Vibration Analysis of a Constant Speed and Constant Pitch Wind Turbine

T. Sunder Selwyn and R. Kesavan

Abstract In order to increase the reliability of the rotating machineries like rotor, gear box, high speed shaft, low speed shaft, generator, and yaw of wind turbine (WT), it is important to monitor the vibration level. The key aim of the paper is to study the vibration characteristics experienced in the 400 kW WT at different load and operating conditions. The experimental vibration analysis of WT components is done and vibration characteristic curves are generated with the help of data acquisition software. These vibration characteristic curves are studied and observations made from them for their severity and effects are analyzed. Some indispensable recommendations have been given for vibration control.

1 Introduction

While fossil fuels are the main fuels for thermal power, there is fear that they will get exhausted eventually in this century. Therefore, we are in need to harvest any other renewable resources. In the continuous search of clean, safe, and renewable energy sources, wind power has emerged as one of the most attractive solutions. Wind turbine (WT) offers a cost-effective alternate renewal energy source. Modern WTs are of slender and elastic construction, above all the rotor blades and the tower. They are, therefore, structures which are extremely prone to vibration. In addition, there is no lack of excitations as the discussion of cyclically alternating rotor forces has shown. These forces can excite certain subsystems or even the entire turbine to vibrate dangerously. The vibration of WT components such as gearbox, generator, nacelle, high speed shaft, low speed shaft, tower, and nacelle

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affect the dynamic stability of the complete system by causing excessive stress and fatigue. The main objectives of this paper are to analyze the vibration characteristic experienced in the gear box, bearing, yaw drive, low speed shaft, high speed shaft, and generator of a WT at different load and operating conditions. The rotor system, generator system, and gear box system which are connected in series, have less Failure Criticality Index but they do cause large downtime and replacement costs [1]. It is generally suggested that the manufacturer should provide a good logistical support and maintain spares of blade, gear, and generator at nearby sites. It is clearly understood that if the yaw system fails, then the electricity generation will be reduced as the yaw system is connected parallel to the entire system.

2 Literature Review

Li [2] stated that there are many types of techniques available for condition monitoring such as vibration analysis, oil analysis, thermography, strain measurements, visual inspection, and self diagnostic sensors but out of all those methods vibration analysis is most preferable in CM because the results obtained at the end of vibration analysis give a definite pattern of vibration spectrum of different parts. Yang et al. [3] investigated condition monitoring and fault diagnosis techniques used in this paper for a WT with a synchronous generator. First, a new condition monitoring technique was proposed based on the phenomena observed in a series of torque-speed experiments. Then, the proposed technique was verified by detecting generator winding and rotor imbalance faults, and investigated a WT mechanical fault by power signal analysis with the aid of the continuous wavelet transforms (CWT). They concluded from their investigations that it was possible, using wind velocity and power transducers, to develop a simple and cheap WT condition monitoring and fault diagnosis system, without resorting to costly vibro-acoustic transducers.

Quan et al. [4] profess "In order to study dynamic characteristics and vibration response of gear system of WT mathematical modeling of gear box by taking into account different parameters like moment of inertia, torsional damp coefficient, torsional stiffness coefficient and the mass of the system is done. The mathematical modeling provides clear information over governing equation of vibration for the system". Hau [5] articulates that the components for total vibration of WTs, the structural dynamic considerations, and the design parameters due to which vibration occur. McMillan and Ault [6] point up that the levels of benefits are dependent on a variety of factors including wind profile, typical downtime duration, and WT subcomponent replacement cost. Cruden et al. [7] avow that there are many methods of data acquisition available for collection of vibration data from WT such as SCADA, online data acquisition, two-way data acquisition, and one-way data acquisition. One-way data acquisition is suitable for experimental analysis since collection of data and report generation can be made according to our requirements.

The literature obtained for vibration in WT was a preliminary knowledge for the development of the experimental vibration analysis in WT components. The components of WT exhibit different vibration spectrum depending upon their dynamic characteristics. The vibration is the important problem in WT which has its major contribution in mechanical component failure. So vibration in WT components has to be continuously monitored for preventive maintenance. The DAS with suitable vibration meter is needed for continuous vibration measurement in WT components at different load and operating conditions. The main objective of vibration measurement is to find the root cause of vibration in individual components and vibration control by means of vibration isolation.

3 Scope

The scopes of the project are as follows:

1. To measure the vibration characteristics of the WTs within the wind speed of 3.3–23 m/s.
2. To record the vibration parameters such as velocity, acceleration, and displacement within the frequency range of 1–20 kHz.

