Mechanical Vibration Monitoring as a Maintenance of Industrial Engine: The Case of Gas Turbines

Sibete Godfrey Ayeabu [1*], Okachi Ikegwuru Ibezimakor [2], Uchendu Imereoma Frank [3]
[1] Department of Mechanical Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria
[2] Department of Mechanical Engineering, Rivers State University, Rivers State, Nigeria
[3] Department of Mechanical Engineering, Rivers State University, Rivers State, Nigeria

* Corresponding Author: **Sibete Godfrey Ayeabu**

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Abstract
Mechanical Vibration Monitoring as a maintenance of industrial engine: The case of gas turbine. The paper therefore conceptualizes vibration monitoring, vibration monitoring technology. It also outlines the causes of mechanical vibration, normal vibration monitoring methods, mechanical vibration monitoring techniques, general surveys on vibration-based fault diagnosis monitoring instruments fitted on test engine. Thus, the paper treats dynamics of beam vibration theory with illustration. The study therefore concluded with useful and meaningful conclusions and recommendations.

Keywords: Vibration monitoring, Mechanical vibration technology, Normal vibration methods, Mechanical vibration monitoring techniques

Introduction

Vibration monitoring is a very important aspect of proactive and predictive maintenance philosophy to Gas turbines. 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 lubricating oil consumption.

The 150,000 GRT vessel using combined diesel and gas (CODAG) is propelled by 2 X GELM 2500 gas turbine rotor shaft and 4 X Wartsila 1646C diesel engines, which give a total power output of 118MW. Hence, the need to establish a viable maintenance policy for gas turbines is one of the goals of this study.

The maintenance policies of industrial machines or engines 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 failure and unexpected downtime. It actually combines the benefits of the repair only breakdown policy and those of preventive maintenance philosophy.

Vibration monitoring, being the planned maintenance technology allows for measurement and comparison to be made with an earlier or foundation or base measurement also called “finger print”. This started as traditional methods of feel or touch, hearing and use of screwdriver on the bearing housing or standing a coin on its edge. Vibration is much more found on marine equipment on board ship due to the adverse effects of sea waves, yaw, rolling and pitching of the hull which carries the engines, also the volatile sea where ships operate affect the accuracy and performance of vibration monitoring censors. Equally vibration can be seen in vehicle engines as it waddles perhaps in motion as the motor driver drives on the road.

The gas turbine engine is made up of several complex components. The rotor shaft is one of the most important parts. It starts from the free end of the engine where a turning motor is fitted and extends down to the load end and carries all the rows of blades on the compressor and turbine sections. In most turbine designs, sleeves, couplings and gear for the gear box are integral parts of the rotor shafts.

Arising from the study, vibrations from the components are pronounced, hence, there is need for a study of vibration monitoring of gas turbine rotor shaft to apply optimum maintenance policy as a strategy for prevention of the gas turbines.

Literature Review

In this section of the study, related literatures will be reviewed such as vibration monitoring and other related issues.

- **Vibration Monitoring**

The concept of "vibration monitoring" is generally defined as the process of using early warning signals in machinery operation and maintenance to detect likely deterioration that could lead to a breakdown without stopping the machine.

It otherwise 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 breakdown without operating it.

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. Furthermore, the practice of vibration monitoring methods allows maintenance to be related directly to the general health of machines and systems.

- **Vibration Monitoring Technology**

It is one of the best prognostic methods currently in use for engine maintenance. Measurement of vibration can be taken on rotation machine, bearing casings with seismic or piezo-electric transducers to measure the casing vibrations and critical machines with eddy-current transducers that directly observe the rotating shafts to measure the radical (and axial) vibration of the shaft. The level of vibration can be compared to baseline values obtained during standards during 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 harmonies, the location and type of problem can be identified. Vibration analysis methods can be divided into two broad categories shown in figure 1.

