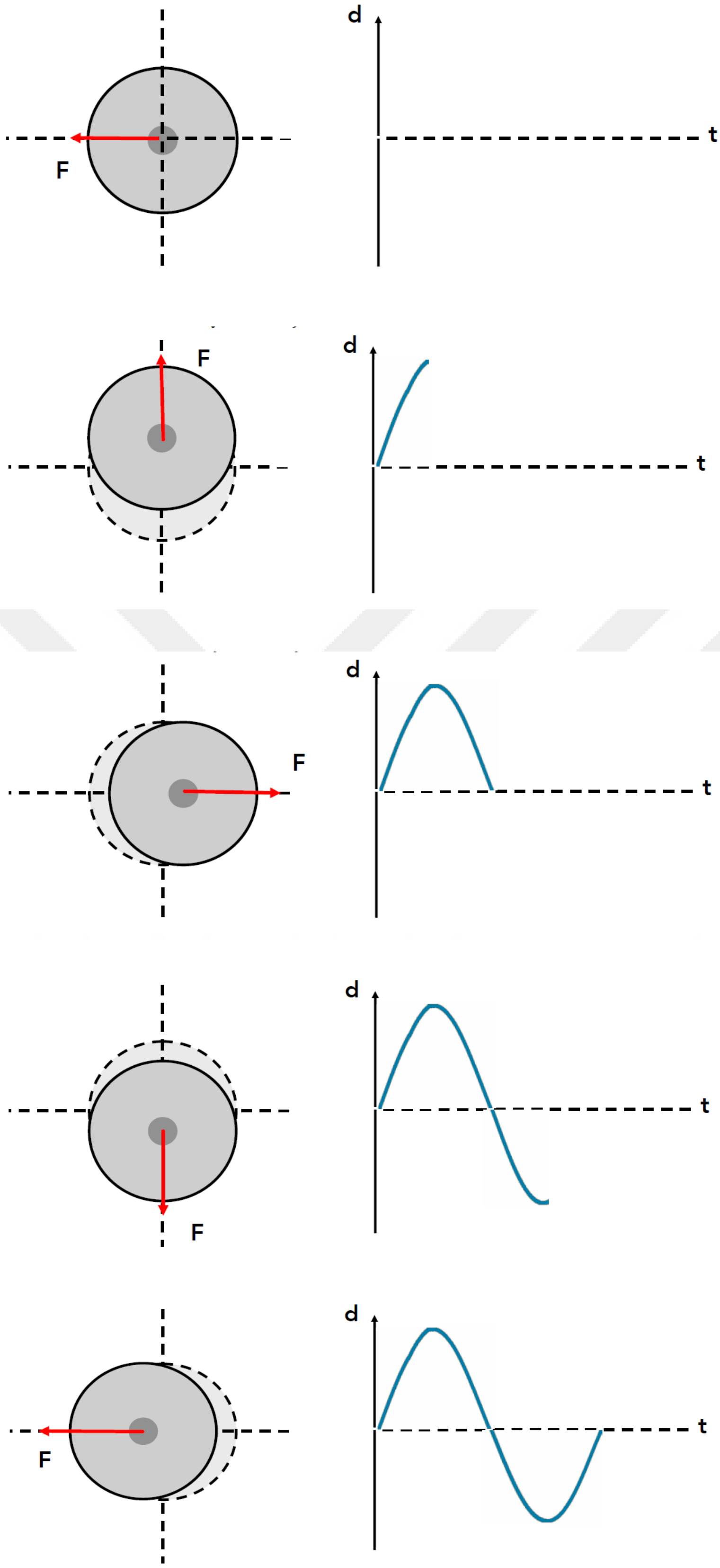

Figure 3.3: Vibration period.

The frequency of a rolling element can be calculated by knowing the value of revaluation per minute. For instance if the rolling element has 600 rpm as revaluation value, the main frequency can be handled by the dividing 60 to the revaluation value for rpm as following:

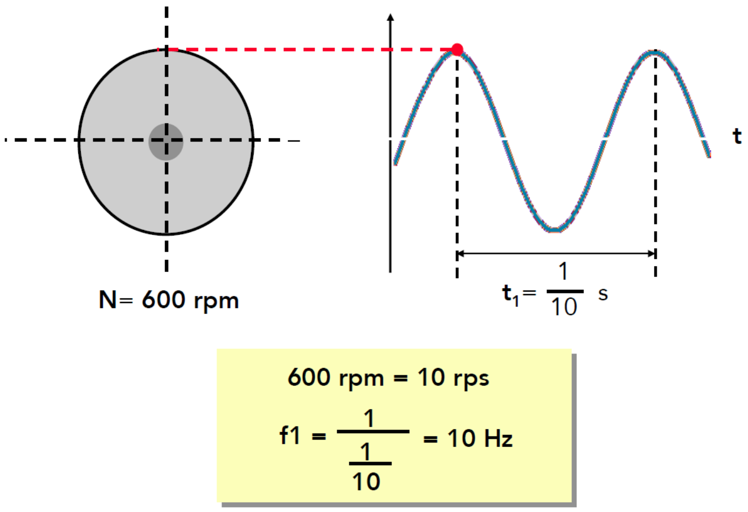

Figure 3.4: Vibration frequency.

The required time to complete one rotation of the vibration is named the period of the vibration. If the machine finishess one cycle of vibration for a second, the period of vibration comes to be 1 of the 60 of a second as expressed in figure 3.4. Although the period of the vibration has very rough definition, the main feature for the vibration frequency is number of complete cycle which is at a certain period of time which is called "cycles-per-second" (CPS) or "cycles-per-minute" (CPM). Tjese terms are the main concept of the vibration analysis because of they are the fundemantel magnitudes while definition of variables. Frequency is related to the cycle of vibration which can be define by this simple formula:

$$\text{Frequency} = 1/\text{Period} \tag{3.1}$$

Basicaly as inference from above formula the frequency of a vibration can be simply define "inverse" of the period of the vibration or vice versa. Because of this reason, if the period is required to complete once rotation which is 1 divided by 60 of a second, then the frequency of the vibration can be called 60 cycles per second or mainly 60 CPS.

In main circumtanence of vibration findings for analysis that is not enough to determine the vibration frequency to observe the vibration time based feature during the period of the vibration. After calculating the inverse of the period to find the vibration frequency can be done by itself. The measurement devices and vibration analyzers usually present a certain numeric value for the vibration frequency which is occured at the mechanism. Although vibration frequency may be defined in numeric circumtananances for cycles per second or CPS, the general used term is to use the Hertz (shortly Hz) instead of CPS so if the vibration frequency is 60 CPS, it can actually call as 60 Hz. Because of this reason many vibration measurement device use and implement in Hertz (Hz), for most industrial vibration enviroment, vibration frequency is measured in cycles per minute which is CPM. While definine vibration frequency in any mechanism rotational speed is mainly in use revouluatin per minute or RPM. That is the common characteristic terms for definitaion different magnitudes as single values in analyses. For example, if a machine rotates in a constan speed 3600 rotation per minute and it can call 3600 RPM, it is much more meaningful to know that a vibration is at 3600 CPM (1 x RPM) at 60 Hz. Those can be converted each other as follow:

The natural frequency in Hertz can be easily converted to CPM:

$$\text{CPM} = \text{Hertz x 60 Seconds/Minute} \tag{3.2}$$

Given a frequency in CPM can be easily converted to Hertz:

$$\text{Hertz} = \text{CPM/60 Seconds/Minute} \tag{3.3}$$

Most vibration is performed in velocity because of the the energy level is proper throughout the frequency range.

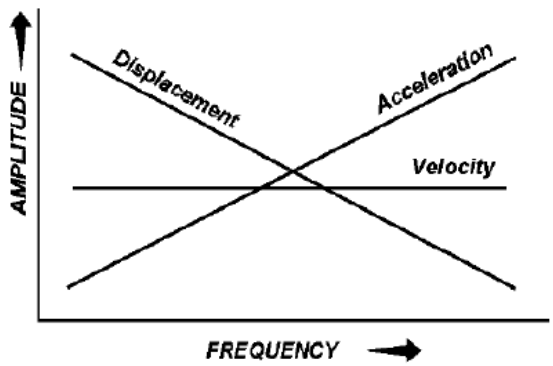

Figure 3.5: Vibration chart.

Displacement can be evaluated in the low frequencies. Acceleration can be evaluated in the higher frequencies. Velocity is proper across a higher range of frequencies.

Vibration has some significances. There are many specific mechanical, operational and environmental effects that can cause high level of vibration in literature. Mainly, when a vibration problem occurss, an analysis of the vibration has to be performed to clarify main reason of vibration not to get specific cause. This is can be done by knowing the natural frequency of vibration.That is very useful during analysis so it can called as essential ground frequency. Vibration natural frequency is a very important data for analysis as a diagnostic tool.

The external forces can be reason of vibration are usually comes from rotating motion of the machine components. That's the known fact that forces in any direction and magnitude based on the rotational speed (RPM) of the machine components cause the most vibration problems that will have frequency harmonics are directly related to the rotational speeds. To express the importance of vibration frequency, assume that a rotating machine with a fan mechanism operating at 2400 RPM and belt driven by an induction motor operating at 3600 RPM, is vibrating with high level measured frequency of 2400 CPM which is one times fan RPM. That obviously show that fan is the source of the vibration, motor or belts are not. By concerning this simple fact has implied in many researche, there are many possible causes that can be reason of the vibration. Typical 1 x RPM vibration can be emerge to: Unbalance, eccentric pulley problem, misalignment, bent shaft problem, looseness effect, distortion, bad belts, high resonance, reciprocating forces, electrical problems.