4 Vibration Measurement Scheme

Vibration analysis is used to determine the operating and mechanical conditions of equipment. A major advantage is that vibration analysis can identify developing problems downtime. This can be achieved by conducting regular monitoring of machine either on continuous basis or at scheduled intervals.

All rotating machines produce vibrations that are a function of the machine dynamics such as the alignment and balance of the rotating part. Measuring the amplitude of vibration at certain frequencies can provide valuable information about the accuracy of shaft alignment and balance, the condition of bearings or gears, and the effect on the machine due to resonance from the housing and other structural elements. The basic vibration measurement scheme of WT with 250 kW is shown in Fig. 1. Its effectiveness relies heavily on someone detecting unusual noises or vibration levels. Ultimately, vibration analysis can be used as part of an overall program to significantly improve equipment reliability. This can include more precise alignment and balancing better quality installations and repairs, and continuously lowering the average vibration levels of equipment in the plant. The time taken (T) to complete one cycle of motion is known as the period of vibration or time period.

$$T = \frac{2\pi}{\omega} \tag{1}$$

where ω is called the circular frequency.

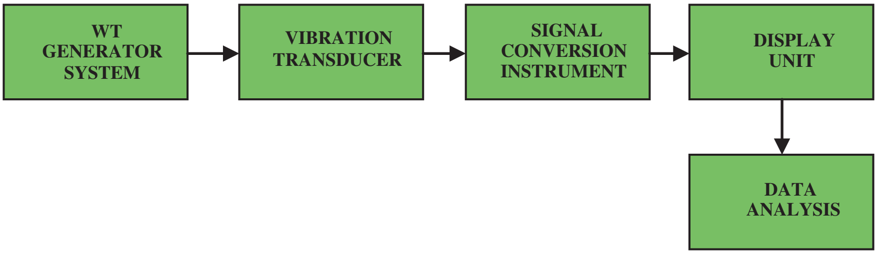

Fig. 1 Basic vibration measurement scheme

4.1 Frequency of Vibration

The number of cycles per unit time is called the frequency of oscillation or the frequency and is denoted by

$$f = \frac{1}{T} = \frac{\omega}{2\pi} \tag{2}$$

Amplitude refers to the maximum value of a vibration. This value can be represented in terms of displacement, velocity, or acceleration.

5 Vibration Analysis of WT

The vibration analysis of the WT is used to diagnose the fault and prevent its occurrence. In WT, the rotor, gear box, high speed shaft, low speed shaft, generator, and yaw are rotating machineries. The flaw of the rotating machineries can cause a significant reduction in power generation and reliability. According to the ISO 10816-3 vibration severity chart, the velocity range up to 3.5 mm/s, the vibration for 400 kW WT is acceptable, and between 3.5 and 7 mm/s, the vibration is satisfactory. But beyond 7 mm/s, the vibration is unacceptable.

5.1 Vibration Analysis of Low Speed Shaft

The Fig. 2 shows the influence of vibration relating to velocity with time. The sudden spectrum rise in the later part of velocity graph depicts the alignment problems. The low speed frequently reaches an unacceptable range of vibration level. From the graph, it is evident that it reaches four times the intolerable range, within a minute. The high vibration in the low speed shaft is due to blade interference and defects in main bearing. The absurd vibrations of rotor system and low speed shaft are an effect of instability, poor structural framework, axial

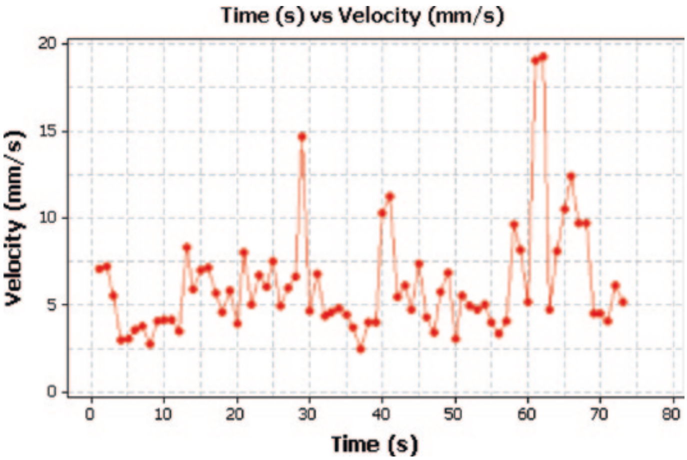

Fig. 2 Low speed shaft vibration relating to velocity with time

interference, and poor aerodynamic profile which increase the static divergence, stall, and flutter.

