Fault Detection and Diagnosis System for Centrifugal Compressor

Mohamed El.boraei, Prof.Dr. M. Abdel-Geliel, Prof.Dr. Medhat El Singaby

Abstract— The world is changing, safety and environment impact became the most important thing, so all industries searching for reliable and fault tolerant control system that prevents and predict fault or to find a root cause for the fault to prevent a disaster. A system that assures the process doesn't go to its threshold limits. A lot of experimental researches have shown methods to detect and diagnose faults. These methods detect and recognize the occurrence of the fault, and give a root cause for the fault. These methods will help to improve the process and make it safer and fault tolerant which a big demand on oil and petrochemical industries. Reliability, operational safety, and environmental protection are very important, in particular for oil and petrochemical processes. If faults occur, consequences can be extremely serious in terms of human life as leakage of a toxic or flammable fluid might take place as a result of faults occurrence that may result in a serious explosion and environmental impact. Furthermore, faults occurrence may result in system failure that causes a total shutdown of the whole plant which leads to an economic loss. Thus, fault detection has been developed recently for:

- Decreasing Production Loss

- Reducing Equipment Damage

- Enhancement of Human Safety

Compressors play an important role in petrochemicals process so it should be protected to prevent any failure which can cause loss of production due to the time needed for maintenance and money loss, so compressors shall be protected by a well-designed controller and instrumentation systems. MATLAB simulation for fault detection and diagnosis system is done and results showed and detected faults happened on the compressor.

Index Terms— Compressors, Fault detection, Fault diagnosis, Fault tolerant systems, Fuzzy systems, Signal monitoring, Vibration analysis

1 Introduction

Compressors make up that class of machinery that's ''all around us'' however of that we have a tendency to are very little aware. In our homes and workplaces, and in nearly any kind of transportation we would use. Compressors serve in refrigeration, engines,

Chemical processes, gas transmission, producing, and in mere concerning each place wherever there's a desire to maneuver or compress the gas. [1], compressors play necessary role in crude oil refineries as increasing pressure of gases, any fault happens on the mechanical device could cause loss on the assembly , upset on the operation or important injury thus a control system that predicts and diagnoses the fault are terribly useful and decreases production loss, reduce equipment damage and enhance human safety. The 1st demand in any Process industry is stability and safety and to have a reliable system, to achieve those requirements we shall take into consideration every element that interacts with the process. A failure or fault can occur in any element which will affect the process, so if the process with high criticality precautions shall be taken to make it more stable, safe & reliable, For optimum selection of fault detection method there are parameters which control this selection as "Desirable characteristics of a fault diagnostic system"[2]

- Quick detection and diagnosis
- Quick detection and diagnosis
- Isolability
- Robustness
- Novelty identifiability
- Classification error estimate
- Adaptability
- Explanation facility
- Modeling requirements
- Storage and computational requirements
- Multiple fault identifiability

The compressor is a mechanical device and as same as many machines contain drive systems with motors, clutches, gears, shafts, belts or chains, and different ball V rolling or oil bearings. Vibrations are usually generated by Inherent machine

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oscillations (e.g. piston-crankshaft, toothed machine tool cutting, axial piston pumps, induction motors), Shaft oscillations with radial or axial displacement, Irregular speed of the shaft (e.g. Kardanjoint or eccentric gears), Torsional shaft oscillation, Impulse wise excitation (e.g. through backlash, cracks, pittings, broken gear teeth).

2 FAULT DETECTION METHODSFAULT DETECTION METHODS

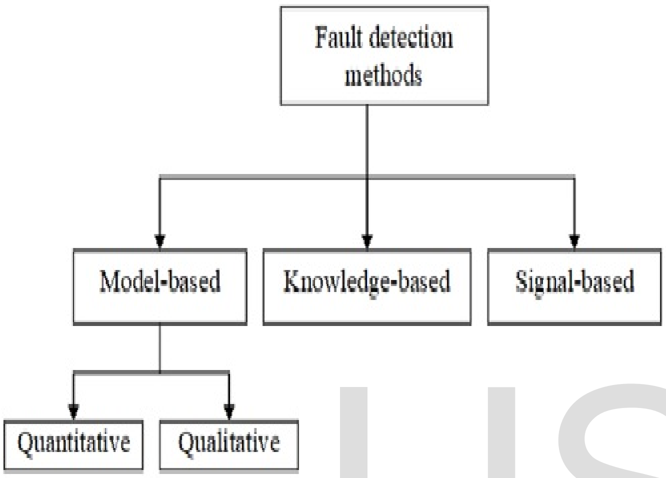

Fig. 1. Fault Detection Methods

2.1 MODEL BASED FAULT DETECTION

The conventional ways of fault detection and identification that use static or dynamic models of the method. They include the observer based method, identification-based method, the mathematical space identification technique. Model-based approaches are generally classified into quantitative and qualitative models. Quantitative models (differential equations, state space methods, transfer functions, etc.) are accustomed to typically utilize results from the sector of the control theory [3]. In qualitative models, the relation between the variables to get the expected system behavior is expressed in terms of qualitative functions centered on totally different units within the method like causative models and abstraction hierarchy [4], [5]. They're used, especially, for big and nonlinear systems. The analysis ways employed in the qualitative model are FTA, FMEA, ETA, structure analysis, etc. The formal approach uses qualitative reasoning and qualitative modeling [3], [4]. These ways will give associate resolution for many fault detection issues. However, in some cases, it cannot offer correct detection results since the valid method mathematical model needed during this technique is troublesome to get in some industrial processes.

