International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:7, No:11, 2013

Vibration Analysis of an Alstom Typhoon Gas Turbine Power Plant Related to Iran Oil Industry

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Abstract**—**Vibration analysis is the most important factor in preventive maintenance. Gas turbine vibration analysis is also one of the most challenging categories in most critical equipment monitoring systems. Utilities are heart of the process in big industrial plants like petrochemical zones. Vibration analysis methods and condition monitoring systems of this kind of equipment developed too much in recent years. On the other hand, too much operation condition consideration in this kind of equipment should be adjusted properly like inlet and outlet pressure and temperature for both turbine and compressor. In this paper the most important tools and hypothesis used for analyzing of gas turbine power plants discussed in details through a real case history related to an Alstom Typhoon gas turbine power plant in Iran oil industries. In addition, the basic principal of vibration behavior caused by mechanical unbalance in gas turbine rotor discussed in details.

Keywords**—**Vibration analysis, gas turbine, time wave form (TWF), fast Fourier transform (FFT), phase angle.

I. Introduction

DIFFERENT maintenance strategies such as corrective maintenance, time based preventive maintenance, condition-based maintenance and predictive maintenance for different equipment developed in recent years. Human being speaks in different languages. When there is some sickness they could speak to the doctors and talk about the pains and discomfort but what is the machine language. Vibration is the machine language.

The faults of machines like misalignment, unbalance, soft foot, bearing damage, high low, and so on is related to different parts of machine and each part have a unique frequency. Vibration analyst is a kind of translator of machine language in predictive maintenance. Some faults like misalignment, high low and soft foot consider as mother of others like bearing or gear damage and rotor touch. By translating this language we can predict these kinds of high costs. Predictive maintenance developed in recent years because of such economic advantages [1].

In this part, basic principal of vibration analysis introduced. Data processing procedure based on measuring the vibration of machine with a transducer connected to a data collector or analyzer. The best points for this purpose are bearings base on machine design process, that all of mechanical load of machine transfer to these locations. In addition, data collector ability and software's developed too much in recent years.

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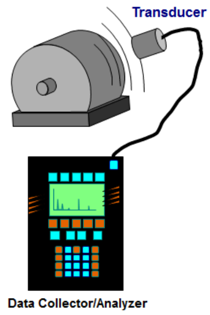

Fig. 1 Measuring machine vibration by transducer and data collector

Fig. 2 shows some typical data collector use in condition monitoring systems. For example, spectra pro are related software for Easy Viber and XMS is related software for Vibro 60.

Fig. 2 Typical data collector with their side facilities like piezoelectric transducers (left easy viber and rightvibro 60)

Time waveform (TWF) is the amplitude –time graph, fast Fourier transform (FFT) will draw by related software's with assist of applied mathematics and condition monitoring techniques. Both FFT and TWF are main graphs in condition monitoring systems.

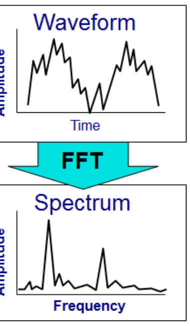

Fig. 3 TWF and FFT

To achieve better understanding in both FFT and TWF some examples explained here. If we have a rotor with small unbalance on the shaft and suppose that this machine has not any other faults or problems.

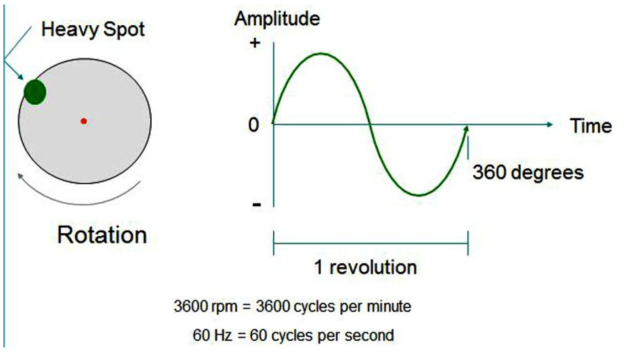

Fig. 4 Shematic of typical unbalance shaft rotating TWF

Now imagine this machine have a cooling fan for bearings cooling purpose or an impeller.