The continuous variation in acceleration graph at operation shown in Fig. 3 denotes mass imbalance, looseness, and increased rotor speed. The Fig. 4 shows that the displacement is varying at a moderate interval but jumps are high which denotes cyclic loading. The frequency spectrum represents that amplitude of vibration increases with increase in operating cycle. The main bearing of the rotor are subjected to abnormal wear, each time a WT is shut off or started. In these conditions, the entire weight of the rotating element rests directly on the lower half of

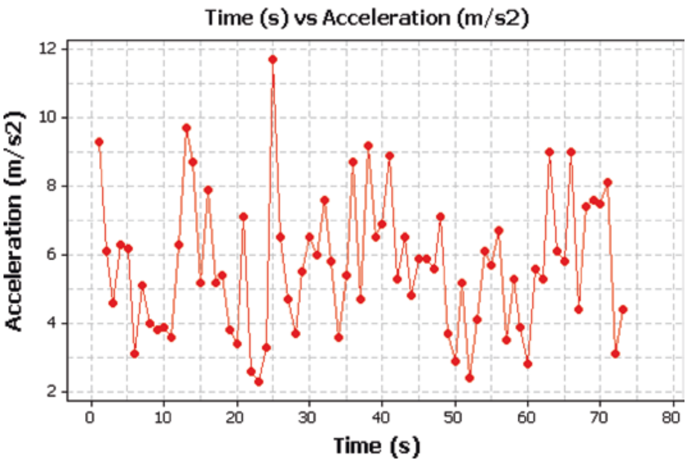

Fig. 3 Low speed shaft vibration relating to the acceleration with time

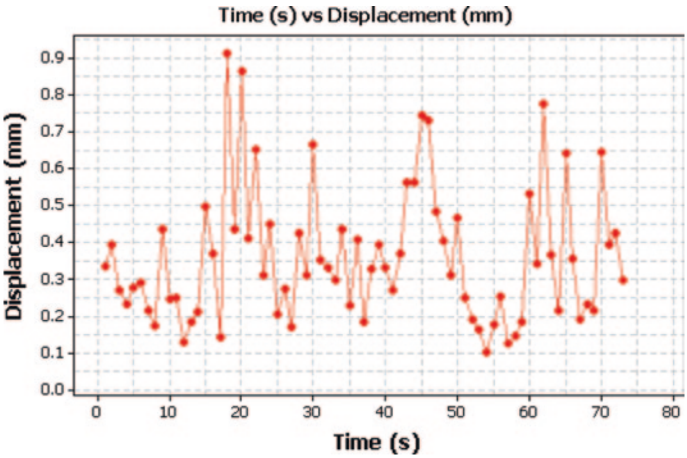

Fig. 4 Low speed shaft vibration relating to the displacement with time

the bearings which result bearing damage. The slackness of the main bearing at the end causes vibration (Fig. 5).

5.2 Vibration Analysis of Gear Box

The failure of WT gearbox is engendered due to many phenomenon such as amplified vibration, prolonged fatigue and stress, inevitable impact load, and increased

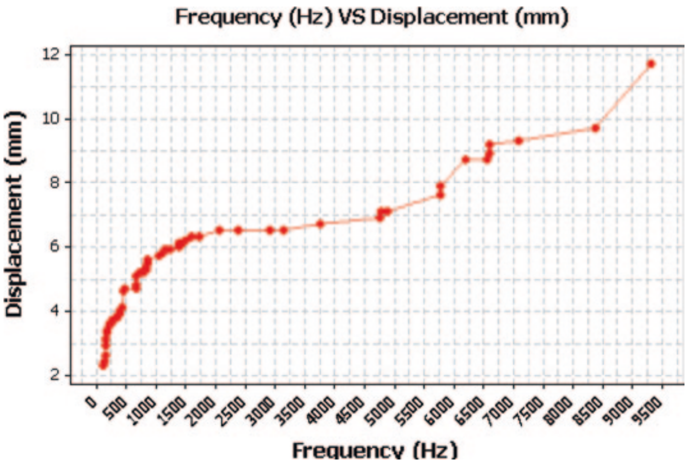

Fig. 5 Low speed shaft vibration relating to the frequency with displacement

shaft speed. The vibration is augmented in gearbox owing to machine imbalance which is the effect of improper assembly and improper design.

