MECHANICAL VIBRATION MONITORING AS A MODERN MAINTENANCE TECHNOLOGY FOR MACHINES

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ABSTRACT

Mechanical vibration monitoring technology is a vibration based monitoring of faith from gas turbine rotor shafts. The paper highlights vibration monitoring technology, vibration monitoring techniques, vibration analysis, Dynamics of bean vibration theory and monitoring instruments fitted on test engine. A conclusion drawn that vibration amplitude on bearing along a rotor shaft depends on the distance of the bearing from the load end of the shaft which is taken as the reference point, and that the size and location of a crack from the reference axis are proportioned to the magnitude of the vibration amplitude. The reseaches therefore recommended that some environmental factors should be considered while carrying out vibration based simulation of gas turbine rotor shafts and artificial neural networks developed to validate modelling in rotor shaft defeats should be given more attention.

Keywords: Vibration, monitoring, vibration monitoring, technology, Analytical monitoring.

1. INTRODUCTION

Mechanical vibration monitoring technology is a modern maintenance to gas turbine as adopted by many engineers today. Shock pulse monitoring is of particular significance in the detection of faults in bearing fitted to rotating components and it is frequency used in vibration monitoring. According to Bob-Manuel (2014) gas turbines are increasingly used for various applications such as power generation, aircraft and ship propulsion, operation of pumps, compressors etc of the various means of producing mechanical energy, the turbine plant is in many respects one of the most satisfactory means. Lubricating oil consumption is also exceptionally low in gas turbines. Therefore, reliability and optimum performance could be high due to reduction of balancing problems and low lubrication oil consumption.

Vibration Monitoring is a very important aspect of this proactive and predictive maintenance philosophy (case ville 2000). It is generally defined as the process of using early warning signals in the machinery operation and maintenance to detect likely deterioration that could lead to a breakdown without stopping the machine. Vibration monitoring involves the process of carrying out measurements and analysis of equipment conditions for the purpose of detecting and diagnosing incipient machine faults and scheduling properly planned stoppages for maintenance before an engine breaks down without opening it. The policies of maintenance have graduated from the breakdown policy through the preventive or scheduled/planned maintenance to the latest preferred optimal maintenance strategy. The optimal maintenance option is proactive and its adoption has prevented machinery from catastrophic future and unexpected down time. It combines the advantages of the repair only (breakdown) policy and those of preventive maintenance philosophy. The significance of mechanical vibration monitoring cannot be over emphasized in modern day maintenance technology. Condition monitoring is done in parallel with planned maintenance and performance monitoring offers the potential for an increased level of confidence in machinery health assessment in comparison with the traditional method of inspection. The major causes mechanical vibration are misalignment in shafts, power or rotational imbalance, cracks and eccentricity in rotating shafts. Other causes include faulty design of machine parts, manufacturing faults, improper assembly and deterioration of machine components in service. These defects often emanates from unbalance forces that cause vibration. Also, mechanical defects and excessive torsional loading lead to vibration and it is allowed to increase beyond acceptable unit limit, it could lead to catastrophic damages. The paper therefore assess vibration monitoring techniques, vibration analysis and others.

2. VIBRATION MONITORING

An overview

The application of vibration methods allow maintenance to be related directly to the general health of machines and systems. Conceptualizing the concept of vibration monitoring according to Engineers is the planned maintenance technique which allows for measurement and comparison to be made with an earlier or base measurement also called "Finger print". This started as traditional methods of feel/touch, hearing, and use of screw driver on the bearing house

or standing a coin on its edge (Tarbet, 2001) Vibration is much more pronounced on marine equipment on board ships due to the adverse effects of sea waves, yaw, rolling and pitching of the hull which carries engines. Also the harsh environment conditions where ship machines operates, affect the accuracy and performance of vibration monitoring sensors. It is equally envisaged that gas turbine would be the propulsion of engine of choice in future due to its advantages. The gas turbine engine is made up of several complex components. The rotor shaft is one of the most important parts. Break down starts there, it often suffer breakdowns that can be traced to the rotor shafts. Such breakdowns include misalignment, imbalance, crack and eccentricity. It starts from the free end of the engine where a turning motor is filled and extend down to the load and carries all the rows of blades on the compressor and turbine sections. In most designs, sleeves, couplings and gears for the gear boxes are integral parts of the rotor shafts.Vibrations from these components are pronounced, hence there is need for a study of vibration monitoring of gas turbine rotor shaft to apply optimum maintenance policy.

