Vibration Analysis of Rotating Shaft with Longitudinal Crack

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Abstract: ***Rotating shafts which are subjected to the hardest conditions in high performance rotating equipments used in the process and utility plants like high speed compressors, steam and gas turbines, generators and pumps and in industrial machines etc. Although when shafts are operated in different type of conditions then serious defects can appear, but these are much suspected to fatigue cracks because of the rapidly fluctuating nature of bending stresses. Because of manufacturing flaws or cyclic loading, cracks frequently appear in rotating shaft, other defects in shafts include bent shaft, misalignment etc. The tensile stress concentration resulting from shear slip causes the new cracks that propagate away from the pre-existing fault. Due to crack on shaft catastrophic failure, machine can be damage, it is hazards to human being, accident will be occur etc. A defect on shaft can be diagnosed by many methods, e.g., ultrasonic detection, electromagnetic method, acoustic emission, vibration analysis. We use vibration analysis method because when shaft rotates then due to defect the vibrational response of the rotating shaft will more or less change. By using the additional vibration extracted from the shaft response due to defect, an on-line condition monitoring system for defect detection might be developed for rotor systems. Other methods of crack detection are time consuming and it does not give proper result that's why we use vibration analysis method.***

Keyword: Catastrophic failure, Vibration analysis, Vibrational response, Online condition monitoring

1. Introduction

A defect on shaft can be diagnosed by many methods, e.g., ultrasonic detection, electromagnetic method, acoustic emission, vibration analysis. We use vibration analysis method because when shaft rotates then due to defect the vibrational response of the rotating shaft will more or less change. By using the additional vibration extracted from the shaft response due to defect, an on-line condition monitoring system for defect detection might be developed for rotor systems. Other methods of crack detection are time consuming and it does not give proper result that's why we use vibration analysis method.

For studying the vibration response of rotating shaft an experimental set up can be made as follows:

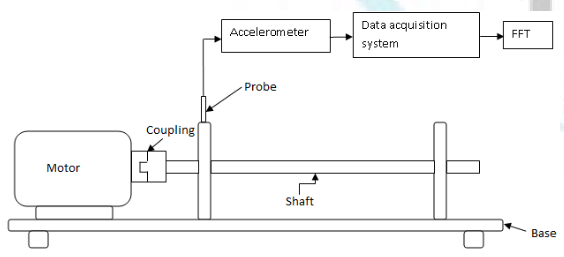


Fig. Schematic representation of proposed experimental setup

Experimental setup consist of a shaft with two test frame support bearing & driven by a variable speed motor. One end of the continuous shaft will connect to a variable speed electric motor. The artificial crack will be developed on shaft by using any convenient method. A piezoelectric accelerometer will be placed on the test rotor system to measure the vibration. The Fast Fourier Transform (FFT) analyzer will be used to acquire the vibration data.

Fundamental Train Frequency (FTF):

It is the rotation rate of the cage supporting the rollers in a rolling element bearing.

It is given by the formula:

$$FTF=\frac{S}{2}\left(1-\frac{Bd}{Pd}cos\emptyset\right)$$

Where,
S = Revolutions per second
Bd =Ball or roller diameter
Pd =Pitch diameter
Φ=Contact angle

Varying compliance frequency (Vc):

When the rolling element set and the cage rotates with a constant angular velocity, a parametrically excited vibration is generated and transmitted through the outer race. These vibrations are produced due to finite number of balls carrying load. The characteristic frequency of this vibration is called the varying compliance frequency (VC) and is given as:

Vc = N x FTF

Where,
N= No. of balls in bearing
FTF= Fundamental Train Frequency

Table 1: Rotational frequency & varying compliance frequency for different speed

Speed(rpm)	Rotational Frequency (Hz)	Varying Compliance frequency (Hz)
500	8.33	25.68
1000	16.67	51.36
1500	25	77.04
2000	33.33	102.72
2500	41.67	128.4

2. Literature Review

Jeslin Thalapil, et.al- The accuracy of this method for prediction of natural frequencies is illustrated by case studies involving both long and short beams with known longitudinal crack details. The natural frequencies show good agreement with the ANSYS results. Both internal and edge cracks have been studied. The method of prediction of crack parameters for a longitudinal axial internal crack has been verified for both long cantilever and simply supported beams.