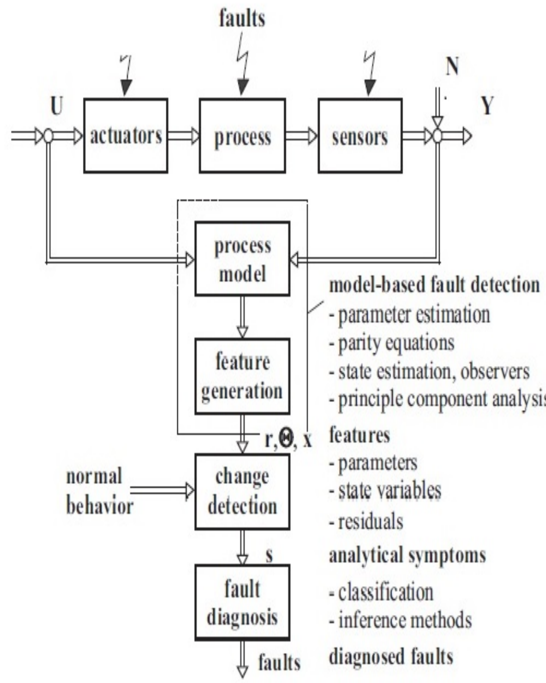

Fig. 2. Scheme for the model-based fault detection [2]

2.2 Knowledge-based approaches

Utilize deep understanding of method structure, method unit functions and qualitative models of the method units below numerous faulty conditions. It may be accustomed to observe faults for a complex production process or for the system in case of nonlinear and uncertain systems [6]-[8]. Recent developments in empirical modelling, like the utilization of computing strategies (neural networks, fuzzy logic, and combination of these methods), have broadened the scope of the quantitative modelling to incorporate 'data based mostly model', in extra to the standard models supported physical principle [9]-[10], [7]. A category of model-free-based FDI approaches has conjointly been developed. Numerous algorithms are enforced using symbolic logic [11], [12], [6], [7], and artificial neural networks [13]-[14]. In several different techniques, completely different operative conditions, as well as traditional and abnormal ones, are treated as patterns. Neural networks are then applied to analyze the web mensuration information and map them to a renowned pattern directly so this system condition is known [13], [14], and [9]. This {method} includes the knowledgeable system method, and also the artificial neural network methodology. A mixture of the analytical and knowledge-based mostly strategies is also the foremost acceptable resolution to some fault detection and diagnosis problems.

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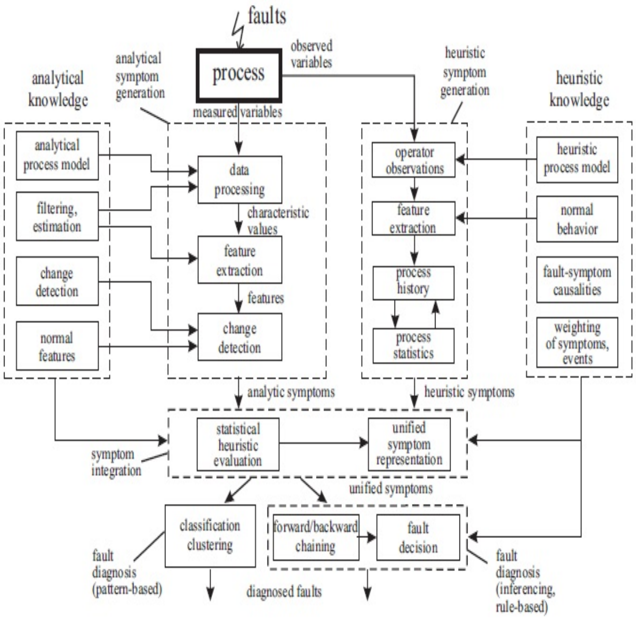

Fig. 3. Overall scheme of knowledge-based fault detection and diagnosis [2]