3. VIBRATION MONITORING TECHNOLOGY

Vibration monitoring occupies a very prominent place in predictive (optimum) maintenance policy (sawyer, 1980). It is one of the best prognostic methods currently in use for engine maintenance. Measurements of vibration can be taken on rotating machine bearing casings with seismic or piezo-electric transducers to measure the casing vibrations, and on the vast majority of critical machines, with eddy-current transducers that directly observe the rotating shafts to measure the radial (axial) vibration of the shaft. The level of vibration can be compared to baseline values obtained during standard load changes, to assess the severity. Interpreting vibration signal obtained is a complex process that requires specialized training and experience. One commonly employed technique is to examine the individual frequencies present in the signal. These frequencies correspond to certain mechanical components or certain malfunctions (such as shaft unbalance or misalignment). By examining these frequencies and their harmonics; the location and type of problem can be identified.

4. VIBRATION MONITORING TECHNIQUES

The techniques for vibration monitoring used to be the dynamic monitoring and signature analysis technique which involves the translation of the contents of a vibration spectrum in frequency or time domain, hence, most vibrations in rotating systems are detected by this method. Brinellings in ball and roller bearings can also be detected in their early stages of failure using this analysis. The analytical method is used in power generating plants and fluid valves that generate their own signatures as well as vibration-based faults diagnosis of gas turbine shaft. Hence, signal analysis technique was adopted in this project. Vibration measuring precepts reveal that raw signal in any mode from a single points on a machine is not a good indicator of the health of the system or plant. Since vibration acts in three dimensional vectors; it requires to be measured at several carefully selected points and directions. The signal is placed into basic components which made up the complex raw wave form. Vibration data of rotating systems are therefore acquired from axial; horizontal and vertical positions of bearing housing before they can be meaningfully analysed.

5. VIBRATION ANALYSIS METHODS

Vibration analysis involves the process of sensed vibration signal in displaced velocity or acceleration amplitude.

 Vibration analysis methods can be divided into two broad categories shown in figure 1:1
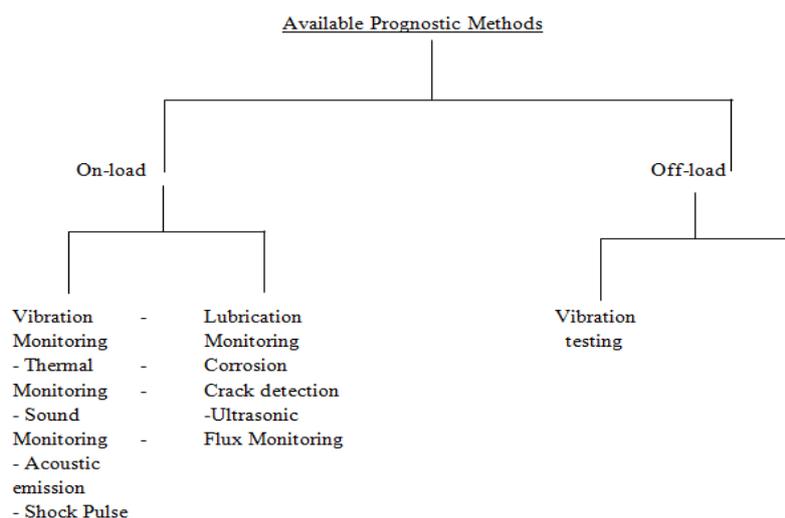

Figure 1:1: Condition Monitoring Methods and groups.

Tero – technology system generally describes a combination of management systems and communication channels which provides support for maintenance through vibration signal analysis. Vibration analysis involves the process of sensed vibration signal in displacement velocity or acceleration amplitude.