The high level vibration frequency is 2400 CPM which is the ground frequency of the fan has reduced to the number of possible reasons from hundreds to only ten possible reasons.

The related vibration characteristic can reduce this number of possible causes even much less. But firstly, there is a known fact that vibration frequency is not related to the rotating speed (RPM) as drive belts, belt problems can be eliminated as a possible reason. Secondly, this is not a reciprocating machine such as screw compressor or engine, that can be also ignore from the list of possible causes. Finally, if the natural frequency is not related to the drive motor in any condition, the possibility of electrical problems can also be eliminated. As it has seen the number of possible causes ohave reduced from 10 to 7 by simply think by executing ground warking conditions.

Vibration analysis is mainly a process which is using elimination method for reasoning. Additional tests and measurements can be taken to reduce the number of possible causes of the vibration problem in any mechanism. However, it is clear that vibration natural frequency, rotating speed of the machine and components, workin are are should known before start to analyse.

That is the clear that all machine related problems will generate one time pick vibration at a frequency equal to the rotating speed of the mechanism. ,but in many situation looseness, misalignment, resonance and reciprocating forces can usually generate vibration at different harmonics at 2x, 3x and sometimes much more different characteristics at RPM harmonics.

Problems with gears are hard to define as vibration cause because of the complex "gear ratio". Ggear ratio can produce vibration in any sequence according to gear type, number of teeth and rotational speed.

There are many effects at fans and pumps will normally show vibration frequencies that are actuating machine mechanism revoluatin per minute times the number of fan blades or impeller vanes. In addition, there are many unpredicted vibration picks on the scale in frequency domain as a vibration value. These are generally occurs on the wearing components on the sytem and at roller element defects.

Consequently, it is important to realize the different mechanism problems can show itself at different frequencies at vibration measurement scale and that is the affect to the vibration frequency character.

3.3 Vibration sensors

Vibration sensors can be classified as accelerometers, velocity sensors, capacitive and eddy current sensors and laser displacement sensors. All these sensors have some advantages and disadvantages according to the application. Detail information about vibration sensors is as following:

3.3.1 Accelerometers

An accelerometer is a sensoring device that measures the vibration, or acceleration of motion of a movement. The force caused by vibration or a change in movement lets say acceleration can causes the mass to load the piezoelectric material which produces an electrical charge that is proportional to the force applied upon it. Since the load is

proportional to the force, and the mass is a constant value, then the load is also proportional to the acceleration.
There are two types of piezoelectric accelerometers or with the common name vibration sensors. The first type is a high impedance sensors. High impedance sensors work as a princible that charging the collected output to the sensor. Piezoelectric crystals converts the mechanical energy toy the electric signal. Then this electric signal is directly connected to measurement device. Measurement device evaluates these signals to define real velocity. This type of accelerometer can also be used for high temperature applications over 120 celcious where low impedance models can not be used.
The second type is a low impedance sensors. A low impedance use electronic capabilities in their structure. Generally FET transistor are common for their structure. Because FET transistors can work at low impedances or call low voltages. The direct connection is not possible with measurement device. Because the low voltage with lots of noise have to be maintained to known signals.These sensors can not work at any working area because of thir electronic structure.
The piezoelectric force generatess a movement which can create of charged transfer in its particles on the crystal surface. This charge is directly depend on the force which is implemented. The forced quartz crystal surface structure changes as one side positive and the other side negative that cause an elctron transfer which meanly electrical voltage. These charged polars accelerate elctron transfer through the FET transistor to transform the known electrical signals.

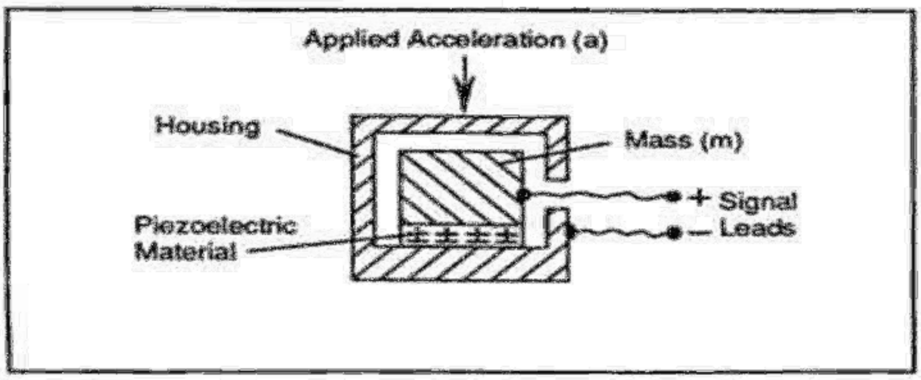

Figure 3.6: Acceloremeter structure (URL-1).

In many this kind of sensor, the forces on the surface is directly result of the applied mechanical load as a mass force. Resulted electrical signal oscillate in certain

frequency range wihich has occurred directly from Newton's law of motion F=ma. That means the inducted charge directly depend on the applied mass load. Crystals perform the electrical signal and transmit over an electronic structure and finally reache to measurement device.
Accelerometers have many advantages. They can be clarified according to thir properties such as design ability, response to level of frequencies, working conditions etc. Some disadvantages are also came across. They may not be sensitive under high frequency noise or can need an external power and electronic integration is necessary as FET transistor integration.

3.3.2 Velocity sensors

When a coil of wire get a movement through a magnetic field, a voltage is induced through the wire of the coil. The induced voltage causes to transfer of the energy from the flux field to the magnet of the wire coil. As the coil is forced through the magnetic field by vibrational movement, a voltage signal can occur while the vibration is produced.

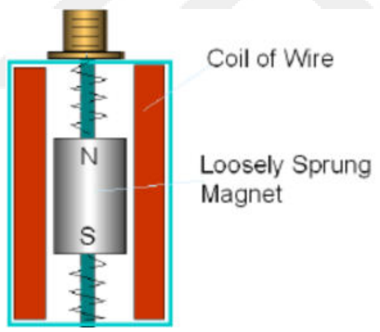

Figure 3.7: Velocity sensor structure (URL-2).

The velocity probe can assume that the first vibration transducers. It has a conductive material with surrounded wire and a simple magnet. If the wire is moved with conductive material, the magnet intends to force the movement. These two movement difference induces a current that changes according to velocity of movement. The inducted current produces a signal directly depend on vibration velocity. That is its own vibration and does not need electronic equipment for conditioning in order to operate. Athough it has low noise induction, there is a disadvantage of this system that low electrical output.

The advantage of the velocity sensors are simple to install to any application, good response at middle level frequencies, high resistance to over temperatures, does not necessary to an external power and lowest cost. On the other hand the disadvantages are low resonant frequency and phase shift problem, high level of noise, big size and heavy, electronic integration is necessary for displacement.

3.3.3 Capacitive and eddy current sensors

Capacitive sensors use the electrical term of "capacitance" to make measurements. Capacitance is an electrical property that exists between any two conductive surfaces with a certain proximity. In general condition, the displacement sensors with small sensing surface means that high performance displacement and this property is the result of positioned close target. Capacitive sensors use to indicate changes in position of a distance for changing capacitance.

Figure 3.8: Eddy current sensor (URL-3).

Eddy currents have a principle that when the system has non stable magnetic field on a conductive material means the motion according to conductor causes a close loop electron flow through the conductor. These flux which move in close loop call as eddy current motion that create electromagnets with magnetic fields that oppose direction of the applied magnetic field. The stronger applied magnetic field, or greater the electrical conductivity through the conductor means greater relative velocity of motion and greater current developing in opposite movement field.

The advantage of the capacitive and eddy current sensors are measure both static and dynamic displacements, certain response at low frequency levels, has no wear, small size and low cost. On the other hand the disadvantages are bounded at high frequency, not calibrated for unknown metal materials, electrical and mechanical noise, difficult to install, require external power.

3.3.4 Laser displacement sensor

The Charge coupled device (CCD) laser displacement sensor uses a triangulation measurement system which is described at the figure 3.9. Laser displacement sensors are in use with a position sensitive detector (PSD). The light reflected from the defined target and passes through the receiver lens to focus on the PSD or CCD. The PSD uses the light source distribution of the beam spot entering the light receiving element to determine the beam spot center and assume this as the target position. The distribution of light quantity is affected by the surface condition of the target. Because of to this reason different variation values can be measured. The CCD detects the peak value of the light severity distribution of the beam for each pixel merge and assumes this as the target position. Therefore, the CCD can be stable highly accurate displacement measurement, not depend on the light quantity distribution of the beam spot.