2.3 Signal based

Signal-based fault detection ways are used for several measured signals of the many processes that show oscillations that are characterized by either their cyclic time behavior, that hold for rotating machines or alternating currents, or random time behavior, that hold for random processes as acoustic noise, turbulence flow or on-off shift of the many customers in electrical or water networks. Those oscillations of cyclic time behavior are known as harmonic (periodic) signals, whereas those of random time behavior is known as random (non-periodic) signals. If changes of those signals are associated with faults within the actuators, the method, and sensors, Signal Model-based mostly Fault-Detection ways is applied [1]. There are a pair of variables signals manageable input (U) and measured output (Y). The measured output (Y) is analyzed. By assumptive special mathematical models for the measured output, appropriate options are calculated, as amplitudes, phases, spectrum frequencies, and correlation functions, sure frequency bandwidth _max of the signal. A comparison with the ascertained options for traditional behavior provides changes to the options that they are thought of as Analytical Symptoms. The Signal Models is divided into Non-Parametric Models (frequency spectra or correlation functions) or constant Models (amplitudes for distinct frequencies or ARMA sort models).In signal-based ways, quantitative ways use signal process ways, like limit checking, spectral analysis, PCA, etc. whereas qualitative ways use data based mostly methodology like fuzzy and neural classification, etc. The signal-based ways, whether or not quantitative or qualitative, don't incorporate model.

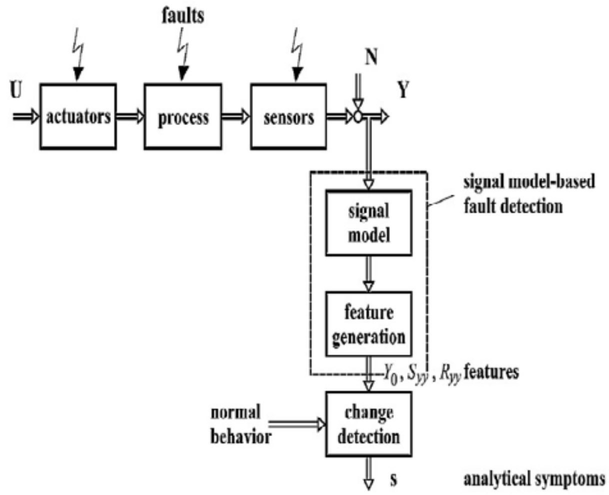

Fig. 4. Scheme for the signal based fault detection [2]

3 Compressor Fault Detection By Vibration Analysis

Vibration analysis: The classical way to analyses stationary harmonic vibration signals is that the harmonic analysis, particularly within the algorithmic, efficient variety of fast Fourier remodel (FFT). The ensuing peaks permit AN intuitive way to extract changes within the frequency peaks caused by faults. Comparison with expected frequencies for, e.g. ball bearings and gears then could permit to isolate several faults. However, the observed frequencies aren't invariably uniquely associated with distinct faults. The utmost entropy spectral estimation is suggested for automatically finding some (2 to 5) distinct frequencies on the value of computations. Sensible results are obtained for a grinding machine, and hacksawing machine, for the extract of damped impulse responses as results of impact impulses caused by ball/rolling bearings or toothed gears, the envelope analysis technique is appropriate. Here, the eigenfrequencies of the machine modes area unit suppressed by a low pass or band pass filter that include the Eigenfrequencies. after determining the magnitude I of the low pass filtered signal, only the positive part of the envelopes remain, This signal is then analyzed by a fast Fourier transform (FFT). By this way, the impact frequency Wimp and its higher harmonics are much better represented as within the FFT of the original signal x(t), wherever it should not be recognized because of the higher contributions of the machine modes[2].

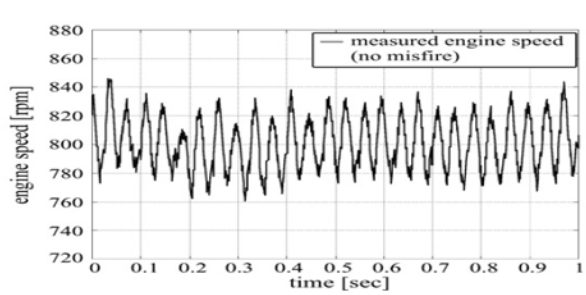

Fig. 5. Time domain vibration reading [2]

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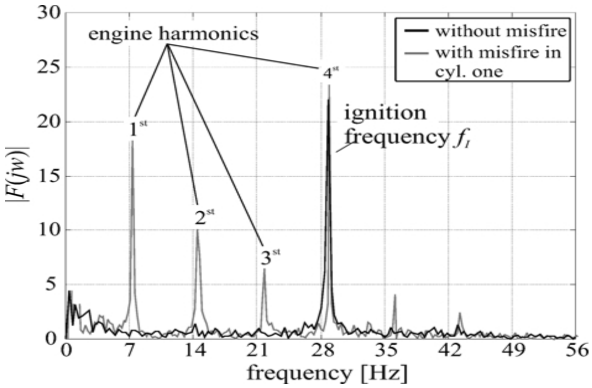

Fig .6. Frequency domain vibration reading [2]

Vibration has traditionally been related to trouble in machines wear, malfunction, noise, and structural damage. in additional recent years, however, vibration has been used to save industry uncountable dollars in machine downtime, analysis of changes in levels of machine vibration has become a vital part of most maintenance programs. A similar analysis is used to solve design issues also on establishing the cause of chronic malfunction and failures. [17]