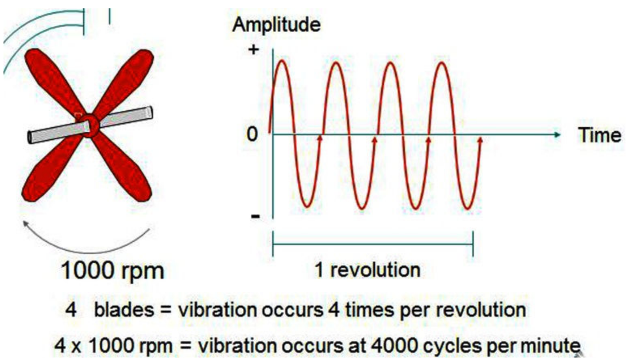

Fig. 5 Blade pass frequency 4X

The frequency increased to 4X if X is equal to the rotational frequency of shaft in Fig. 1. Now just imagine that this machine has a gear coupling and the gears have 12 teeth.

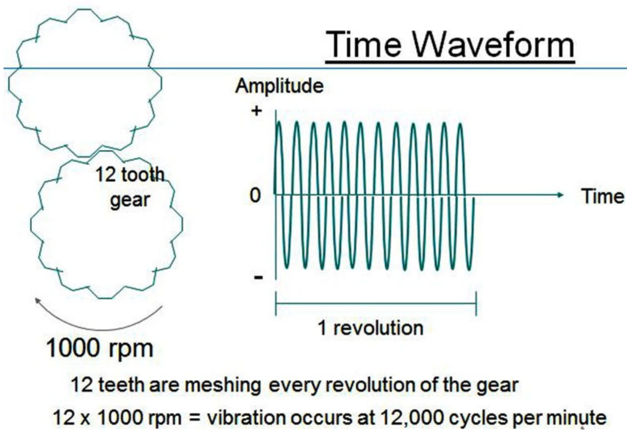

Fig. 6 Gear mesh frequency 12 X

The frequency increase to 12X (X is equal to the rotational frequency of shaft in Fig. 1). Now just imagine that we have all these part in a machine together.

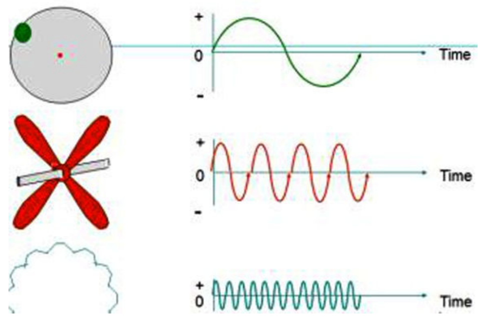

Fig. 7 Typical machine different parts frequencies

In real industrial applications machines usually consist of several different parts, each parts have a unique frequency thus we have usually complex TWF.

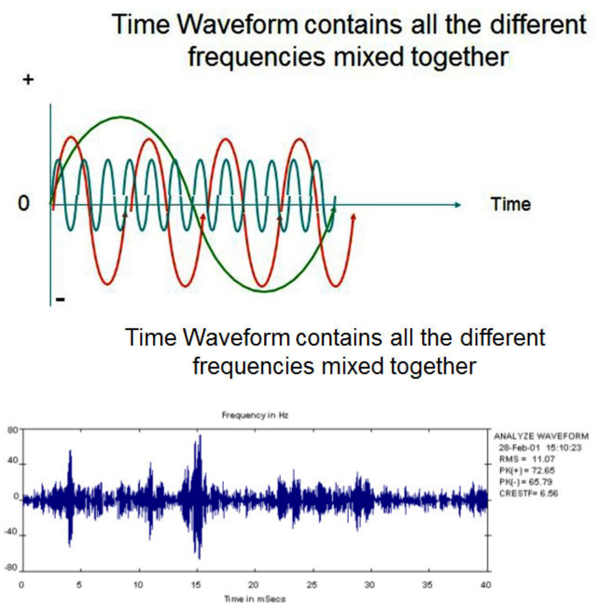

Fig. 8 Complex TWF

But how we can decompose these kinds of complex TWF in real application? If you remember the Fourier transform in mathematical engineering this will the key concept for this purpose in different data collectors and related software's that help us to separates individual frequencies and then detects how much vibration exist at each frequency.