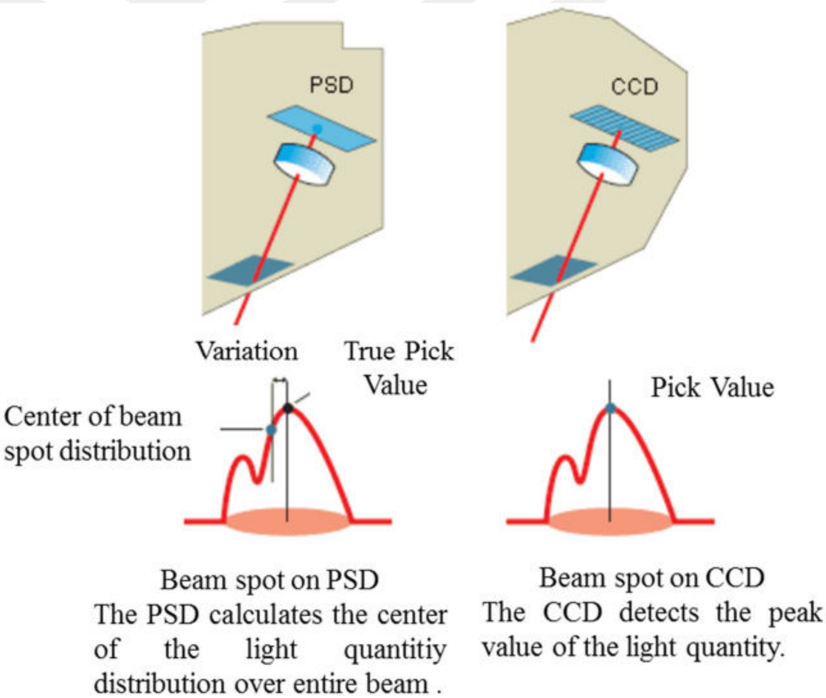

Figure 3.9: Laser displacement sensor structure (URL-4).

These sensors can be used in high temperature working areas and applications, but there is no further information about advantages and disadvantages.

3.4 Vibration analysis detection

Vibration analysis consist of some logical steps. These are detection, analysis and correction. Detection should be implemented by the devices or sensors then analysis occurs by software program or just like ours with an expert system. The last step is the correction through the analysis.

3.4.1 Detection

Detection includes measuring and observable vibration magnitutes at certain locations for every mechanism included in the preventive maintenance activity with periodic measurements. Obviously, if there is a permanent system, online vibration monitoring systems are also possible. The objective is to recognise significant increases in a machine vibration level to warn before problems are occured. In a simple way, hand-held vibration measurement devices can be used to take a measurement of a machine vibration magnitute. The instrument has a transducer that is held or attached as horizontally or vertically to the bearing cap of the machine. Tramsducer sensors measure the machine vibration and converts it to the corresponding electrical signal that is the result of the measurement device as a vibration magnitude.

Regular vibration measurements taken by manual monitoring instruments which can save the data in their memories with a drawing. This drawing includes machine specifications, vibration technician identify measurement locations and positions. The drawing form also includes tables with magnitudes for recording the data in both tabular form as well as graphic trends to provide a clear history of the machine condition and trends. All changings are in the program as increasing and decreasing values to guide the user. For many programs that involve only a small number of mechanism and measurement points, a manually operated instrument or data recording system may be quite proper instead of big permanent system installation.

However, there are a lot of mechanism and measurement point in both vertical and horizontal directions. The collection of measured values can be analysed in two form. First as empirical analyses, second trend analysis. Trend analysis can give an idea about behavior of vibration level in both frequency and time domain.

In general, the typical system consists of a software program which can persuade the maintenance activities with its recommendations and a compatible vibration instrument device for collecting data with a certain period in the field. The data collecting data should be in frequency domain to analyze so many software for vibration analysis detection convert vibration data domain from time domain to frequency domain by using Fourier Transform Method. This converting operation called as FFT process or spectral analysis.

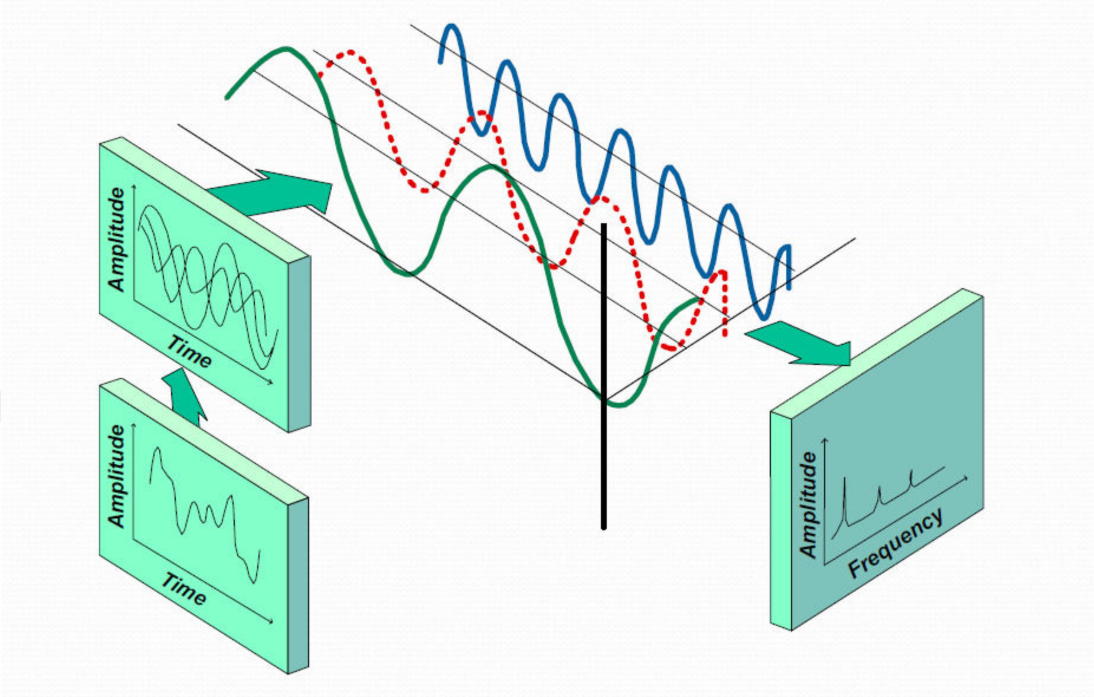

Figure 3.10: Vibration frequency.

Many of the vibration analysis softwares are not only collecting and trending the vibration values but also inference some results to advice the user. Most systems uses some algortihms with defined signals to covert them to frequency domain to give an oppurtinity to analyse signals in FFT spectral analysis.

The software should include following highlights:

1. Listing all mechanisms which should be in the program.
2. Identifying the bearing locations and types where readings will be taken for each mechanism.
3. Identifying the directions (horizontal and vertical) where readings will be taken on each mechanism.
4. Identify the vibration parameters according the type, size and working condition of the mechanism to integrate the program.
5. Establish alarm or warning magnitutes for each measurement.
6. Establish details for spectral (FFT) analysis.
7. Organize machines according to working hours

8. Define and make a routes for each mechanism.
9. Crate a schedule for machine measurement.

At first aspect, this may seem like a heavy and time consuming process. However, most commercial vibration predictive maintenance software programs are very "user friendly" with many specifications that greatly simplify the process during the setting up the program.

The software program use created measurement order. This order can easily change by user. For example the user can change period or measurement point in the software. In addition, the user can select a different mechanism and can load into the vibration data collector instrument device from the computer program. With the measurement device loaded, the operator can implement the program with assigned schedule and order. The display on the instrument screen will command the operator step by step about measurement route. After installation of measurement sensor, there are a few steps should be done by operator. The operator should press ‘’measure’’ button and then after certain of time the operator will peress the ‘’ store’’ button to finish measurement.

Next, the operator pushes a button for next measurement. After the data has been collected, the operator returns to the computer to download the measured data to the computer software by following a few simple instructions. Once the measured data has been downloaded, numerous reports can be generated to analyse those machines that have came across a significant increase in vibration or have exceeded a defined alarm level, investigating developing problems. A report canhandle as software toll. This report gives an oppurtinity to hava an idea about measurement points, vibration levels, alarm levels and last vibration value of those mechanisms as it has been programmed. The software can also present trend of the vibration characteristic. Trends let to see vibration character and gives an idea about future vibration values. Sudden increases in vibration magnitude is an important case and instant action should have taken for that mechanism. Alarms and trends give some ideas about vibration severity and characteristic. The automated system for data collection and computerized data collecting systems simply progress on the same purpose and use the simple hand vibration meters princible and data sheet. However, the automated systems let the computer to do what it does best, and that can take place important criteria for high efficient data monitoring operations.

Although in many mechanism can be protected by periodic checks of vibration measurements, some machines may not be well analysed or recognized by manual monitorin methods. High performance and sustainable mechanisms such as turbines whish consume high power or compressors at high speeds can develop problems suddenly without any preliminary warning. These kind of mechanisms may require continuous, online monitoring systems.

3.4.2 Analysis

If measurements have taken by manual or online monitoring, the permenately following step is to clarify the problem or problems with scheduled maintenance operations. This is the exact purpose of vibration analysis to prevent problems by evaluating their vibration characteristics.

In most cases, the same measurement device and computer software used for periodic vibration measurements for every data collection operation A systematic vibration analysis can then be completed to identify the more common mechanism faults such as: Unbalance, misalignment on axials, looseness on mechanic parts, mechanical wearing, broken bearings, eccentricity problems, worn gears, motor electrical problems, drive belt problems, distortion.

The handled data from detection sensors can be analyzed and detected to correct the failures. There are some detected vibration data and can be analyzed by using correction methods.

3.4.3 Correction

If vibration values are collected and have been realized and analysed, corrections can be necessary with scheduled for a proper time as maintenance operation. Correction needs some time and ability at the plant. This kind of requiremnts can not be possible everytime. The repair time should be minimum in many case. If the vibration problem is diagnosed as unbalance or the like others, the operation time can get much more than expexted. In these cases online monitoring with same instrument used to detect and analyze the problem can be used to perform for continuous monitoring.