Frequency Analysis: the benefit with that a fault is identified from sensible check knowledge is directly proportional to the knowledge out there concerning the design of the machine and its operating mechanisms, particularly once an equivalent frequency is used to establish totally different faults; e.g., mass unbalance, looseness and misalignment. The basic techniques used to conduct fault diagnosis utilize the time waveform, orbit, spectrum and phase, the frequencies that are acquired from shaft displacement and casing mounted transducers are related to the known frequencies of the machine. The form and frequency of the time waveform and the orbit provide insight into the physical characteristics of the motion of the shaft and casing. Phase shows the time relation between vibrations measured at numerous location on the machine; this called relative phase. Phase also provides info about the time relationship between vibration at one machine and a fixed reference on the shaft or casing; this is often termed absolute phase. The spectrum is an amplitude versus the record of the vibration activity at a specific location on the machine. [17]

Mass unbalance: Rotating unbalance is the uneven distribution of mass around an axis of rotation. A rotating mass, or rotor, is claimed to be out of balance once its center of mass (inertia axis) is out of alignment with the center of rotation, Mass unbalance can be detected once distinct of 1x frequency with much lower values of 2x, 3x, etc. it corrected by field or search balanc-
ing[17].

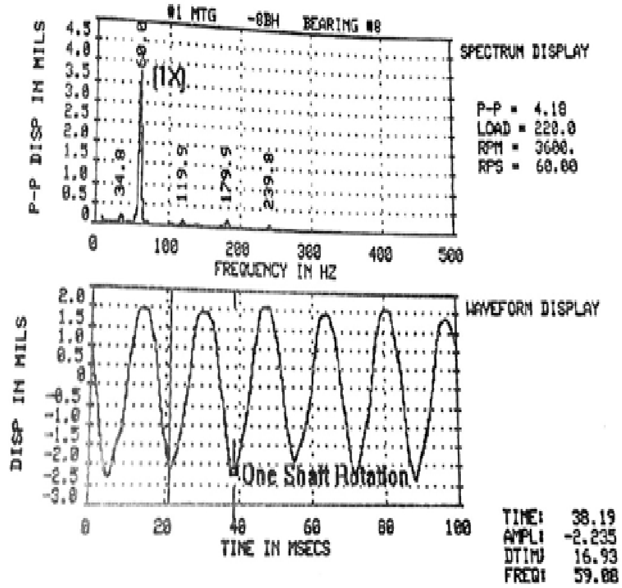

Fig .7. Mass unbalance spectrum and wave form display [17]

Misalignment: the inaccurate arrangement or position of something in relation to something else, misalignment can be detected once distinct of 1x frequency with equal values or higher values of 2x, 3x, it corrected by hot or cold alignment [17].

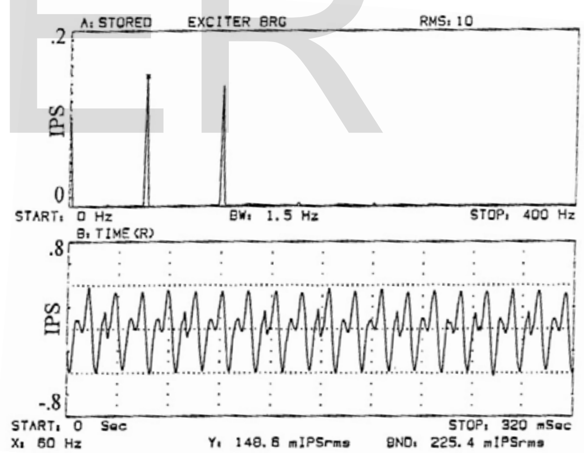

Fig .8. Misalignment spectrum and wave form display [17]

Fluid film bearing wear and excessive clearance: can be detected once high 1x frequency with high 1/2x typically 1-1/2X, it corrected by bearing replacement [17].

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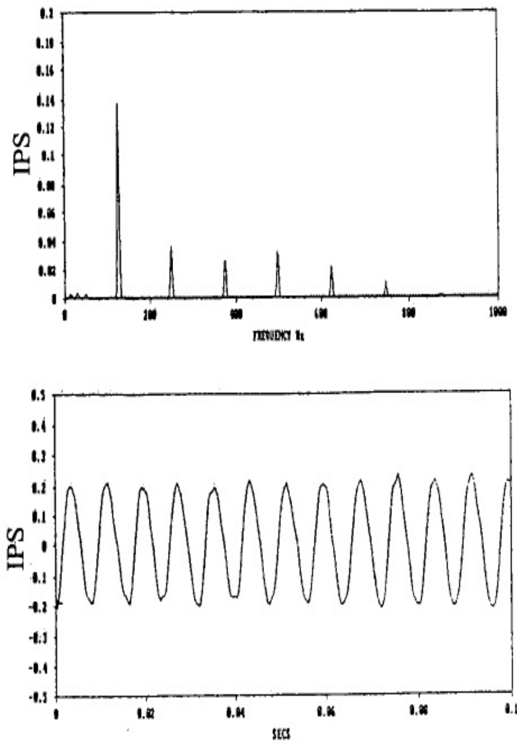


Fig. 9 .Bearing wear and excessive clearance spectrum and wave form display [17]

Surge: The prevalence and resultant vibration knowledge acquisition led to draw an alternative methodology to detect surge significantly throughout field testing. The plots and observations on them are shown below.