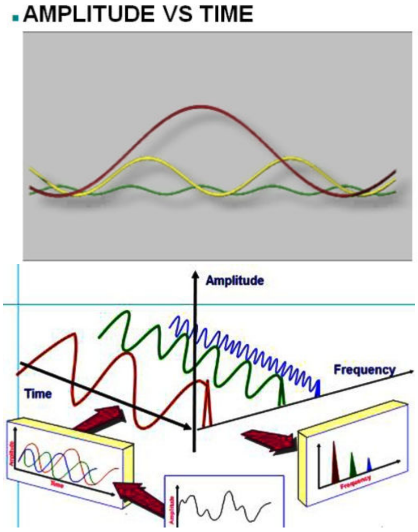

Fig. 9 Schematic of a typical TWF and FFT

Now just come back to our machine that have 3 basic frequency thus this machine have theses all frequencies in its FFT then by monitoring these frequencies amplitude we can monitoring the condition of gear shaft unbalance and impeller separately.

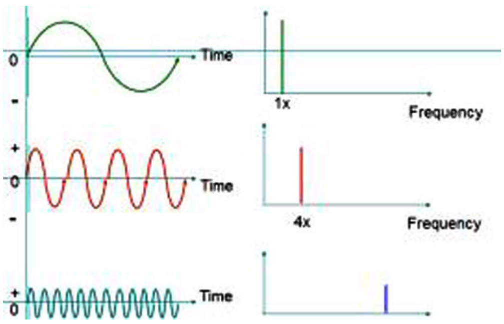

Fig. 10 Unbalance (rotor) 1X, gear mesh 12 X and blade pass frequency 4X

Optimized Integrated Kurtosis-based Algorithm for Z-filter (I-kazTM) Coefficient using multilevel signal decomposition technique developed in recent years. The I-kazTM coefficient (Z) was originally developed base on the second order of Daubechiessignal decomposition. Higher order of I-kazTM coefficients, 3rd order (3Z), 4th order (4Z), 5th order (5Z), 6th order (6Z), and 7th order (7Z) were investigated by analyzing their response using two types of synthetic signals, TSA and TSB.

The optimized order of I-kaz Multi Level coefficient was chosen base on the sensitiveness of the coefficient response with respect to the changes of amplitude in TSA and frequency in TSB synthetic signals to simplifying the process. Consider a typical dynamic signal as illustrated in Fig. 11. The decomposition of the signal in the time domain was done by considering the two order of the Daubechies concept in signal decomposition process [2].

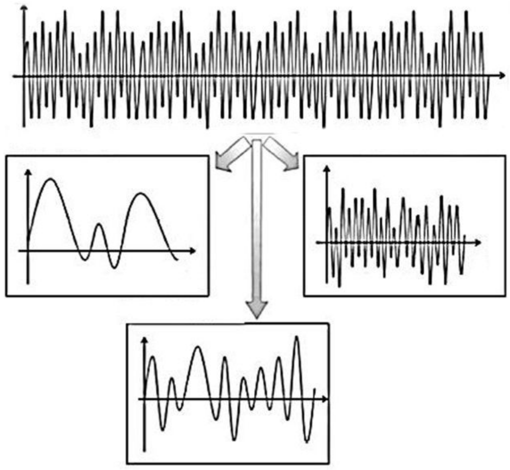

Fig. 11 The decomposition process of a signal in I-kaz procedure

The software's have some facilities like cursor that can calculate these frequencies accurately and compare them with the previous FFT. Machine parts have a unique frequency and by monitoring these frequencies, we can achieve the condition of each machine component separately and accurately.