3.5 Diagnostic charts

Vibration analysis take place with some rule and facts. Diagnostic charts and experience is essential during the analysis. The sample situations and remarks are at the following:

3.5.1 Mass unbalance

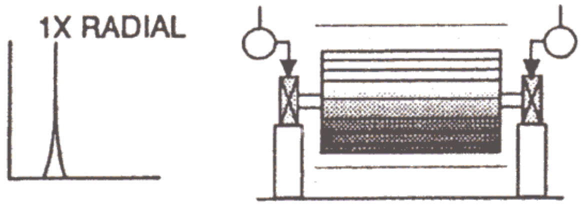

Figure 3.11: Mass unbalance graph.

Mass unbalance mostly in one phase and steady. Mainly, amplitude of the vibration regarding to unbalance will increase by the square of the speed below first rotor critical vibration value. 1X RPM can easily be observed as a peak value on the spectrum.

3.5.2 Eccentric rotor

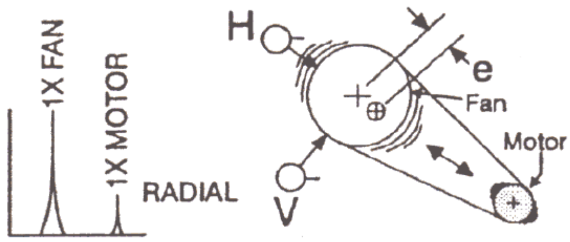

Figure 3.12: Eccentric rotor.

Eccentricity rotor problem occurs when center of rotation is shifted from geometric centerline of a pulley, gear, and bearing. Largest vibration occurs at around 1X RPM of eccentric component in a direction through centerlines of the between two rotors.

3.5.3 Bend shaft

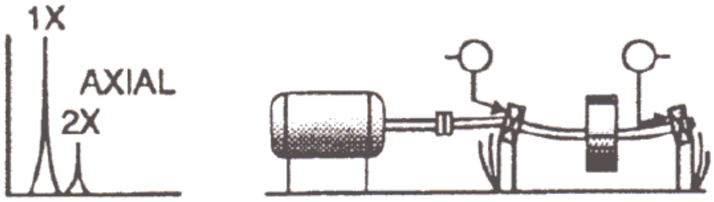

Figure 3.13: Bend shaft.

Bent shaft problems are the reason of high axial vibration in one direction with axial phase differences along the 180º. The high value vibration normally occurs at 1X if bent near sahft center, but at 2X can also occur if bent is near the coupling.

3.5.4 Misalignment

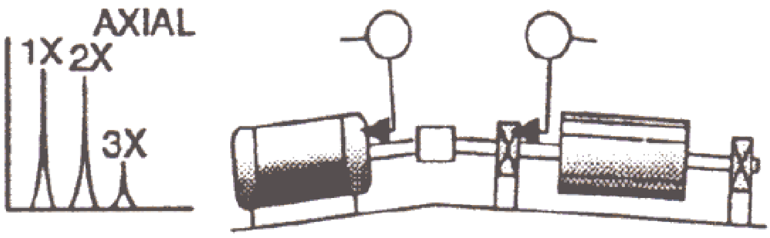

Figure 3.14: Bend misallignment.

Misalignment can be defined by high axial vibration or 180º out of phase across the coupling. Typcally misalignment will have high axial vibration with both 1X and 2X RPM. However, it can also take place around 1X, 2X or 3X to dominate. These effects may also show coupling problems as well.

3.5.5 Mechanical looseness

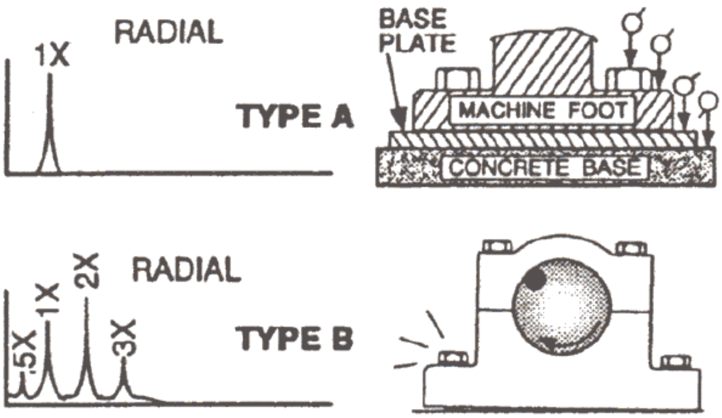

Figure 3.15: Mechanical looseness.

Mechanical loosenes can be classified by either Type A and B.

Type A is related to structural looseness or weakness of machine feet, beseplate or ground surface loose hold down bolts of the mechanism at the base. Phase analysis may observe approximately 90º to 180º phase difference between vertical measurements on bolt, machine feet or ground base itself.

Type B is mostly related by loose ground surface bolts, cracks in frame structure or in bearing housings.

3.5.6 Hydraulic and Aerodynamic forces

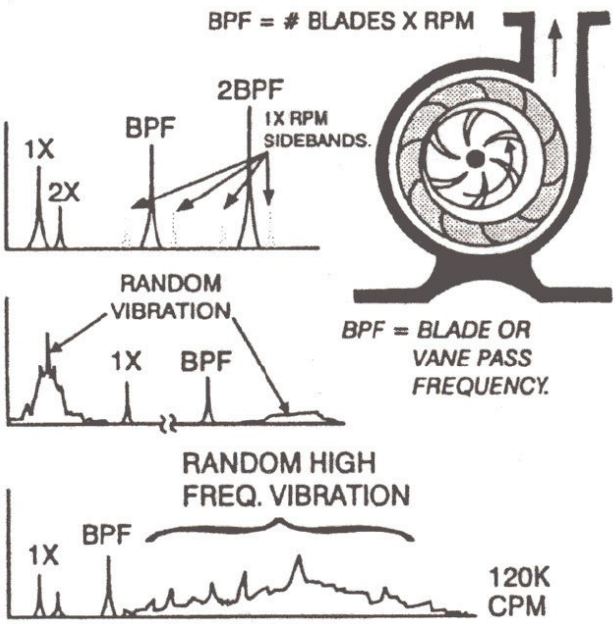

Figure 3.16: Hydraulic and Aerodynamic forces.

Blade Pass Frequency (BPF) is equal to number of blades time vibration rpm. This frequency is mainly in pumps, fans and compressors, and in normal case does not present a problem. However, large amplitute BPF and its harmonics can be generated in pump if ther is a gap between rotating vanes and stationary diffusers which are not equal all the way around.

Flow turbalance is common in blowers due to different pressure at velocity of the air passing through the fan which is connected to ductwork. This unsteady flow causes turbalance with high magnitude of vibration.

Cavitation is one of the main vibration problems for pumps. It produces random, higher frequency vibration energy. In normal condition cavitation can get insufficient suction pressure which is called starvation. Cavitation is too dangerous for pump as internally if the procautions are not teken.

3.5.7 Belt drive problems

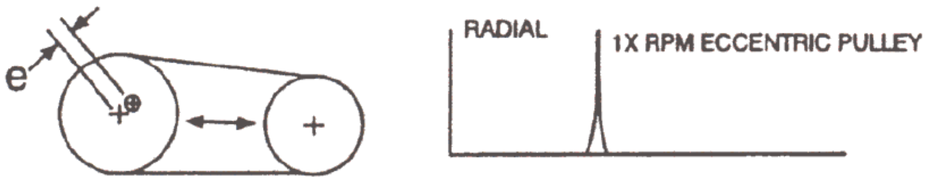

Figure 3.17: Belt drive.

Belt drive problems can be reason high amplitude of vibration values if the belt natural frequency is close the induction motor frequency or to driven rpm. Belt ground frequency can be altered by changing either the belt tension, length or cross section of the belt.

4. EXPERT SYSTEM DESIGN AND IMPLEMENTATION

Expert systems are software that supports the relation between people would have defined an expert and system which requires knowledge for advice or a recommendation in any application. Most decision-making processes can be claasified into small groups. The human expert usually makes decisions itself and does not show extra performance to handle results. However, they become obvious when the reason for the decision is explained to someone else, or the decision process is in teached to others. A decision can be based on known facts that by one by would not be resultant, but human brain does not work like that. It has integrated some heuristis taugh so the rules which needs to created must called ‘’rules of thumb”.

Experts mainly explain it with the rules of thumb that they have learned to reache right results. For example, if a decision is being made about decision for maintenance activity, a top-level rule for this sample might be, “If vibration degree has a high value, a maintenance action should be implemented.” This could be a valuable rule, but unless you know if “the machine has a high vibration”; you can’t estimate what is the reason? If you wanted to know what the best decision is, you should ask to somebody who is expert, “How do you know that if the vibration has high risk?" This would lead to other rules, “If the vibration amount has higher than than safe operation value 5, then it means that it has a high risk". If an operator of the expert system spends adequate time with the expert, and know everything they say. However, the process can be difficult and long because there are thousands of people who may make similar decisions. The real problem is the data which the expert has, can not be classified store or saved. These results can be reason of any problem. The system recomendates an action for example to a maintenace operation.

An expert system needs rules which are defined from knowledge and experiments from an expert. The rules should be based on logical inference to have an oppurtinity that integration to computer systems. The rules are evaluated by the expert system inference engine, which built by the specific rules together to solve a much more copmlex problem. The system continue by asking questions to the user, and checks the information given to make a decision what extra information is needed to chose the right one. Generally, meaningless questions are not asked, but releated areas should estimated with details. When all of the data is given, the system decide its last decison, which may include some recommendations with different level of confidence amount.

4.1 Corvid expert system

Exsys Corvid is a revolutionary approach for providing and developing knowledge automation expert system. The corvid system can present hard complex processes by using an interactive form which can be easily prepare into a web page.