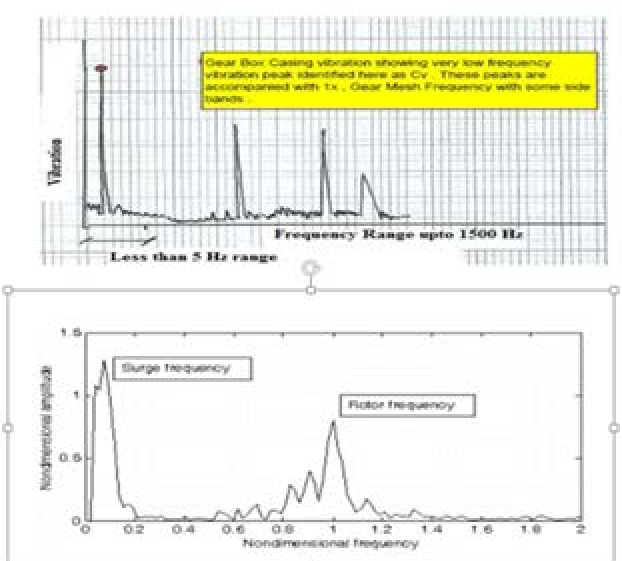


Fig. 10. Surge spectrum [18]

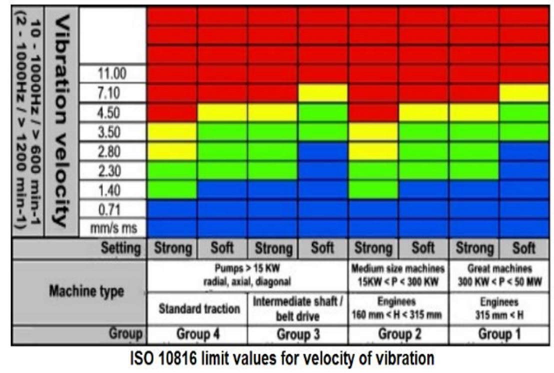


Fig. 11. ISO limits for vibration amplitudes.

Fig 11 shows limits for vibration on machinery according to ISO standard.

4 MATLAB SIMULATION

The following section illustrates the steps of fault detection by vibration analysis. By using fast Fourier MATLAB to transform collected time domain data from real life to frequency domain and check share of error between the results and real-life frequency domain data, fig 12 shows time domain data collected from Bentley Nivada vibration system and fig 13 shows frequency domain data collected from Bentley Nivada vibration system, fig 14 shows MATLAB frequency domain generated file, Fig 15 shows the error between real-life data and generated data by MATLAB with error 1.25 Hz with error share 1.031% that is good accuracy and distinction in magnitude 16.67 and with error share 70% this error due to completely different scan cycle between real life system and MATLAB however it may be neglected because of amplitude readings is high in each graph which provides the same vibration indication.

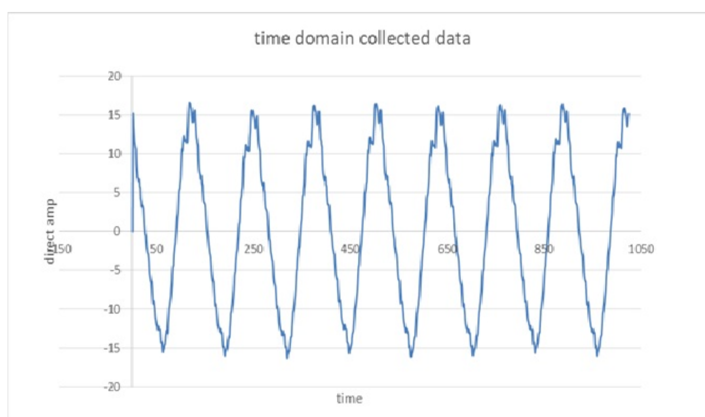


Fig. 12.frequency domain generated by MATLAB.