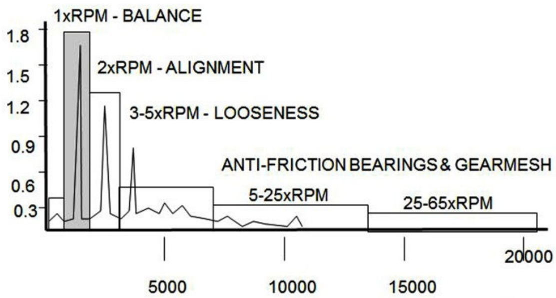

Fig. 12 General fault diagnosis typical diagram

Trend of overall frequencies and vibration spectrum provide useful information to analyze defects in roller bearings. Trend indicates severity of vibration in defective bearings. Vibration domain spectrum identifies amplitudes corresponding to defect frequencies and enables to predict presence of defects on inner race and outer race of roller bearings.

The distinct and different behavior of vibration signals from bearings with inner race defect and outer race defect helps in identifying the defects in roller bearings. Several frequency exist in ball bearings inner race, outer race, cage, ball rotational and ball travel frequency can all detected by software in FFT by adding the bearing code number and types to the software for each point in initial monitoring situation. The software will calculate all frequencies automatically [3].

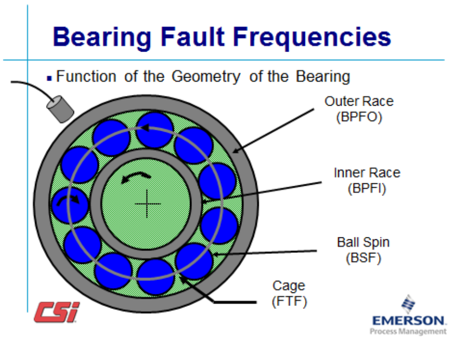

Fig. 13 Bearing Fault Frequencies

1X generally related to faults like unbalance, bent shaft, misalignment and soft foot because these faults amplified by main rotational shaft speed. The phase analysis may help us to distinguish the different characteristics of these faults and help us to diagnose the machine fault correctly.2x also may related to misalignment or soft foot, 3x amplified by mechanical or rotary looseness's. High frequencies vibrations also may cause by some gear or bearing problems (between 1000 to 20000 Hz).

These diagrams just introduce general view to achieve better understanding of vibration analysis in machine fault diagnosis. In real application professional software's help us to analyze the machine vibration with FFT and other types of machine vibration graphs and also monitoring techniques. There are also some global standard for overall vibration alert and danger limits for different type of equipment usually base on machine KW and also types of machine foundation like rigid and flexible foundations.

Besides, vibration history of machines plays a big role to such vibration limits definition in all fields in preventive maintenance. Nowadays data collector software's have different types of facilities that can help us to monitoring special band frequencies in FFT for any further fault diagnosis applications [4].

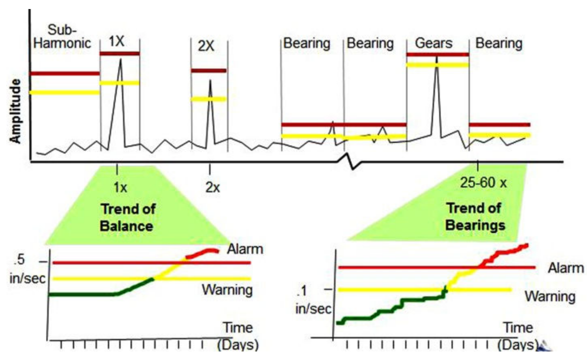

Fig. 14 Frequency band trending with alarm and danger conditions [5]

II. Experimental Details

Alstom typhoon gas turbine is a kind of utility in our plant. In addition, it has an important role in process. Therefore it is somewhat most critical equipment. TWF, FFT, orbit and phase analysis all are important factors in gas turbine vibration analysis. In this part, the vibration monitoring system of this gas turbine and all key important elements in gas turbine vibration analysis explained in details.

The gas turbine equipped with bently Nevada online monitoring system. The system based on non-contact probe that monitoring the shaft vibration usually in micrometer peak to peak. The overall vibration has some limit standard that adjusts for alert and danger condition. In fair condition (passing the alert limit), the alarm lamp will indicate close monitoring condition and by passing danger limit the gas turbine will trip to prevent harmful damages in machine.