Corvid has a new approach for expert system developments such as object structure, Logic Blocks, Action Blocks and Java template. In this manner implementing tools to build an expert systems is the main goal of the corvid. Exsys tools have obviously implement the usual rule based approach for examining logic structure. Corvid has many user with many application on this approache.

There are two approache are object oriented and tru object oriented. Object oriented approache has princible like human brain and continue step by step with some confidence value. The ground statement is ‘’If… Then…’’. It is a rule with combined a condition and it also creates a new statement for next rule.Because of this reason this more common and suitable for more complex and difficult situations and hifh performance for programmers. On the other hand a true object-oriented programming language for VB generally provides and supports object based features. Because of this property many programmers prefer to use VB when compared with other programming languages. Corvid copy the VB model princible. It supports an object-oriented structure that makes it easy to build systems by using techniques and properties of variables, while is not necessary to change the principle they think. In this manner the decision-making steps and logic can be easily described. The result has a possibility to change and great development environment that can be learned. Exsys corvid system has 7 types of variables that support a wide range of properties. The collection variable has an ability that information to be “collected” from multiple rule executions and enables many new functionalities. Many of techniques and properties for all of the variables let them to be used in suitable ways to solve problems with display results.

4.1.1 Heuristics and Rules

Expert system princibles follow the term "rules of thumb" which is a heuristic. That is a well known fact that command the decision making process is the combination of all the heuristics. They let the entire decision making problem which has to be solved. In human understanding, specific heuristics need to combine carefully and systematically. Behind this proposal, the system does not have to require an extra decision making tool to implement its own logic flow unlike the human brain. A large part of building an expert system is classifiyng the specific decision steps and converting them into a logic form that a computer can understand and use.

IF/THEN rule is most common statement base reasoning tool. This is a rule where there is a condition we call it IF part that can be checked to be true or false based on the data. When the IF part lets say condition is true, the statements in the THEN part can also assume as true.

IF

1X Vibration Value is occured.

THEN

There should be vibration on motor.

Exsys Corvid rules have similarities with the form of heuristic as human understanding by using statements and logic algebra. For instance, "If the vibration value has over the alarm value, it means that the maintenance activity needs to be applied." The statement form is:

IF

The vibration value is over the alarm value.

AND the process should go on.

THEN

The maintenance activity needs to be applied.

This statement rule prove a small amount of collocation can be very easy and understable for human mean. If similar rules applied for each of the heuristics in the decision-making process, a logical result can be obtained by the expert system.

4.1.2 Inference engine

Human brain have an ability to think processes and combines the heuristics heuristic. On the other hand, computers can also be implemented as effective as human brain.

The Exsys Corvid use a tool to analyze which is called "Inference Engine". This tool combines the individual rules to solve the coplex problems. Basically the Inference Engine try to determine following questions:

1. What can be the possible answers for the problem?
2. What information is necessary for problem definition?
3. Is there any way to define or calculate the necessary information from other rules?
4. Is there enough information is available to eliminate a possible answer?
5. What is the difference between remaining answers?
6. Which answer is based on the rules?

Inference Engine can make If/Then rules in an expert system with very different forms. On this command base rules are not induvial and are mostly equivalent according to lines of code; they are facts and different ways have to be crated by inference engine. This makes the expert system approach much more useful, effective and user friendly for knowledge transmit than traditional programming methods.

4.1.3 Backward chaining / Forward chaining

Bacward chaining can easily be defined that combination of rules. Backward chaining is "goal driven". Defining the proper goals is part of the expert system development process, but in normal condition the goals which have higher degree than others have possible potential recommendations. The Inference Engine can determine what it is necessary to meet a specific goal including defination when that goal is obey the requirements or not.

The Inference Engine analyses the necessary data if the first possible goal is reachable and proper for the user. The system requires information on the unique situation should be analyzed to make this determination. This data can come from other rules or different sources such as databases and spreadsheets or handled data from asking additional questions to the user. For instance, if the first aim of the rule is to determine results, the answer or recommendation obviously will be maintenance is necessary as described previous example. The Inference Engine needs to check the rules to find one that would be related of making this decision or recommendation:

IF

The vibration value is higher.

AND the process should go on.

THEN

The maintenance is necessary.

The Inference Engine has implement a mainly a statement, but it can not proceed without more data. To make a further determination, it needs to know if “The vibration value is higher”. Determining the statement is true that becomes the new goal for the Inference Engine. The original goal is not forgotten, but it is temporarily focussed by the new goal. The Inference Engine have a look for a rule that can related to something about vibration value or decision result as recommendation. It finds:

IF

The vibration value is greater than 5

THEN

The machine has a high vibration.

If this rule is true, the Inference Engine needs to know the vibration value limit to decide next goal or the next rule. This might come from a database or different data source which it can also operator itself. The Inference Engine needs to determine where and how to get the necessary data. This process has just one goal which is requiring data that leads to another goal or can be repeated many times in logic view. This “chain” rule based flow going backwards from the highest level to the lowest level that is why is given as name to it backward chaining. When information is readylow degree of goals can be drop off from chain sequence up to inference engine has successed the high level of goals which are the initial tasks for inference engine. As a result of consultant an expert have several advices before reach the conclusion. The important thing to command the system with right questions. For instances the redundant questions can disturb to reache right conclusion. Backward chaining working principle follow this process in expert systems.

4.1.4 Confidence

Another useful feature of Exsys Corvid system is “confidence factor” which is that the rules can get level for reliability. This property gives an oppurtinuty to categorize the recommendations according to their degree of confidence with the idea of "best fit" as a result. It is also possible to give a special recommendation with certain precision. Often multiple recommendations can be possible at different times and the system presents them to the user with different confidence values.

4.2 Knowledge acquisition

Knowledge acquisition is a kind of process should be defined by rules and ontologies which are required for a knowledge-based system. The expert system can describe the initial tasks associated with developing findings, interviewing domain experts and capturing their knowledge by rules.Aditional objects, and frame-based ontologies can be source of knowledge based rules.

The vibration datas are inputs for the expert system. The expert system recomend a maintenace activity or estimate the reason of the vibration. The expert system uses forward chaining method to reache the result and IF-Then rules are imlemented.

The vibration datas are collected from different measuring points so the IF-Then rules cares the measuring points and asks the user as type of vibration for the measuring points.

The ontology in this project tries to investigate the vibration problems on four different actuating mechanism. These are Motor-pump, Motor-Reductor-Chain, Motor-Belt-Fan and Motor-Fan. The details and sample dialogs about actuating mechanisms are as following:

4.2.1 Motor – pump mechanism

This mechanism consists of an induction motor and a simple pump. The motor-pump groups are common actuating mechanisms in industie and the cavitation, alignment problems and mechanical loosness are main reasons for vibration. The common vibration datas are seen at first, second and third harmonics in frequency domain so the expert system evelaute those vibration datas with measuring points.

The sample dialogs are:

IF:

Choose the actuating mechanism: Motor – Pump

AND: Choose measuring point: Horizontal Vibration

AND: [Vibration Value1X] >= [Vibration value2X]

AND: [Vibration Value2X] >= [Vibration value3X]

AND: [Vibration value3X] >= 0

THEN:

''There is a misalignment through the horizontal axes. Check by coupling setting device. ''

Motor-Pump mechanisms have sensitive actuating axes. The tolerances for the misalignment is very limited so many company checks the misalignments periodicaly as amintenance activityby using laser coupling setting devices. The other dialog is;

IF:

Choose the actuating mechanism: Motor – Pump

AND: Choose measuring point: There is random vibration a vertical axes.

AND: [Vibration Value1X] > 0

AND: [Vibration Value1X] >= [Vibration value2X]

AND: [Vibration value3X] = 0

THEN:

‘’There is cavitation on pump. Maintenace is needed. ‘’

Cavitation is also common problem for motor-pump groups. When the pumps are in use with higher capacity, the cavitation can occurs during time and generally the vibration value emerges randomly on vertical axes.

The next dialog is;

IF:

Choose the actuating mechanism: Motor – Pump

AND: Choose mesuring point: Horizontal Vibration

AND: [Vibration Value1X] - [Vibration value2X] > 5

AND: [Vibration value3X] = 0

THEN:

‘’There is a bending on coupling. Check the coupling. ‘’

IF:

Choose the actuating mechanism: Motor – Pump

AND: Choose measuring point: There is random vibration a horizantal axes.

AND: [Vibration Value2X] >= [Vibration value1X]

AND: [Vibration value3X] = 0

THEN:

‘’There is a mechanical wearing on motor or pump coupling. Maintenace is needed. ‘’

IF:

Choose the actuating mechanism: Motor – Pump

AND: Choose measuring point: Horizontal Vibration

AND: [Vibration Value2X] >= [Vibration value1X]

AND: [Vibration value3X] = 0

THEN:

‘’There is more than one vibration reason. Detail analysis is necessary.‘’

IF:

Choose the actuating mechanism: Motor – Pump

AND: Choose mesuring point: Vertical Vibration

AND: [Vibration Value1X] > 0

AND: [Vibration Value2X] = 0

AND: [Vibration value3X] = 0

THEN:

‘’There is mechanical wearing on pump. Maintenance is needed.‘’

IF:

Choose the actuating mechanism: Motor – Pump

AND: Choose mesuring point: There is random vibration a vetical axes.