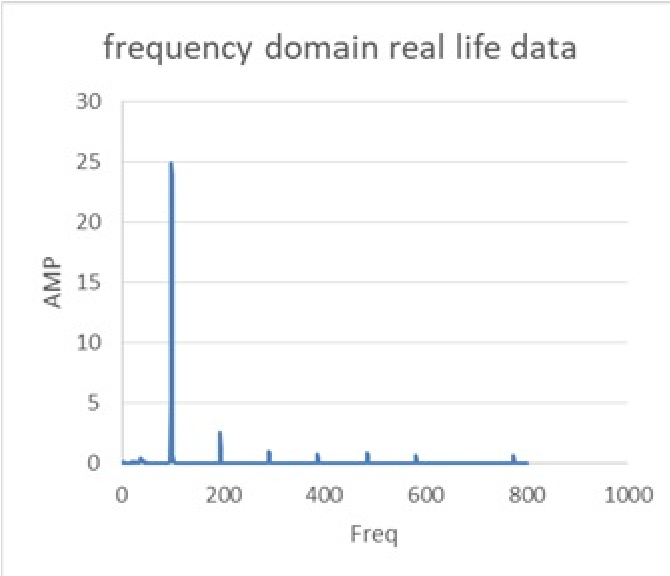


Fig. 13.frequency domain collected from real life data.

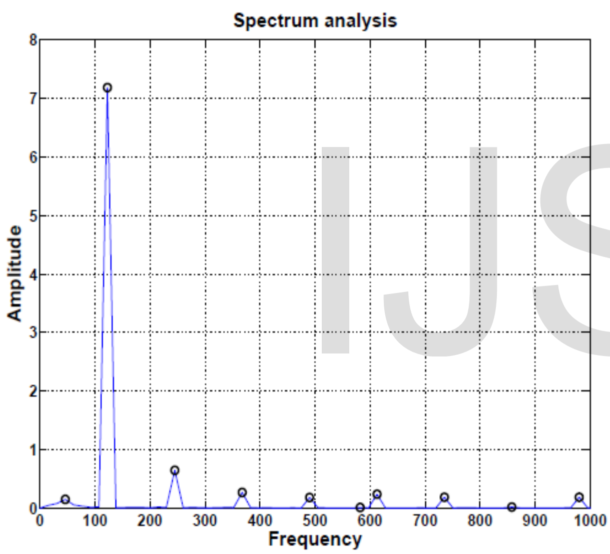


Fig. 14.frequency domain generated by MATLAB.

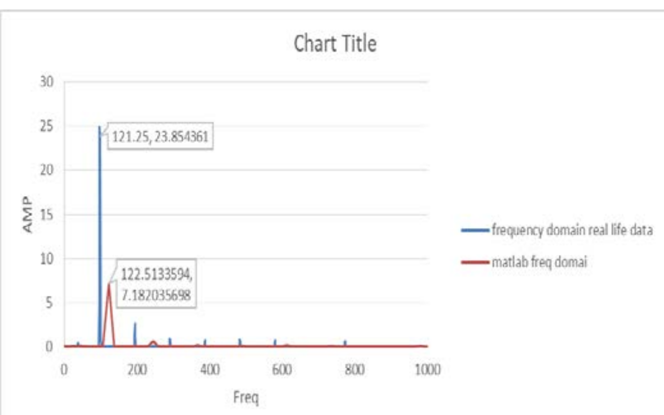


Fig.15.frequency domain generated by MATLAB and real life data.

Second step is spectrum study by aim of MATLAB code to notice velocity amplitudes at fundamental frequency and its harmonics, fig 16 shows the MATLAB code detects peeks at every frequency,MATLAB code need to specify the fundamental frequency and it's preselected on 50 Hz as all motor operated compressors wattage is 50 cycle per second however in our case study its steam turbine operated thus has totally different frequency that is 120 Hz, the values of every velocity amplitudes at fundamental frequency and its harmonics are generated by this matlab code.