The gear tooth damage is caused by abrasion, anisotropy, friction, and improper lubrication. The ill evitable fatigue is mainly because of excessive cyclic load which is a consequence of wind gusts and poor load distribution. The impact load has the main concern to increase vibration and reduce the lifetime of gearbox.

The Fig. 6 describes the vibration effect due to wind turbulence. The gearbox vibration is little and most probability within the limit. However, it reaches the maximum unacceptable range due to the impact of sudden load on the brake, uncertainty in the wind. The defects in the gear and misalignment of high speed and low speed shaft pull down the gear efficiency. The Fig. 7 represents the mass imbalance in a

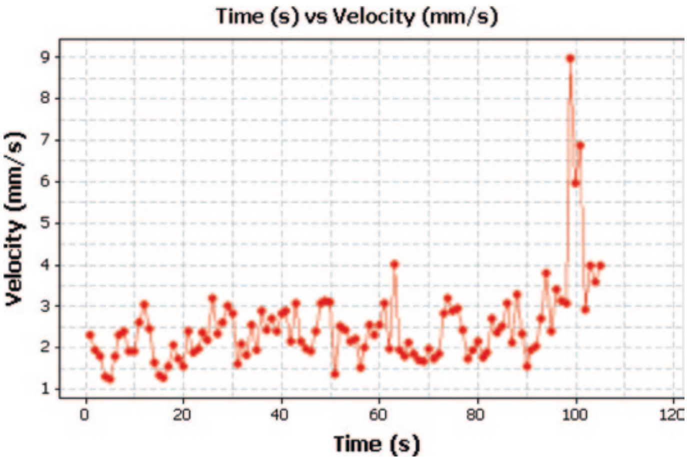

Fig. 6 Gear box vibration relating to the velocity with time

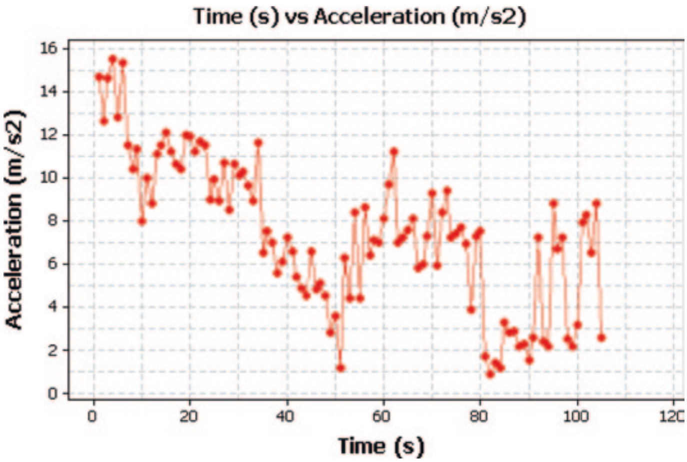

Fig. 7 Gear box vibration relating to the acceleration with time

minor level and friction. The maximum displacement for analyzed time is exposed in Fig. 8 and reveals high at initial state so vibration should be curtailed. The frequency spectrum delineates the effect of fluctuating load and increased wind speed (Fig. 9).

5.3 Vibration Analysis of High Speed Shaft

The shafts comprised with gear box are the low and high speed shafts, each of them has their own observable fact of failure. The damage of high speed shaft is owing to bent shaft, misaligned bearing, mass imbalance, and mechanical looseness.