The bently Nevada main board equipped with some bently Nevada connections for mentioned data collectors like Easy Viber that help us to monitor FFT, TWF, and phase values. The system also equipped with overall vibration monitoring in process system. In addition, Process conditions like inlet and outlet pressures and temperatures monitored in these kinds of systems.

Fig. 15 Typical board monitoring system

Fig. 16 Typical none contact probe

International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:7, No:11, 2013

Fig. 17 Bently Nevada connection board 3500 series machinery monitoring system

Furthermore, Wireless condition monitoring system developed in recent years for most critical equipment like gas turbines. The advantages of these kinds of systems are reducing the role of special tools installation errors. In addition, the accuracy and speed of this kind of monitoring system is much better than conventional portable systems.

The disadvantages of these kinds of systems are high cost of them. Nowadays TWF vibration analysis plays a big role in preventive maintenance especially in most critical equipment like gas turbines [6].

In this stage basic principal of TWF vibration analysis explained. The time wave form analysis usually complex in industrial equipment but sometimes have some simple academic shapes that could easily represented some main faults in machines. Otherwise, we should compare these kinds of graphs with machine history and compare the changes accurately by different cursors and facilities in nowadays softwares.

There is some limitation in FFT analysis. In such cases TWF analysis will help a lot. The TWF analysis should be effective in some fields like, Low speed applications (less than 100 RPM), Indication of true amplitude in situations where impacts occur such as assessment of rolling element bearing defect severity, gears, sleeve bearing machines with X-Y probes (2 channel orbit analysis), looseness, rubs and beats. As we can see, many of these faults usually occur in gas turbines and other most critical equipment like rub, looseness and sleeve bearing problems. For time waveform analysis it is recommended that 1600 lines (4096 samples are used). This ensures that the data collected has sufficient accuracy and key events are captured. Here are some academic TWF samples usually useful in most critical equipment.

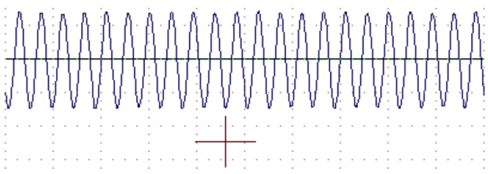

Fig. 18 Unbalance rotor TWF

There are three conditions that must be presented simultaneously to representing unbalance rotor. TWF should be have sine waveform, FFT must be mostly in 1X and all direction overall vibration should be high. Besides, 90 shift phase between horizontal and vertical or bently Nevada direction should be presented.

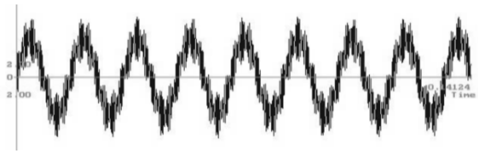

Fig. 19 High frequency TWF

High frequency TWF can represent roller bearing or gear faults in centrifugal pumps or gearboxes. In most critical equipment it should be due to some process abnormality impact in compressor.

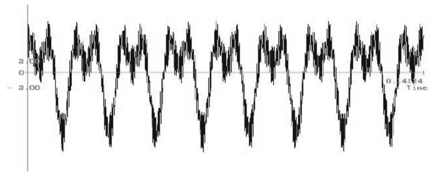

Fig. 20 Classical misalignment TWF

Classical MW shape TWF can represent misalignment in any industrial equipment. Typical rotors rub TWF illustrated in Fig 21.

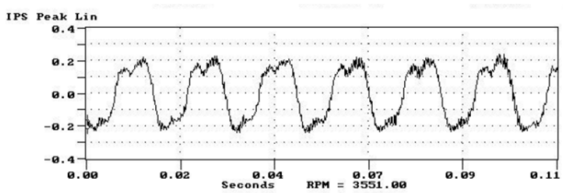

Fig. 21 Typical classic rotor rubs TWF

Beats and Modulation effects can represent some process problem mixed with some ordinary or abnormal mechanical frequency and it is usually hard to diagnosis in most critical equipment.