AND: [Vibration Value1X] > 0

AND: [Vibration Value2X] = 0

AND: [Vibration value3X] = 0

THEN:

‘’The maintenance is needed for the pump. ‘’

IF:

Choose the actuating mechanism: Motor – Pump

AND: Choose mesuring point: Horizontal Vibration

AND: [Vibration Value1X] > 0

AND: [Vibration Value2X] = 0

AND: [Vibration value3X] = 0

THEN:

‘’Check the motor feeth. There is tightining problem on the screws.‘’

IF:

Choose the actuating mechanism: Motor – Pump

AND: Choose mesuring point: Vertical Vibration

AND: [Vibration Value1X] = 0

AND: [Vibration Value2X] = 0

AND: [Vibration Value3X] > 0

THEN:

''There is a friction on motor or pump. Maintenance is needed.''

4.2.2 Motor – reductor – chain mechanism

Motor – Reductor – Chain Mechanism consist of an induction motor, a reductor and chain. This mechanism actuates the power through the gear group with certain ratio to the load. Reductor is a gear group that transduce the same power by changing both torque and velocity. Induction motor actuates power to the reductor and chain just aligned that power to the last equipment which will use the power.

All actuating mechanisms in this thesis will use the first, second and third harmanics during the vibration analysis. Because all induction motors in Europe is 50 HZ so three harmonic is enough to anlyze to vibration.

The sample rules are:

IF:

Choose the actuating mechanism: Motor – Reductor – Chain

AND: Choose mesuring point: Horizontal Vibration

AND: [Vibration Value1X] >= [Vibration value2X]

AND: [Vibration Value2X] >= [Vibration value3X]

THEN:

''There is a friction on motor or pump. Maintenance is necessary.''

IF:

Choose the actuating mechanism: Motor – Reductor – Chain

AND: Choose mesuring point: Horizontal Vibration

AND: [Vibration Value1X] >= [Vibration value3X]

AND: [Vibration Value3X] > [Vibration value2X]

THEN:

''There is a wear on reductor. Maintenance is necessary.''

IF:

Choose the actuating mechanism: Motor – Reductor – Chain

AND: Choose mesuring point: Horizontal Vibration

AND: [Vibration Value1X] > 0

AND: [Vibration Value2X] = 0

AND: [Vibration value3X] = 0

THEN:

‘’There is a weakining at stator resistance of motor. Maintenace is necessary.‘’

IF:

Choose the actuating mechanism: Motor – Reductor – Chain

AND: Choose mesuring point: Vertical Vibration

AND: [Vibration Value1X] > 0

AND: [Vibration Value2X] >= 0

AND: [Vibration value3X] = 0

THEN:

‘Check the resistance of the stator and rotor for motor.‘’

IF:

Choose the actuating mechanism: Motor – Reductor – Chain

AND: Choose mesuring point: There is a random vibration on horizantal axes.

THEN:

‘’Check the driver parameters of motor.‘’

IF:

Choose the actuating mechanism: Motor – Reductor – Chain

AND: Choose mesuring point: There is a random vibration on vertical axes.

THEN:

‘’Check the driver parameters of motor.‘’

4.2.3 Motor – belt – fan mechanism

Motor – Belt – Fan Mechanism is a difficult mechanisms to analyze. The main reason for this difficultie is the belt. Actuating belts are commonly used to transfer power by using rotational motion from one shaft to another. Belt driven fans are used many application such as heating, ventilation, air conditioning and cooling systems.

The belt has many forms. Flat, toothed, and ‘’V’’ form belts are the main type of belts. Flat belts transfer a load by using its pretensioned property so the pulleys act like capstans because of belt this property. Flat belts can be generally very efficient, if not forced to run on pulleys which have copmles gear ratios to accommodate misalignments.

Belt wear can occur at the presence of frequencies not only at belt rpm, but also at multiples of belt rpm (harmonics). Mainly, when belt wear has occured, the peak at

2X belt rpm will get bigger value than the peak at 1X belt rpm. If belt wear is obvious, it will usually produce many harmonics at belt speed. Belt speed will always be lower than either the motor or fan speed (rpm) in normal condition.

The sample dialogs are:

IF:

Choose the actuating mechanism: Motor – Belt – Fan

AND: Choose mesuring point: Horizontal Vibration

AND: Is there any pick vibration value before the [Vaibration Value1X], Yes

AND: [Vibration Value2X] = 0

AND: [Vibration value3X] = 0

THEN:

‘’There is a misalignment at the center of motor side. Maintenance is necessary.‘’

IF:

Choose the actuating mechanism: Motor – Belt – Fan

AND: Choose mesuring point: Horizontal Vibration

AND: Is there any pick vibration value before the [Vaibration Value1X], Yes

AND: [Vibration Value1X] > 0

THEN:

‘’ Check bearing shells on the shaft‘’

IF:

Choose the actuating mechanism: Motor – Belt – Fan

AND: Choose mesuring point: Vertical Vibration

AND: Is there any vibration value around [Vaibration Value1X], Yes

AND: [Vibration Value1X] > 0

THEN:

‘’ Ther is resonance on the belt. Change the belt.‘’

IF:

Choose the actuating mechanism: Motor – Belt – Fan

AND: Choose mesuring point: Vertical Vibration

AND: Is there any vibration value around [Vaibration Value1X], No

THEN:

‘’ Check the belt tension ‘’.

IF:

Choose the actuating mechanism: Motor – Belt – Fan

AND: Choose mesuring point: There is a random vibration on horizantal axes.

THEN:

‘’There is balance on the fan. Maintenance is necessary.‘’

IF:

Choose the actuating mechanism: Motor – Belt – Fan

AND: Choose mesuring point: There is a random vibration on vertical axes.

THEN:

‘’There is balance on the fan. Maintenance is necessary.‘’

4.2.4 Motor – fan mechanism

The main principal of operation for a centrifugal fan is the shaft mounted rotating wheel (impeller) inside a scroll type housing structure energy to the air stream or gas turbines that have rotation by the fan. Centrifugal fans use centrifugal force to increase the velocity of the air as it passes between the fan wheel blades and exits at the last edge of the fan wheel. We can assume the fans are the velocity generators for their air moving property.

Fans are subjected to functional forces generated by their operating speed. These functional forces can cause dynamic vibration and may generated from the rotating parts by themselves. Unbalanced fan wheels and drives are some of the force examples that cause vibration by meaned as couple unbalance.

One of the common vibration problem on fans is the unbalance. Force Unbalance vibration characteristic is in phase and steady. Vibration magnitude due to unbalance can increase by the square of speed (a 3X speed increase = 9X higher vibration) as discussed the chapter diagnostic chart. 1X RPM is always present and normally dominates the frequency spectrum. Axial misalignment is the other common problem with motor-fan mechanisms. When it has occured, the vibration at fan speed can reache the highest vibration peak in spectrum taken on the motor. It can be confirmed by measuring phase in the axial direction at fan speed. Misalignment will cause phase differences at around 180° between the motor and fan bearings (close to the pulleys) with phase measurements taken at fan speed.

Here is the some sample dialogs:

IF:

Choose the actuating mechanism: Motor – Fan

AND: Choose mesuring point: Horizontal Vibration

AND: [Vibration Value1X] > 0

AND: [Vibration Value2X] > 0

AND: [Vibration value3X] >= 0

THEN:

‘’Check the bearings of the motor and fan ‘’.

IF:

Choose the actuating mechanism: Motor – Fan

AND: Choose mesuring point: Vertical Vibration

AND: [Vibration Value1X] > 0

AND: [Vibration Value2X] > 0

AND: [Vibration value3X] >= 0

THEN:

‘’Check the shaft of the motor and fan coupling. Chang the bearings. ‘’.

IF:

Choose the actuating mechanism: Motor – Fan

AND: Choose mesuring point: There is a random vibration on horizantal axes.

THEN:

‘’There is balance on the fan. Maintenance is necessary. ‘’

IF:

Choose the actuating mechanism: Motor – Fan

AND: Choose mesuring point: There is a random vibration on vertical axes.

THEN:

‘’There is balance on the fan. Maintenance is necessary.

5. EXPERIMENTAL RESULTS

Experimental results of vibration analysis prove that vibration analysis has significant importance for industry. It provides detailed information concerning the reason of the faults and defects. Commonly, information from experimental vibration analysis result is used for the preventive maintenance operations not to have unplanned production stops. It usually implemented on the mechanisms such as; Motor – Pump, Motor – Belt – Fan, Motor – Fan and Motor – Reductor – Chain.

Vibration data have been measured by vibration sensors and the datas collected by special device which use the spectrum analysis to show results. These results are the inputs for the expert system. Finally the expert system evaluates the inputs and gives recomendations to the user with its result.