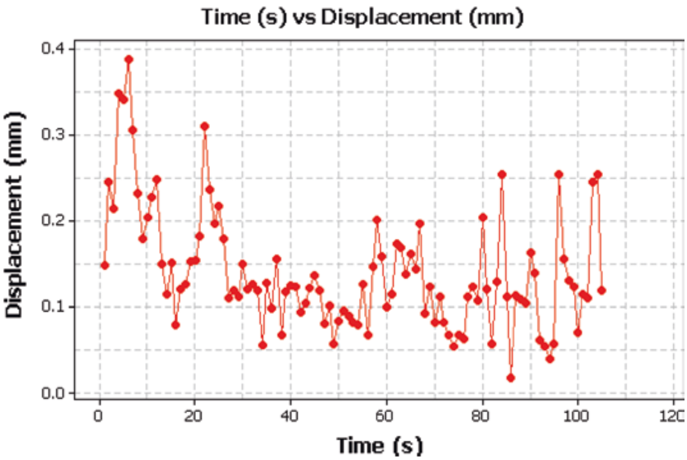

Fig. 8 Gear box vibration relating to the displacement with time

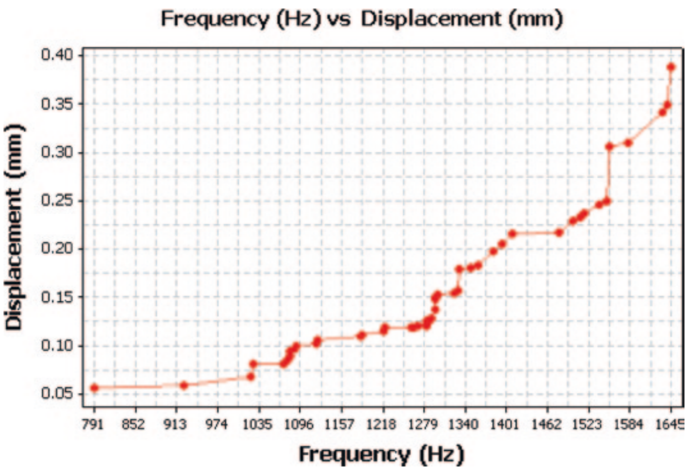

Fig. 9 Gear box vibration relating to the frequency with displacement

The Fig. 10 makes known that the high speed shaft has extremely heavy vibration and the limit crosses its allowable value. The vibration in the high speed shaft causes damage in the gear box, coupling, and generator.

The extreme vibration is noted in the high speed shaft that causes frequent misalignment problem in the generator. The acceleration and displacement graphs shown in Figs. 11 and 12 are the evidences for that the level of vibration in the high speed shaft is terribly high. Displacement is the actual change in distance or position of an object relative to a reference point and is usually expressed in units of mm (Fig. 13).