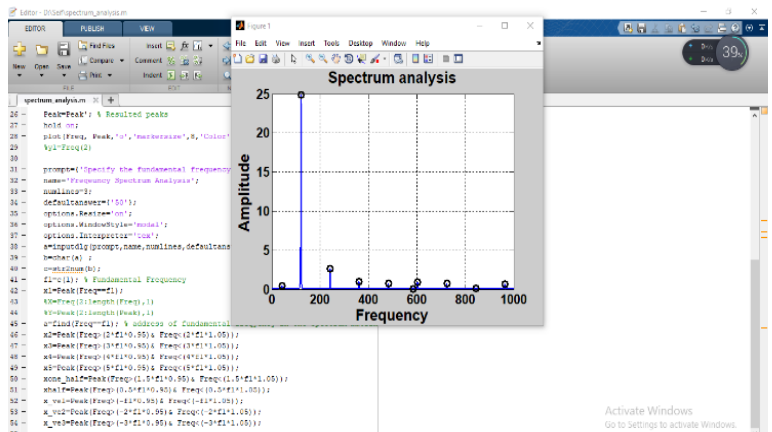
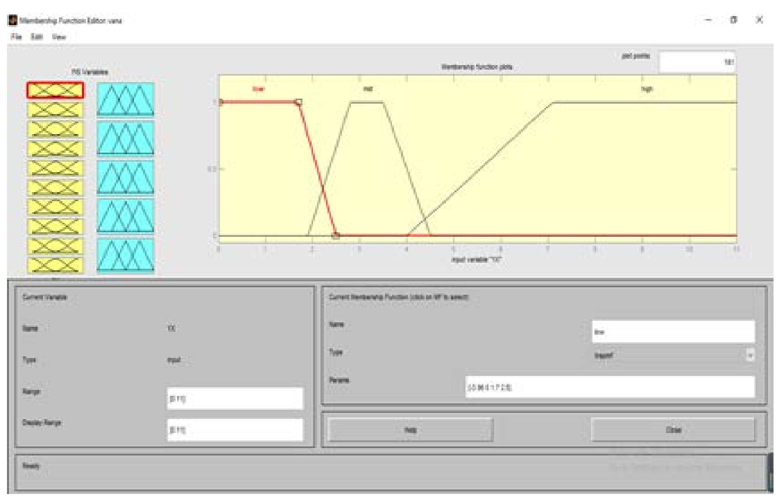
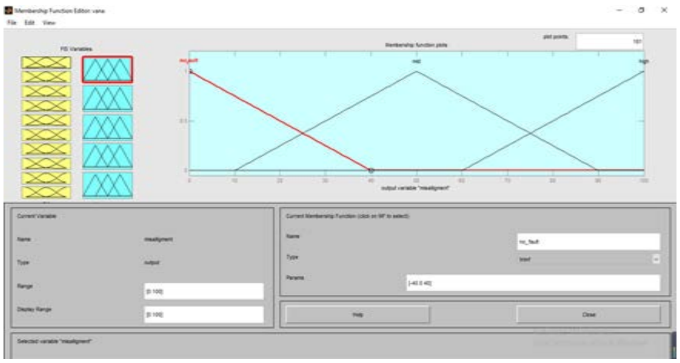


Fig. 16. Peek detection by MATLAB code.

Third step fuzzy logic spectrum analysis and diagnosis, fuzzy logic is employed to observe faults and to diagnose it by learning the vibration spectrum and all vibration fundamentals are used to design the fuzzy logic used for the analysis and within the following steps: Fuzzification: Membership functions used to graphically describe a scenario, fig 17 a,b shown membership function for inputs and outputs, membership limits were chosen per ISO 10816 for all inputs and outputs as proportion from zero to 100% to point out fault proportion.



A



B

Fig.17 A, B. member ship function for input and outputs.

Rule Evaluation: Break down the control problem into a series of IF X AND Y, THEN Z rules based on the fuzzy logic rules. These IF X AND Y, THEN Z rules should define the desired system output response for the given systems input conditions. Fig 18 shows if and then rules for the system.

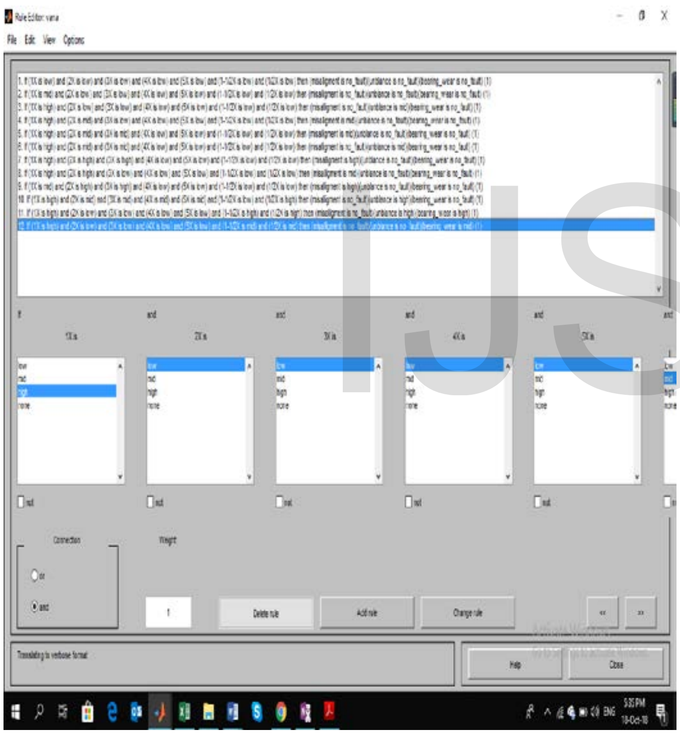


Fig.18 .if and then rules.

Defuzzification: Obtaining the crisp results, test the system, evaluate results and make the necessary adjustments until the desired result is obtained.

4th step Testing the entire system, when creating MATLAB code for time domain to frequency domain and MATLAB code for spectrum analysis and fuzzy logic code for detection and diagnosis, a Simulink design was created to examine the entire system and to envision if the system is correct or not .fig 19 shows Simulink design which is a fuzzy logic system with inputs from workspace containing the values of velocity amplitude at fundamental frequency and its harmonics, fuzzy logic system starts to review the inputs and offers final output with fault and its diagnosis as fig 19.