All data for experiment results are collected from real industrial applications. Some samples are given in Figures X, Y:

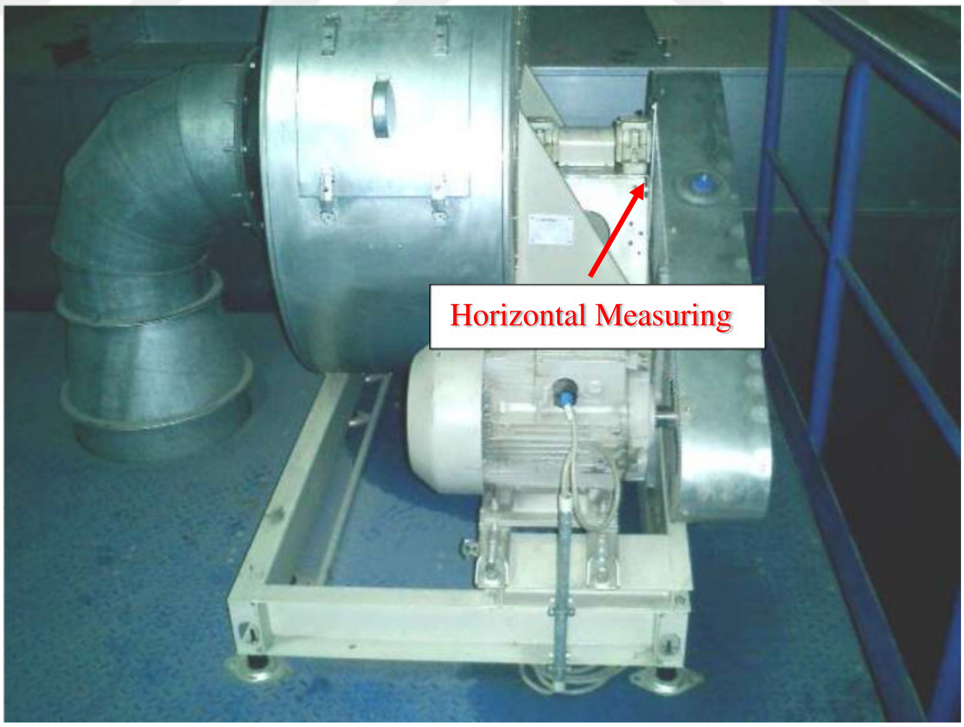

Figure 5.1: Motor-fan-belt mechanism horizontal measuring

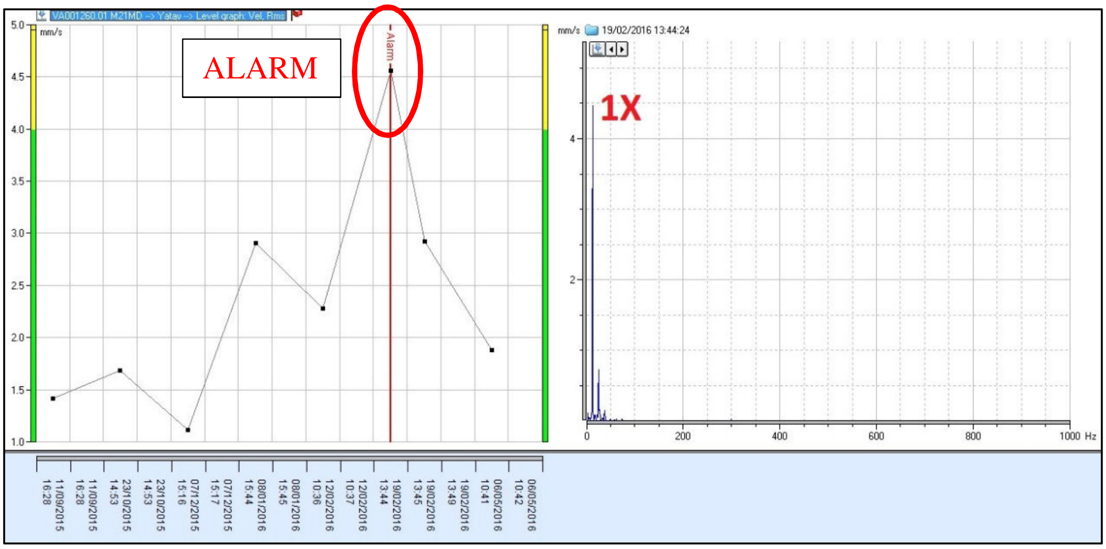

Figure 5.2: Motor-fan-belt mechanism measuring results.

This is a Motor-Fan-Belt Mechanism and horizontal measuring results. There is a vibration value 1X around 4 and there is no other vibration value (2X=0, 3X=0). The expert system recommends us ‘’There is a misalignment at the center of motor side. Maintenance is necessary. ‘’. The device define the vibration value over ‘’3’’ as an alarm at the marked area on vibration results chart. After implementation of the expert system recomendation the vibration value is decresed around the 2 to the normal values and it shows us expert system gives the right advices to the users. The other experimental result is;

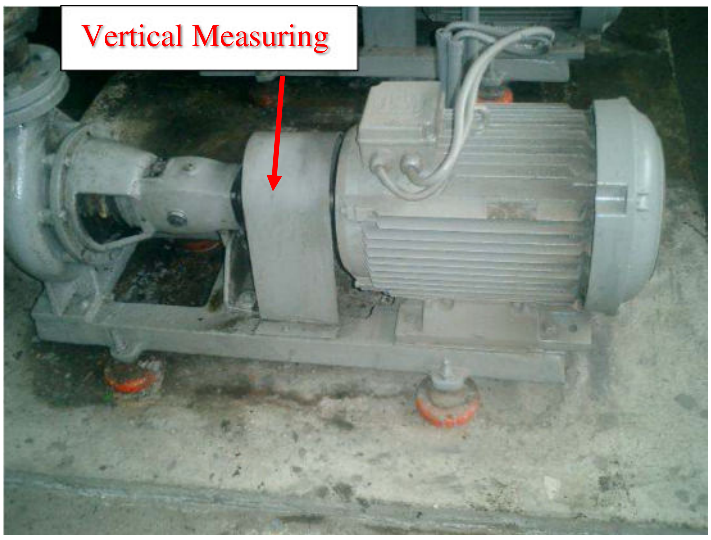

Figure 5.3: Motor-pump mechanism vertical measuring.

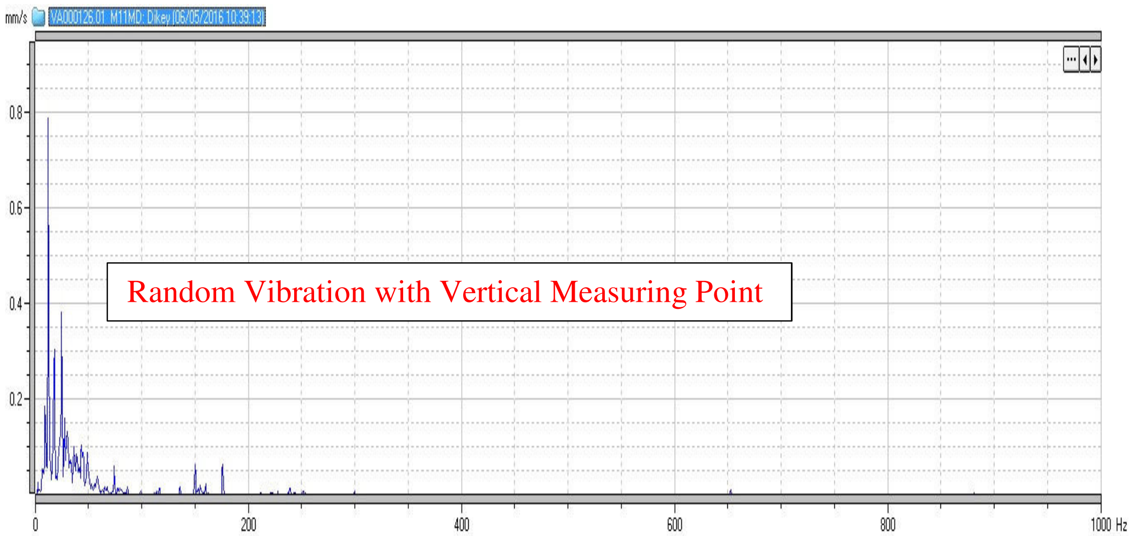

Figure 5.4: Motor-pump mechanism measuring results.

The mechanism is a Motor-Pump Mechanism and the measuring results are on vertical axes. The results are randomly with vertical measuring point and there is no other certain picks through the frequency scale. When we follow these inputs, the expert system recommend the user ‘’ Maintenance is necessary for the pump. ‘’. The expert systems cannot say certain things in many situation because of the rotating system complexity or combining of many reason. The system can define the reason of the problem as section but not as sub components.

Figure 5.5: Motor-fan mechanism horizontal measuring.

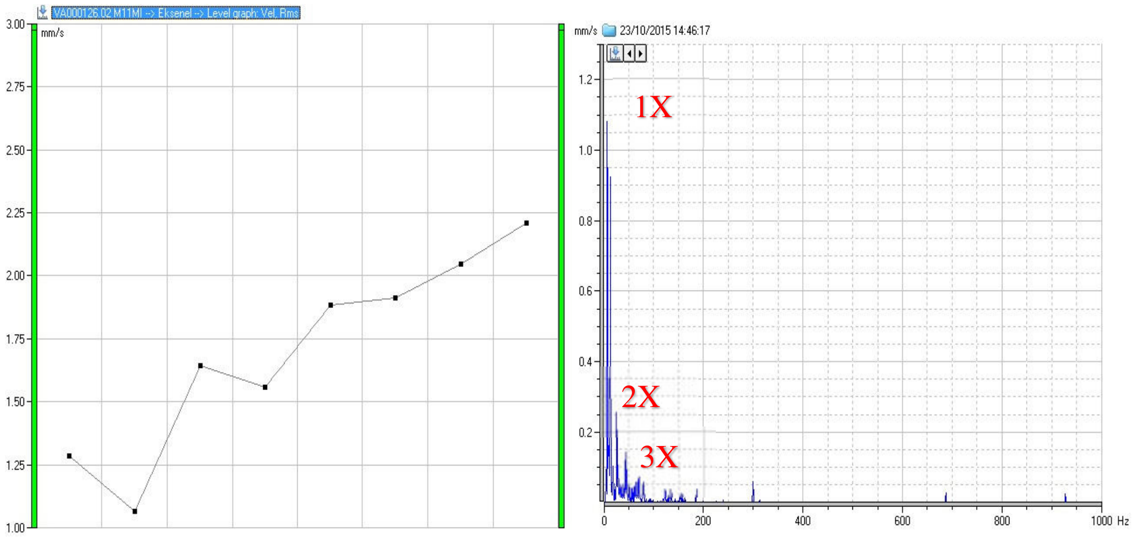

Figure 5.6: Motor-fan mechanism measuring results.