6. GENERAL SURVEYS ON MECHANICAL VIBRATION BASED FAULTS DIAGNOSIS

The analysis of vibration signatures have been used to solve some industrial problems on active systems. This includes ways of diagnosing the causes of mechanical vibrations and the methods of preventing them. The studies were simply based on the use of signature analysis technique without being analytical or computer-based in solving vibration problems. Dynamic vibration monitoring technique can also be used to solve mechanical problems. For this method which is now obsolete, the measurement is taken in form of noise waves in decibel and therefore can be converted to vibration signal in mm/sec as the case may be. There are now many modern instruments and techniques for acquiring and analyzing vibration signal.

7. FAULT ANALYSIS IN ROTATING MACHINES

The operational efficiency and low maintenance cost of rotating machines are crucial design requirements in today's complex rotor dynamics. Hence, there is need for innovative health monitoring and diagnostic schemes instead of the use of crisis management from design to operational stages. The most imminent faults in rotor shafts of gas turbines are crack which results from, eccentricity, bow and bends, misalignment; whirl and journal bearing defects resulting to mass imbalance. These faults pose the most frequent causes of engine failure; hence early detection is highly desirable for gas turbine diagnostic and prognostic systems. Though potentially critical for the engines' health, these faults are seldom detectable through changes in thermal behavior of an engine. This section is therefore devoted to analyzing gas turbine rotor shaft faults and proffering solution to identified faults. Several empirical approaches in faults diagnosis of rotating machinery are based on the analysis of vibration signals. These include spectral analysis, orbit diagrams, complexity indices and more recently neutral networks, beam theory and fuzzy logic. Vibration signals pose a key challenge to classical signal processing due to the non-stationary nature of their spectrums. Recently, digital signal processing algorithms such as Fast Fourier. Transform (FFT), Artificial Neural Networks (ANN), Newton's 2nd law and Torsional Vibration Analysis (TVA) were considered as promising tools in the vibration based analysis of gas turbines rotor shafts. These techniques were therefore considered mainly in the areas of misalignment, mass imbalance, whirl bowed and cracked shafts, which are most imminent rotor-dynamic problems. Hence, effective on-line model-based monitoring and diagnostic algorithm were used in this work. The theoretical analysis was based on algorithm for signal processing and parameter identification.

8. DYNAMICS OF BEAM VIBRATION THEORY

Uniform beams are usually classified according to the type of support or boundary layer conditions at the ends. An in-depth knowledge of beams vibration characteristics provides the basis for their dynamic analysis. knowledge of the differential equations of motion for beam vibrations and boundary conditions enables one to calculate the natural frequencies of a rotating shaft. The analytical treatments of ideal beam give a valuable starting point to understand the behavior beam vibrations.
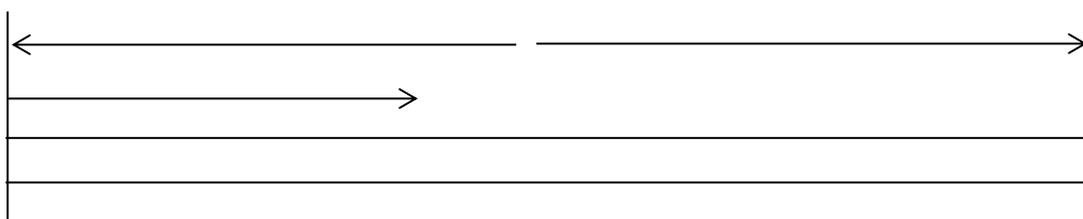

Figure 2:1 Classical analysis of an ideal beam in the analysis of a beam shown in the figure 2:1, the differential equations of motion for the lateral vibration is expressed as:

$$\frac{d^4y}{dx^4} - B^4Y = 0$$

Where $B = \sqrt[4]{\dfrac{Nar^2}{gEI}}$

N = weight of beam per unit length = YA; kg/m

L = length of beam (cm)