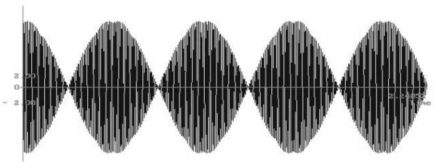

Fig. 22 Typical classic Beats & Modulation effects in TWF

Random impacts can representing in TWF, related FFT, and usually caused by some process abnormality in gas turbines and other most critical equipment [7].

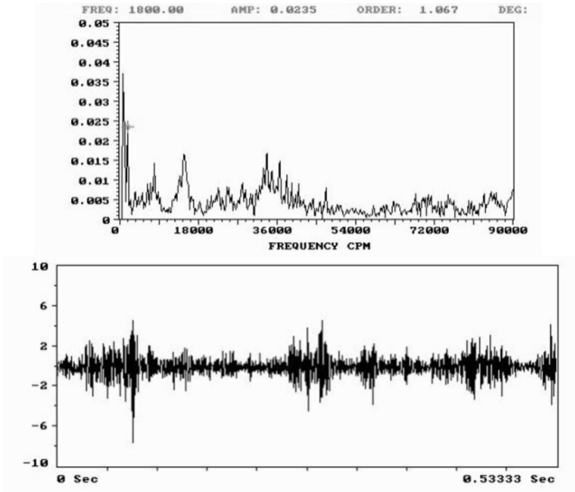

Fig. 23 Typical classic random impacts FFT and TWF

The orbit is combination of two TWF in different direction usually two main bently Nevada direction in most critical equipment and can represented the motion of shaft in such equipment like gas turbines. That is why orbit analysis can help us a lot in such equipment vibration analysis. Especially, when we have a good bank of TWF data and can obtain previous history of shaft orbits and compare them with new machine condition. Phase analysis is one of the other key factors in distinguishing real faults of machine. It could help us by triggering (usually) 1X frequency.

TWF obtain by a key phasor and related reflector system on main shafts. in none critical equipment it can help us a lot to distinguish between the 1X faults in FFT like unbalance, soft foot, bent shaft, and misalignment. Beside this it is the key factor to diagnosis the high low flange and also mechanical looseness.

In most critical equipment phase analysis is a key element especially in run up, coast down and bode diagrams that all base on phase elements and help us a lot to realizing the gas turbine or any other most critical equipment condition.

These kinds of techniques will help us in some complex fault diagnosis process like shaft crack in most critical equipment. Misalignment could also detect by this method properly. Unbalance could be in different parts like main rotor or coupling. The coupling unbalance is more difficult to diagnosis because of interfere the misalignment characteristic with unbalance characteristic in both TWF and FFT. The phase analysis could help us a lot in these kinds of conditions to distinguish between these two main coupling faults [8].

Shaft crack also considered as one of important faults in all most critical equipment and gas turbines. This fault is usually hard to diagnosis. Shaft crack may be longitudinal or radial and it may have some microscopic dimensions. In such cases none contact probe may detect wrong or fake data, alert, trip, TWF and orbit. This kind of crack will disappear by metal spray in maintenance activities [9].

Process parameters of all most critical equipment always play an important role in vibration analysis.

Nowadays many methods developed in modeling processing condition of such equipment. Systematic analysis of two-stage, axial flow turbine by using of different losses models and a new suggested algorithm based on one-dimensional simulation developed in recent years.

The suggested method is found to be effective, fast and stable, in obtaining performance characteristics of multi-stage axial flow turbines. In one-dimensional modeling, mass flow rate, pressure ratio and efficiency are unknown, with define turbine geometry, inlet total pressure and temperature the turbine performance characteristics can be modeled. This modeling is based on common thermodynamics and aerodynamics principles in a mean streamline analysis under steady state condition [10].

Many vibration environments are not related to a specific driving frequency and may have input from multiple sources which may not be harmonically related. Examples may be excited from turbulent flow as in airflow over a wing or past a car body, or acoustic input from jet engine exhaust, wheels running over a road, etc.