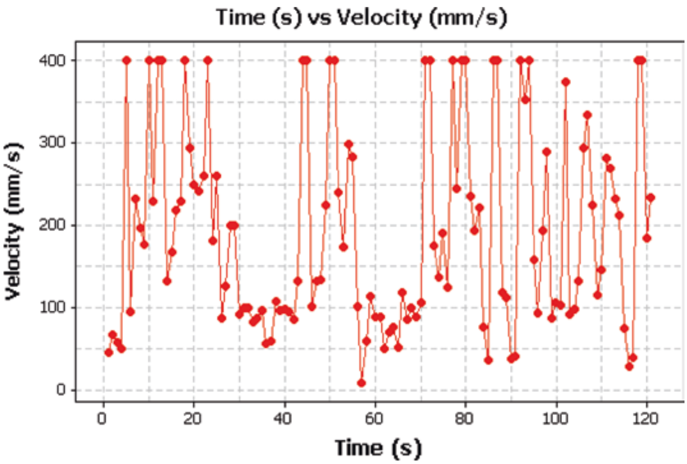

Fig. 10 High speed shaft vibration relating to velocity with time

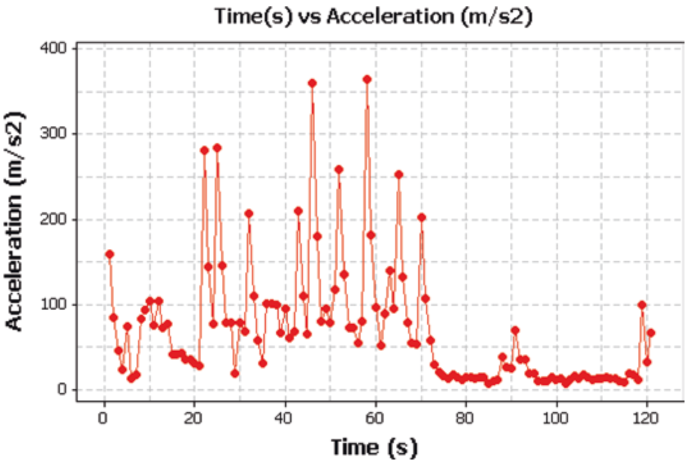

Fig. 11 High speed shaft vibration relating to the acceleration with time

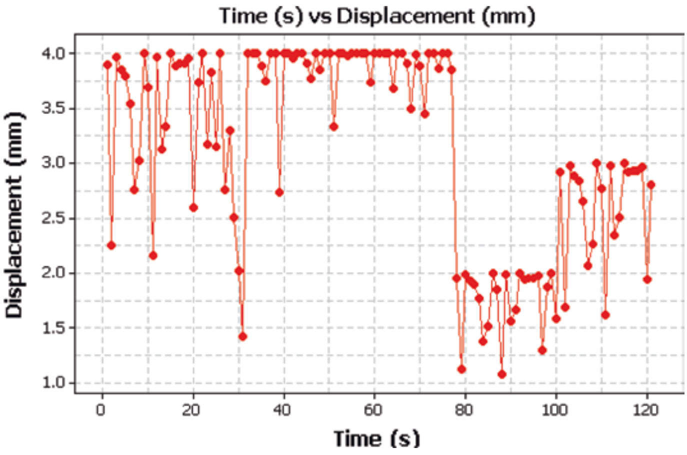

Fig. 12 High speed shaft vibration relating to displacement with time

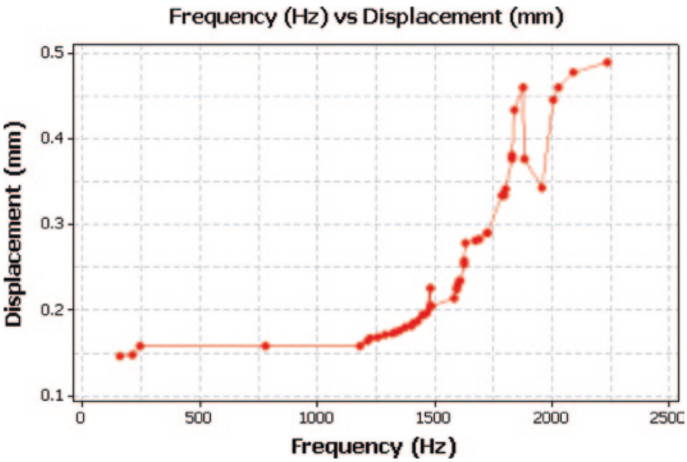

Fig. 13 High speed shaft vibration relating to frequency with displacement

5.4 Vibration Analysis of Generator

The failure of generator system is largely due to heavy vibration and electrical faults. The vibration has the effects in generator system such as soft foot, excessive brush wear, increase of electrodynamic fields, eddy current effect, and overhanging. The fault in rotor is engendered due to rotor lead failure and improper fixing of wedges and banding. The other nominal causes such as vibration, carbon brush worn out occur due to frequent transition from generator G1 to G2, improper fixing, and increased wind speed. The impact load caused due to radial preload and axial load damages bearing which in turn produces deformation in generator components.

The graph in Fig. 14 clearly shows that the rise in velocity in a rapid pattern denotes the increased speed and transition state. The key monitoring parameters for generators include bearings, casing and shaft, line frequency, and running speed (Fig. 15).

The generator rotors always seek the magnetic center of their casings. As a result, they tend to thrust in the axial direction. In almost all cases, this axial movement, or endplay, generates a vibration (Figs. 16, 17).