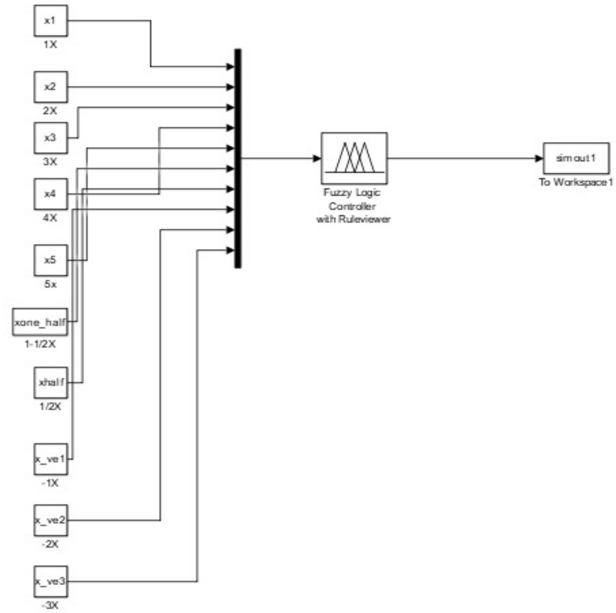


Fig. 19. MATLAB Simulink design.

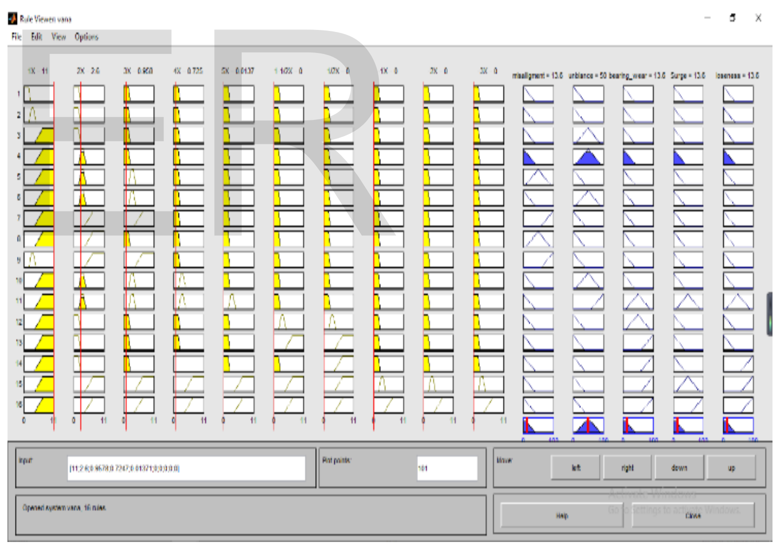


Fig. 20. System outputs.

5 System Verification

As shown in the previous section each fault has a graph or signature differentiate between it and the other faults. By comparing the output from the fuzzy system as shown in fig 20 the following was found:

- The system detects unbalance fault with 50 %.
- The graph shown in Fig 16 a, b shows that X1 value is around 25 and the X2 value is around 2.5.
- The fuzzy system is accurate as detects 1x with high value and 2 x with a medium value which means that there is unbalance.

6 Real Life Implementation Architecture

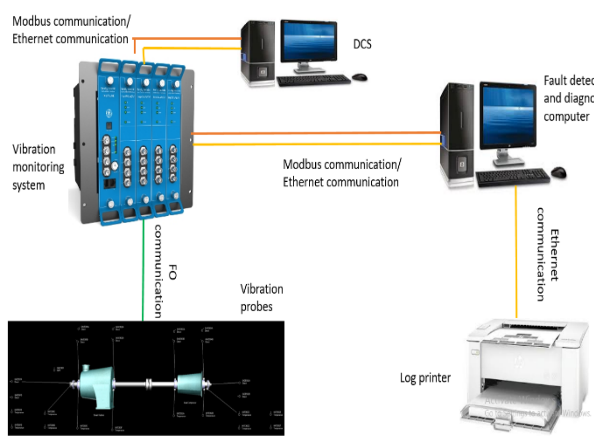


Fig. 21. System architecture.

Fig 21 shows system architecture for the fault detection and diagnosis system, the vibration probes installed on the compressor connected to input modules communicates with vibration monitoring system by Fiber optic cables for fast response and no losses , the vibration monitoring system communicates with DCS and fault detection and diagnosis system with Modbus or Ethernet communication , the fault detection system will study the data and print reports with the results, fault detection system can be connected to DCS for controlling but this step is critical so the fault detection system will notify the responsible person who will decide the actions.

7 Conclusion

The simulation of the system by MATLAB shows that for machinery equipment the most recommended fault diagnosis and detection are a signal based by vibration analysis for the following reasons:

- Vibration measurement is easy.
- Vibration readings give good symptoms to detect the fault.
- No need for complex model study as needed in model-based fault detection methods.
- Vibration response is high (when faults start to appears vibration starts to change).

8 Appendices

Apindex "A": compressor Case study.
Apindex"B": Matlab codes.

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