With these types of vibration, it may be more accurate, or interested to analyze and tested using random vibration. Unlike sinusoidal vibration, acceleration, velocity and displacement are not directly related by any specific frequency. Of primary concern in random testing is the complete spectral content of the vibration being measured or generated.

Most random vibration testing is conducted using Gaussian random suppositions for both measurement and specification purposes. With Gaussian assumptions, there is no definable maximum amplitude and the amplitude levels are measured in RMS (root-mean-squared) values.

On the other hand in low frequency applications like reciprocating compressor data usually measured by peak to peak .the on line monitoring rod drop system also available for such most critical equipment. In addition, vibration analysis could be extremely useful for mechanical part of electro motor or generators fault diagnosis (like all kind of bearings or gear couplings) [11].

The machine foundation condition is also one of the basic principal in preventive maintenance as well as machine installation. There are two kind of machine foundation, flexible and rigid. Type of foundation has a direct role in vibration standard of machines. Soft foot, mechanical looseness and foundation problem could diagnose by phase analysis in preventive maintenance.

Nowadays some kind of data collector and related softwares developed for vibration modal analysis that could help us a lot in foundation problem diagnosis (like VDAU-6000 condition monitoring system).

The foundation design techniques also developed too much in recent years. Damping is a complex phenomenon, which acts in the form of absorption and dissipation of the energy in the vibrational systems. Different factors effect on the damping such as type of joints in the connections.

In addition, more effective and efficient shock absorber designed in recent years that reduced the machine vibrations especially in some critical location like air-cooling and cooling tower fans [12].

Also the effect of different machine and process parameter on the main rotor or shaft natural frequency of all most critical equipment widely investigated in recent years and nowadays we have better understanding of such matters in most critical equipment. Such fault diagnosis usually more effective in startup and shut down machine trend parameter (Coast down and run up characteristics or bode diagram) [13].

III. Results and Discussion

All gas turbines utility systems consist of five main parts, basic gas turbine, air compressor, air preheater, combustion chamber and generator. Inlet and outlet pressure and temperature considered as main critical process parameter in all gas turbine systems [14].

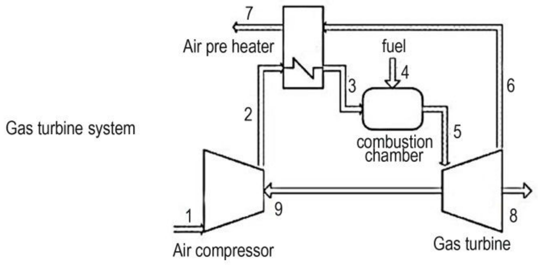

Fig. 24 Gas turbine system

In this part, the case history related to a gas turbine Alstom typhoon in Iran oil industries explained. All critical process parameter trends was on the range of technical document of gas turbine and in normal condition .The overall vibration data on bently Nevada main board increased too much but not overflowing the vibration ranges. The arrow showed the direction of this increasing in bently Nevada panel at Sunday, July 8, 2012.

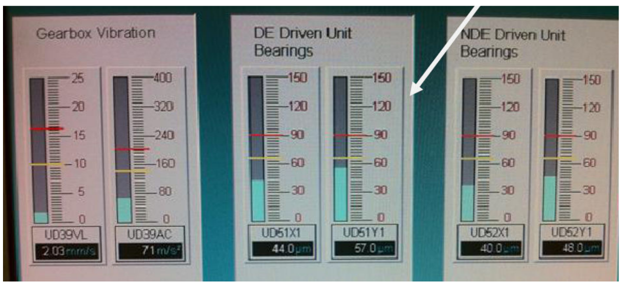

Fig. 25 Bently Nevada panel before vibration analysis process

The TWF and related orbit of NDE driven unit bearings showed that there are some rub in this point and the oil samples should be analyzed. The oil analysis report confirmed the phenomena (rotor rubs). Therefore, it was strongly recommended to check the bearing clearances in this point.