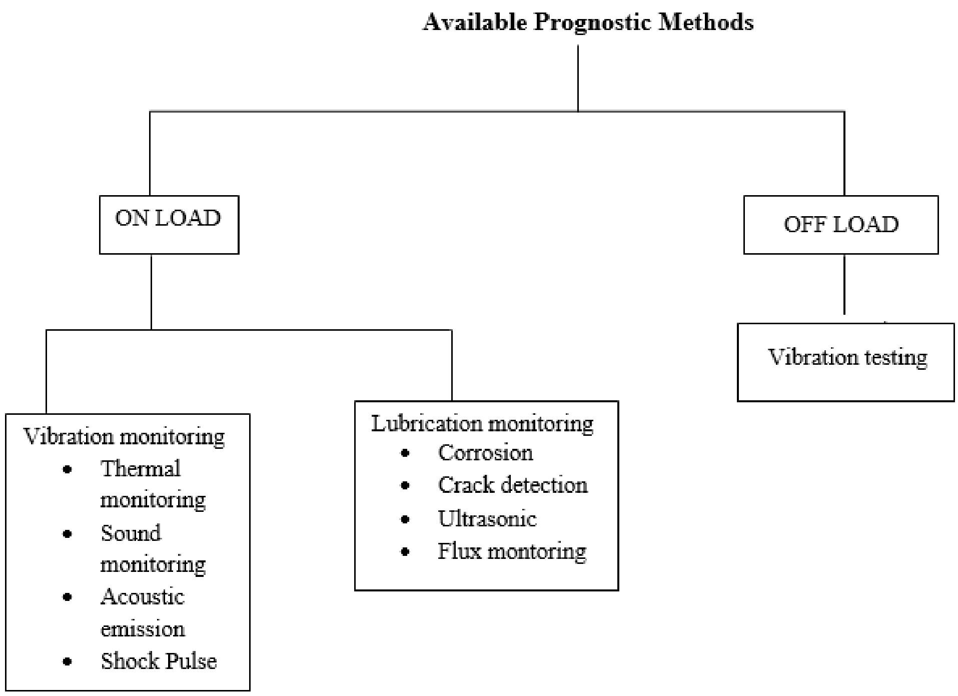

Fig 1: Condition Monitoring methods and their groups

Tero-technology system generally describes a combination of management system and communication channels which provide support for maintenance through vibration signal analysis. Typical contributions include:

- Techniques which reduce downtime.
- Personnel selection and training programmes for operating and maintenance personnel.

Causes of Mechanical Vibration

The major causes of mechanical vibration are misalignment in shafts, others include:

- Power or rotational imbalance.
- Cracks and eccentricity in rotating shafts.
- Faulty design of machine parts.
- Manufacturing faults.
- Improper assembly and deterioration of machine components in service.

These defects often emanate from unbalanced forces that cause vibrations. Also, mechanical defects and excessive torsional loading lead to vibration and if it is allowed to increase beyond acceptable limit, it could lead to catastrophic damages.

Normal Vibration Monitoring Methods

Some of the normal vibration monitoring methods include signal sensing, vibration analysis and discrete frequency analysis and each of these methods is normally used in sequence.

a) Signal sensing method: This method involves the processing of vibration signal using either accelerometers or velocity transducers.
b) Vibration analysis on the other hand involves the processing of sensed vibration signal in displacement, velocity or acceleration amplitude.

In some investigations, it was reported that journal bearing movement could adequately be monitored by means of two proximity sensors to the control computer monitor such that shaft eccentricity can be recorded. Vibration limits for various classes of machines have already been established in the German VDI specification 2056 and general machinery vibration severity chart.

- **Mechanical Vibration Monitoring Techniques**

The techniques for mechanical vibration monitoring used to be the dynamic monitoring and signature analysis technique which involves the translation of the contents of vibration spectrum in frequency or time domain, hence, most vibrations in rotating systems are detected by this method.
This 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 turbines shafts. Hence, signal analysis technique was adopted in this project.
Vibration measuring precepts reveal that raw signals in any mode from a signal point on a machine is not a good indicator of the health of the system or plants. 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 make up the complex raw wave from.
Vibration data of rotating systems are therefore acquired from axial, horizontal and vertical positions of bearing housing before they can be meaningfully analyzed.