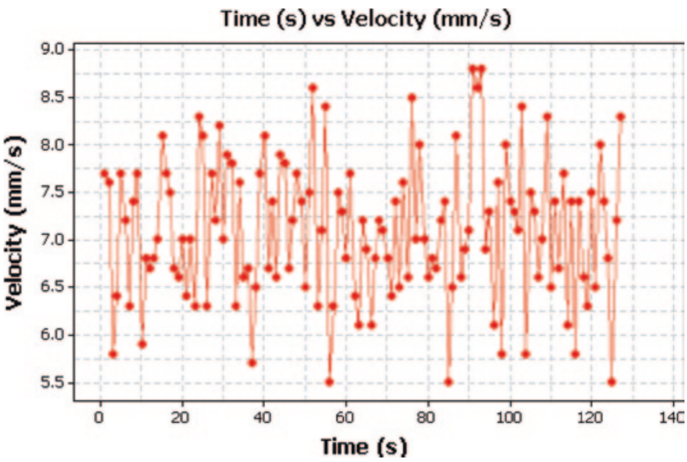

Fig. 14 Generator vibration relating to the velocity with time

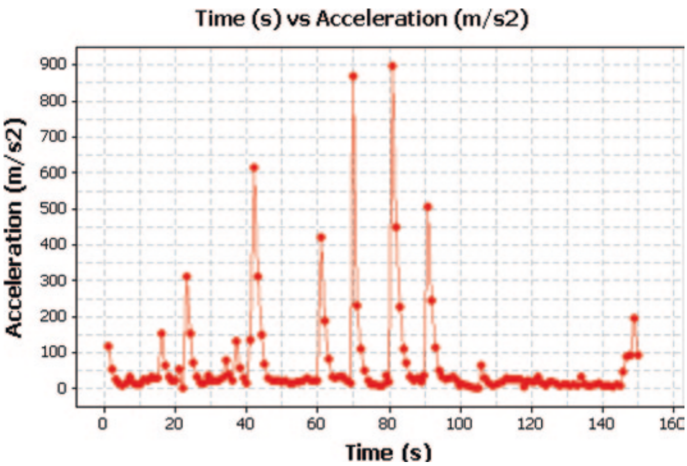

Fig. 15 Generator vibration relating to acceleration with time

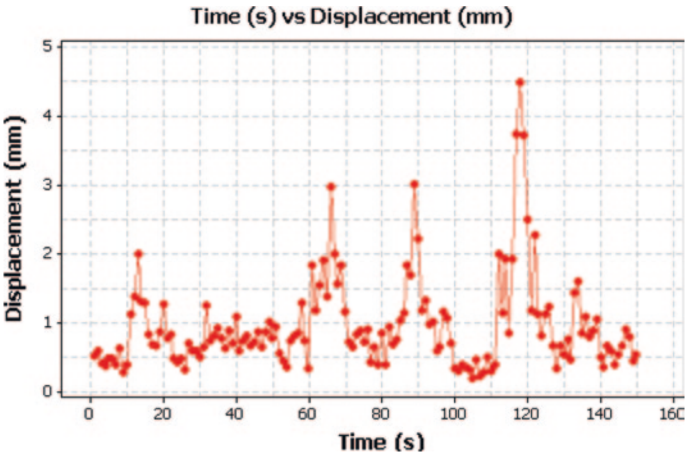

Fig. 16 Generator vibration relating to the displacement with time

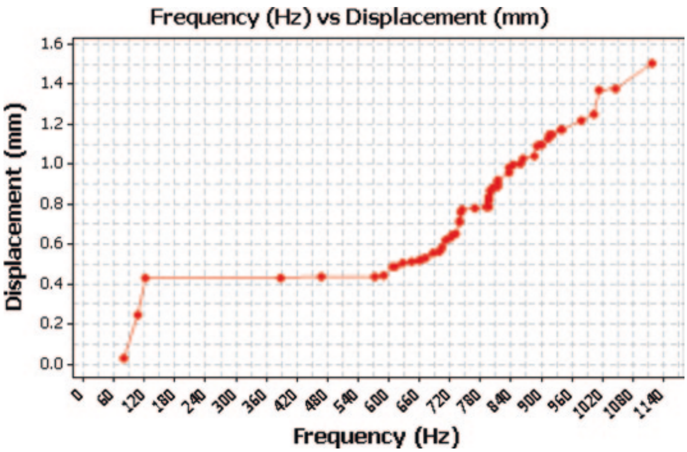

Fig. 17 Generator vibration relating to frequency with displacement

5.5 Vibration Analysis of Yaw System

The letdown of yaw system is induced due to heavy vibration, yaw motor worn out, yaw gear failure, and yaw brake failure. The profound vibration is engendered by wind turbulence, improper yaw braking, and yaw planetary failure that owe to the stress on gear tooth and friction.

The velocity graph of the yaw system shown in Fig. 18 depicts that the velocity rise is moderate and jump in velocity at shorter intervals throughout the curve is due to wind gusts.

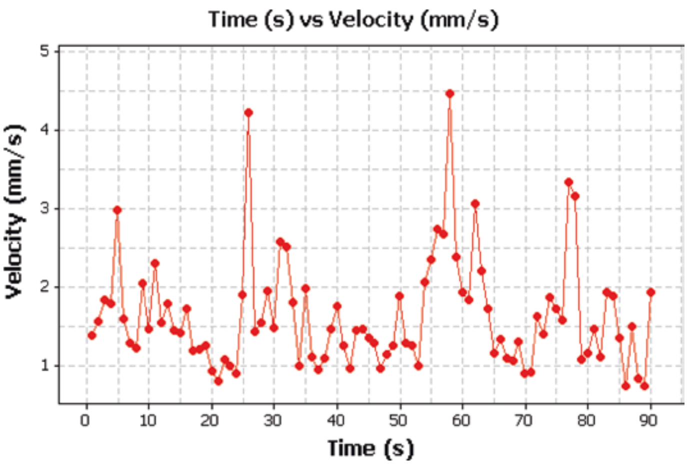

Fig. 18 Yaw vibration relating to the velocity with time

The yaw gear tooths are stressed by excessive cyclic loading and a structural dynamics. The abrasion of pinion and sleeve ring, the condomination of grease, and melting of the lubricant due to high temperature made high vibration in the planetary. The gust wind makes the yaw vibration. The single jump in acceleration shown in Fig. 19 at the later part of the curve represents fault in yaw planetary. The fluctuation in displacement at shorter intervals denote fault in sleeve ring. The frequency spectrum denotes increased vibration for analyzed condition (Figs. 20, 21).