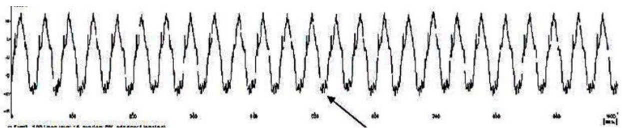

Fig. 26 Regular periodic rubs in NDE driven unit bearings

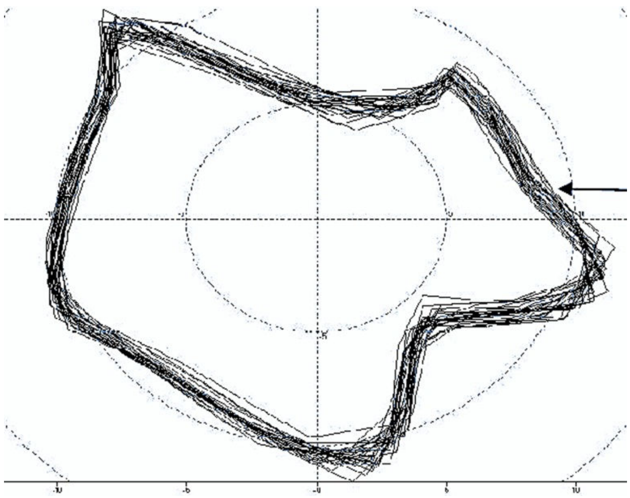

Fig. 27 Rub in NDE driven unit bearings orbit

In addition, drive end unit bearings TWF and FFT represented the dynamic unbalance in this point (comparative to previous TWF and FFT in this location).

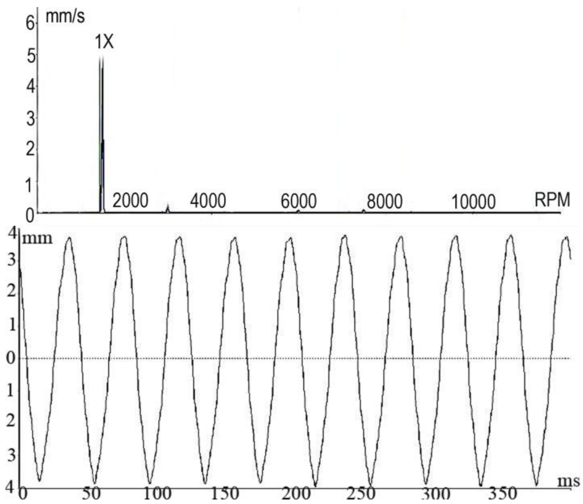

Fig. 28 Drive end unit bearings TWF and FFT

Therefore, dynamic balance process recommended after applying static balance. This kind of field balance process consist of accurate, time consuming and critical try and error balancing activities by adding suitable balancing weights in correct directions in panel 2.

Fig. 29 Balancing weights positions (dynamic balancing panel-panel 2)

After balancing process and check the bearing, clearances the overall vibration, decreased considerably specially in unbalance point. The vibration amounts reduced to previous status and the vibration analysis was successful.

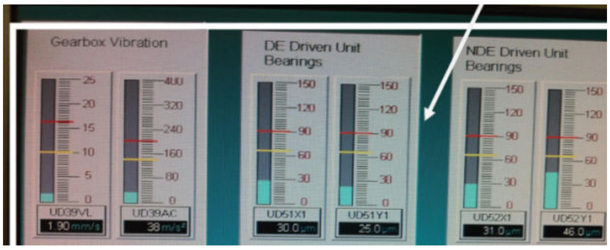

Fig. 30 Bently Nevada panel after balancing process

IV. Current and Future Development

In gas turbine vibration analysis, we should have good monitoring data bank like overall vibration, FFT, TWF, orbit and phase values. By comparing the data, we can achieve the optimum recommendation in this matter. It is also important to have a suitable understanding of process conditions like inlet and outlet pressure and temperatures and their allowable limits to analysis some aspect of TWF behaviors.

The mechanical unbalance could be one of the basic causes of increasing both related and absolute vibration of gas turbines. This fault could be detected by sine wave form of TWF and 90-degree shift phase between two main directions of none contact probes related to overall vibration phase values. It is worthy to know that both directions should have considerably high amount of overall vibration in turbine rotor frequency.

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