Y=Density of material, $N/m3$

A=Area, m^2

F= Frequency, rad/s

E= Young's modules of elastically, N/m2

I= Moment of inertia, m^4

The solution of equation for its natural frequency is expressed as;

$$f = \frac{B^2}{2\pi}\sqrt{\frac{}{N}} \qquad \beta^2 = \frac{}{L^2}$$

If $= 2 = B^2 L^2$

Than f $=$

$$\frac{2}{2\pi}\sqrt{\frac{8EL}{NL4}}$$

By substituting in material properties for steel which is

$E = 207 \times 10^3 MP_a$ and $Y = 76850 N/M^2$ in equal the frequency becomes

$f = 8182 K/L^2$

Where

K = radius of gyration, mm

L = length, m

The frequency factor 2 is also a constant and depends on the types of boundary condition and mode shape. The faults that can manifest in beams of this type are bends; bows and run-outs. When such beams exist as rotors of gas turbines, then torsional vibration may also easily manifest during rotation.

9. ROTOR – STATOR RUB DYNAMICS

Newton's law, the model for contact forces (Hetzian), and adoption of an appropriate mathematical model can be used to instigate dynamics of rotor or blade casing systems. Dynamical behavior of rotating machines during rub interaction is expressed as;

$$M \frac{}{r_m} = m + \frac{}{r_a} = G + R + Fn$$
$$r_B$$

Where M = Mass of rotor, Kg r_m

G = Gravity, M^2/S

T = Linear restoring force on beaming; kg/m2

The cross section of the rotor was modeled with two generalized coordinates. The disk was translated in the X and Y directions and rotates around z – direction.

A pair of ODEs that evolved from such a motion as shown in equation is scaled and simplified as:

$..X + 2C_2 \, x + x = - \{K:8^u(\cos(10) - \mu S \, Sin0)\}$

$+ Ear2 \, cos0r\}$

$.Y + 2 Sy + x = - \{K8^m (\sin 0 - urcos (-)) + Ear^2 co(+)G$

Where X = Acceleration in x – direction

Y = Acceleration in Y – direction

X = Velocity in x – direction

Y = Velocity in y - direction

X = Displacement in X – direction

Y = Displacement in y – direction

= Dimensionless damping

KB = stiffness constant for Hertzian Contact force

N = Coefficient of coulomb friction

E = Eccentricity ration

G = Dimensionless gravity

C = Deformation exponent for Herten contact force

$(1 \leq a \leq 2)$

(f) = Dimensionless rotational speed

β = Dimensionless constant which depends on shaft stiffness and Hertzian contact force

$ = Dimensionless constant which depends on rotor velocity at impact point = velocity of rotor at impact point, m/s<g (s) if 8>O:

= shear stress. The imbalance rub – impact faults were modeled as changes in the parameters - $\xi K \beta_2 \mu s E$, and G which in turn caused the dynamic behavior of the states, X and Y to changes moving from one operating regime to another linear, period doubting, quasi-periodic, or chaotic. This type of fault would generally lead to beaning misalignment, imbalance in shaft axis and thus excessive vibration which could result to bending and bowing of shaft. Rotor stator dynamics often manifest in form of mass and/or rotational imbalance which results from misalignment of shafts.

10. CONCLUSION AND RECOMMENDATIONS

The paper so for discussed the mechanical vibration monitoring as a modern day maintenance technology for gas turbine machine in which the instruments fitted on the gas turbine for the monitoring of the various performance parameters including speed and combustion monitoring sensors, pressure and differential pressure transmitters, igniters, flame detector and thermocouples, inlet-guide vane control and gas control valve protectors, vibration sensor/pickups and protectors and temperature control sensor and protectors. The trajectories of vibration wave forms from some turbine stations can manifest from the operations of gas turbines especially when there is a defect. The conclusion on vibration amplitude on bearings along a rotor shaft depends on the distance of the bearing from the load end of the shaft which is taken as the reference. The longer the distance of the bearing is from the reference point, the higher the amplitude of vibration, the size and the location of a crack from the reference axis are proportional to the magnitude of the vibration amplitude. The following recommendations are proffered as solutions to mechanical vibration in gas turbine machines including the artificial neural networks developed to validate modeling in rotor shaft defects should be given more attention, then some environmental factors should be considered while carrying out vibration-based simulation of gas turbine rotor shafts and further studies in the areas of provision of easier programming technique and simulation of the crack curve should be carried out on the proposed crack curve so that it could be used universally and implemented wisely.

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