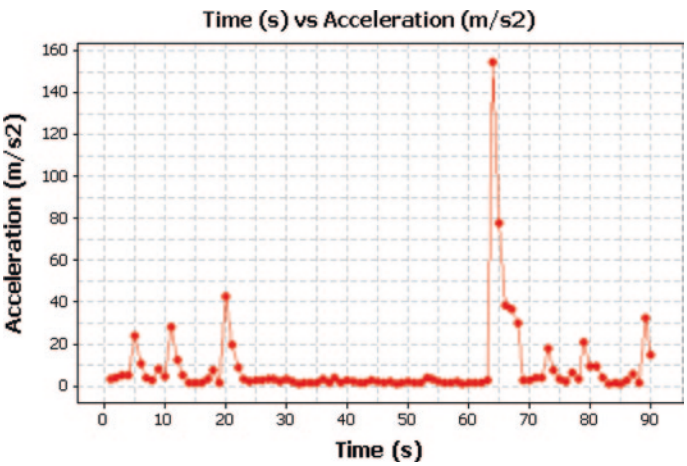

Fig. 19 Yaw vibration relating to acceleration with time

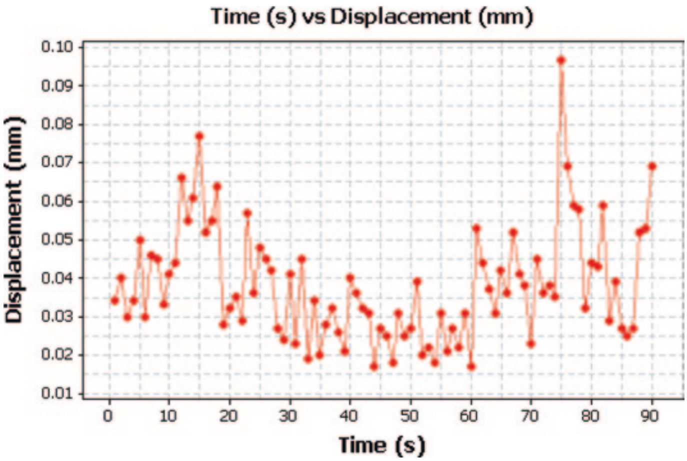

Fig. 20 Yaw vibration relating to displacement with time

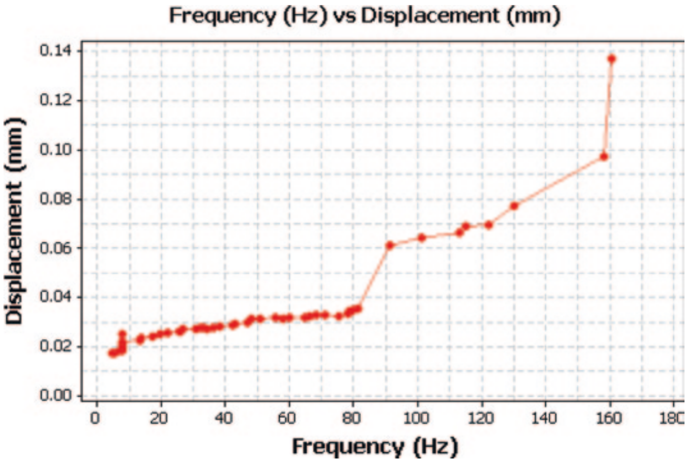

Fig. 21 Yaw vibration relating to the frequency with displacement

6 Conclusion

The vibration characteristic curves are generated with the help of vibration meter and data acquisition software. These vibration characteristic curves are computed and observations made from them for their severity and effects are analyzed. This paper concluded that large vibrations occurred in the high speed shaft, which reduce the reliability of the system. They require high speed shaft vibration monitoring measurement points in addition to standard casing measurement points. This requires the addition of permanently mounted proximity sensor, or displacement, transducers that can measure actual shaft deviation. The fluctuations in the wind, frequent grid off, and the transition of generator are the primary causes of vibration. The gear box vibration is also due to over loading, abrasion, and chemical attack. The generator is an overhanging structure and the misalignment of the high speed shaft makes the generator to vibrate.

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