General Survey on Vibration-Based Fault Diagnosis

The analysis of vibration signatories has been used to solve 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 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 decibels 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 signals.

Monitor Instruments Fitted on Test Engines

Some instruments fitted on the gas turbine for the monitoring of various performance parameters are as follows.

- Speed and combustion monitoring sponsors.
- Pressure and differential pressure transmitters
- Igniters, flame detector and thermocouples.
- Inlet guide vane control and gas control vane protectors.
- Vibration sensor/pickups and protectors.
- Temperature control sensor and protectors.

In this work on modeling of vibration-based faults in rotor shafts of gas turbine effort was also made in the description of instruments for monitoring and speed sensors.

Dynamic of Beam Vibration Theory

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

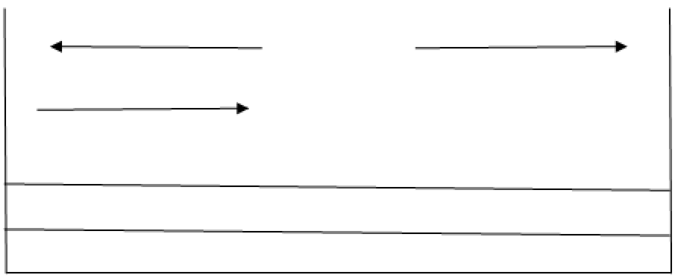

Fig 2: Classical Analysis of an ideal beam

In the analysis of a beam shown in figure 1, the differential equation of motion for the lateral vibration is expressed as:

$$\frac{d4y}{dx4} = \beta 4y = 0 \quad (2.1)$$

$$\text{Where } \beta = \frac{{}^{4}\sqrt{\mu m2}}{gE1} \quad (2.2)$$

μ = Weight of beam per unit length= A, Kg/m
L = Length of beam (m)
Y = Density of material, N/m^3
A = Area, m^2
W = Frequency, rad/s
E = Young’s modulus of elasticity, N/m^2
I = Moment of inertia, m^4

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

$$F = \frac{\beta}{2\pi}\sqrt{\frac{gE1}{\mu}}\beta^2 = \frac{\lambda}{L^2} \quad (2.3)$$

$$\text{If } \lambda = B^2L^2 \quad (2.4)$$

$$\text{Then: } F = \frac{\lambda}{2\pi}\sqrt{\frac{gE1}{\mu L^4}} \quad (2.5)$$

By substituting in the material properties for steel which is E = 207 X 10^3mpa and y = 76850N/m^3 in equation (1.5) the frequency becomes.

$$F = .818\,\lambda/L^2 \tag{2.6}$$

Where
K = Radius of gyration, mm
L = Length, m

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

Conclusion

The conclusions are presented as follows

- 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 point. The longer the distance of the bearing is from the reference point, the higher the amplitude of vibration.
- The size and location of a crack from the reference axis are proportional to magnitude of the vibration amplitude.
- By means of measured vibration amplitude and the fundamental natural frequency of rotor shafts, it is possible to determine the approximate likely position of a crack along the rotor shaft for prognosis and diagnosis in plant maintenance.
- An acceptable combination of continuous online vibration monitoring, wave form/spectral analysis, adaptive modeling, torsional vibration analysis and artificial neutral networks in form of integrated vibration monitoring system to protect the gas turbine engine from downtime are presented.

Recommendations

The recommendations are as follows

- Further studies in the areas of easier programming technique and stimulation of the crack curve should be carried out on the proposed crack curve so that it could be used universally.
- The artificial neutral networks developed to validate modeling in rotor shaft defects should be given more attention.

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