The releated picture is a Motor-Fan mechanism. This mechanisms can react as many form of vibration because of fan blades. The balance of the fan can be reasoned of many problem. Generally, the certain pick around 1x and then random frequencies Show that there is balance problem on the fan. In measured values shaow that there are picks in 1X, 2X and 3X and it means that the advice is ‘’Check the bearings of the motor and fan ‘’. The motor bearing and fan bearing are very close so we can not exactly define real bearing defect. Mainly if there is a defect on one of the bearing we should check the others also so the recomendation suggest the absolutely right advice to the user.

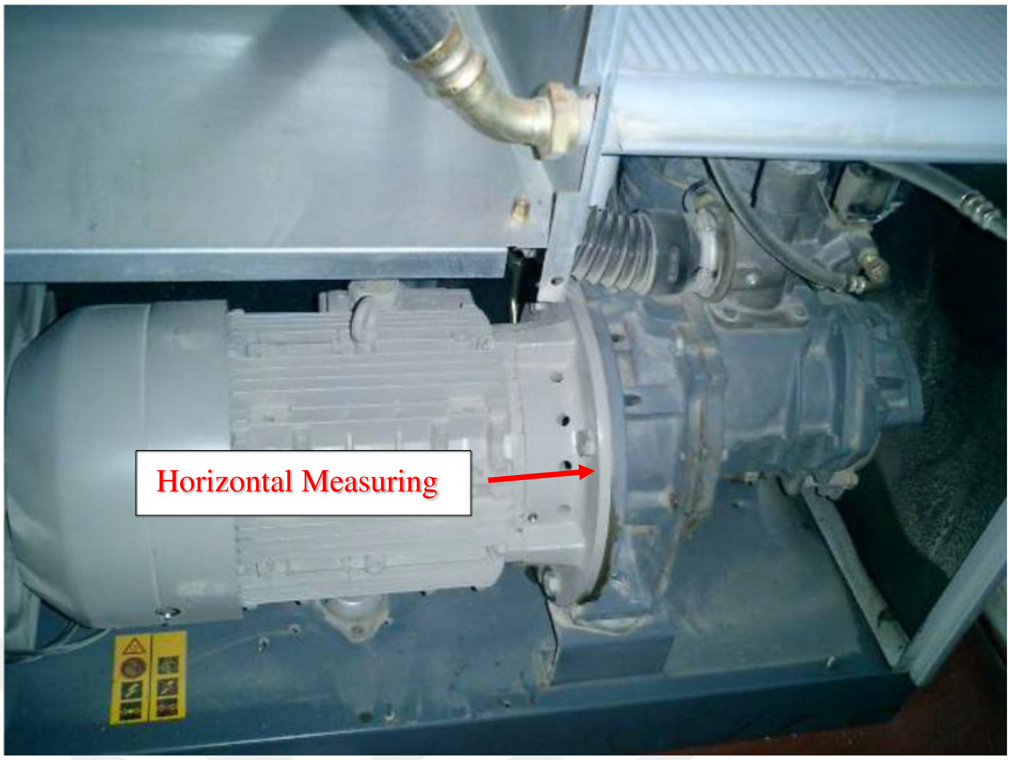

Figure 5.7: Motor-reductor-chain mechanism horizontal measuring.

The Motor-Reductor-Chain mechanism is the last experimental mechanisms. These mechanisms are more common than the others. Although these mechanisms are common, they can be very complex for the performing analysis because of the reductor structure. Reductors are a group of gear so the main reason of the vibration are mostly combination of them. The experts generally come across a certain pick on 1X and 3X with half amount of 1X. The other picks help to define real problem.

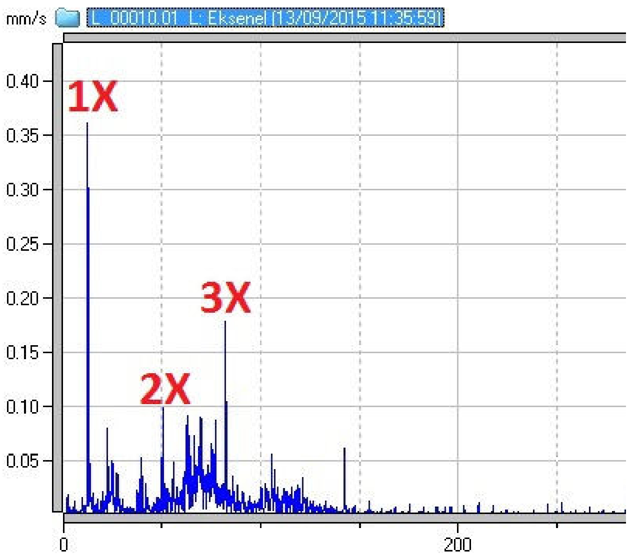

Figure 5.8: Motor-reductor-chain mechanism measuring results.

There is a certain pick on 1X and 3X with the half amount of 1X. There is also 2X with the half amount 3X then we can easily say that this is a reductor problem because there is no reason at the the other equipments to have 2X. Obviously, 2X is a result of the one of the other gear in the reductor so the expert system define this failure as ‘’There is a wear on reductor. Maintenance is necessary. ‘’ .

Vibration was measured on four different mechanisms in real industrial conditions. The results show that machine vibration has particular characteristics. The expert system evaluates all significant inputs which is collected by vibration measuring device in frequency domain, and give the right results as vibration reason. The certain diminishing on vibration results are the easily observed after implementing the given recomendations by the expert system.

Experimental investigation also demonstrate that the more information is collected, the more reliable results can obtain. It is clear from these experiments that the decision tree is a simple application system once it is built completely.

6. CONCLUSION

The main aim of this thesis was to improve the field of condition monitoring and fault diagnosis for induction motor applications by using an expert system for predictive maintenance operations. The common mechanisms of the induction motor in industrial enviroment have increased for condition monitoring of their high efficiency working periods. Fault diagnosis of different mechanisms based on an expert system is the main goal of this research. Literature analysis is revised in wide range to summarize state of the new techniques that are related to the methods implemented in this research. The first part of the thesis presented as literature review that provides the fundamentals of the both induction motors with their mechanisms through the faults to survey of the analysis as a diagnosis method. Secondly, the new chapter provides an overview of the vibration analysis for fault diagnosis methods. Thirdly, the next chapter presents an overview of the expert system for fault diagnosis of induction motor. Fourthly, the review provides experimental results with real industrial mechanisms.

The condition monitoring and fault diagnosis of induction motors is reached very popular application areas in recent years from traditional methods to artificial intelligent methods, such as ES, FLS, and ANN.The accurate mathematical models are not enough for this kind of system.It is also difficult to build. The artificial intelligence methods create an approach that are enough for detection of future faults. Instead, this stochastic optimisation technique that can be used expert system to define failures or to recognise the effects of vibration before failure.

The time and frequency records obtained under the applied fault and working conditions as described in earlier chapters of this thesis. All measured values provide a source of fault dependent data. It has been implied that the fault conditions implemented into the different kind of induction motor mechanisms and their components such as rotor eccentricity, broken rotor bars, and damaged end bearing, fan, belt and reductor. All measured data are collected and fault conditions occurred under the load on mechanisms such as shaft misalignment, unbalanced load, and faulty gearbox. The results which are obtained by confirmed measurement devices and analysed in frequency domain. Online and continuous monitoring supports detail analyses and accurate results. However for induction motors running continuously for long periods, then the data collection can be possible under steady state running conditions. A proper set of time records for enough much data can be readily obtained while the mechanisms are operating under suitable load levels. This is common used technique for determining machine condition by capturing and analysing a time record of the output of a vibration transducer but time based analysises are not enough to detect real reasons of the faults. That's another concept which converting from time base signal to frequency base signal. Mainly, vibration transducers are common piezo-based accelerometers and they are mounted at suitable locations on a machine structure.Thats is general horizontal or vertical direction of the mechanism. The output of these transducers gives the acceleration of vibration according the defined alarm levels before. If more measurement point or more different measurement sensors are necessary, both the velocity and displacement of vibration can be implemented. The overall vibration level can be plotted and trended and evaluated against predetermined criteria which is already described by rules to permit initial judgements to be made on machine condition. Expert system uses those inputs to reach the recomendations.

The results explained in the above paragraphs were obtained from fault related data collected under accelerating conditions with normal working conditions and processed using the FFT algorithm with specific measurement device software. Consequently, the FFT algorithm is implemented for stationary vibration peaks as 1X, 2X, 3X.

The further results have showed that the system is so rebust and the system has alsı prove the itsel with different kind of mechanisms. While collection of data both manual and online monitoring systems have been used to reache high diagnostic success rate. Ideally the manual and online monitoring systems can serve in real time and provide continuous access to a health condition report. The type of the mechanism or vibration characteristic can decide the type of the monitoring.

Induction motors are in use with wide variety of applications with the changing numbers from relatively low power consumption to many industrial application. Mainly an expert system has programmed for induction motor fault analysis based on vibration magnitude with a high sucess rate in real industrie applications.

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PUBLICATIONS, PRESENTATIONS AND PATENTS FROM THESIS

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