Hemant G. Waikar, et.al- By using the additional vibration extracted from the shaft due to defect, an on-line condition monitoring system for crack detection might be developed for rotor systems. Even for smaller crack, rotating shaft creates the vibrations. So, the vibration monitoring is more useful for detecting crack in rotating shaft.

D.Y. Zheng*,et.al- The overall additional flexibility matrix instead of the local additional flexibility matrix is used to obtain the total flexibility matrix of a cracked beam. The stiffness matrix is then obtained from the total flexibility matrix. As a result, more accurate natural frequencies of a cracked beam are obtained.

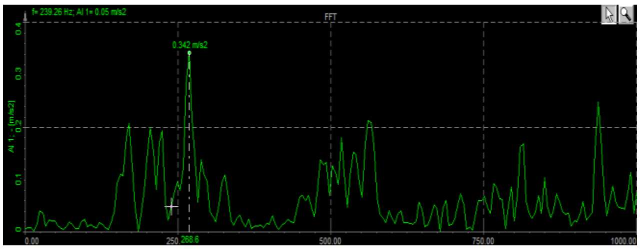
S. Prabhakar-A method to identify the crack location in a rotor bearing system based on wavelet transform is presented. The fundamental mode shape of the cracked rotor system is wavelet transformed. The sudden change of wavelet coefficients at crack location is suggested for identification of crack location in a rotor system. The present method can be extended to on line identification of crack location in a rotor system and the work is under progress.

H. Abdi,et.al - Longitudinal and circumferential cracks often form in turbo generator shafts under cyclic torsion. The presence of such cracks could significantly impact the shaft dynamic response. A parametric study was carried out to understand the effect of these cracks on the shaft resonance frequency. Frequency response of a longitudinally cracked shaft was investigated by modelling the cracked section as a shaft with a reduced torsional rigidity. A correction factor was defined as the torsional rigidity of the cracked shaft to that of the uncracked shaft. The torsional rigidity correction factor of the shaft was found to be just a function of crack depth to the shaft radius. The effect of the crack surface interactions was taken into the consideration and was found to be very small for crack depths less than 20% of the shaft radius.

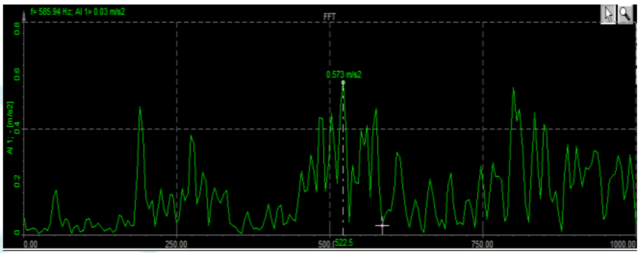
S. M. NABAVI et. al - The three-dimensional finite element method, in conjunction with the weight function method, is used for computing the stress intensity factor at the deepest and surface points of a longitudinal semi-elliptical crack in a cylinder. The transition aspect ratios are calculated for different relative depths and cylinder lengths. A closed formstress intensity factor at the surface point of a semielliptical crack in a finite length cylinder is derived.

3. Frequencies for Various Speeds

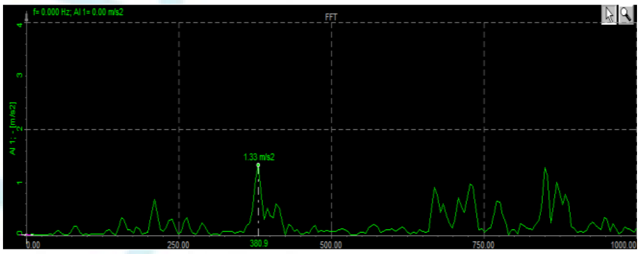
Case 1- crack location at 370mm from bearing 1, depth 4.20 & speed 500rpm



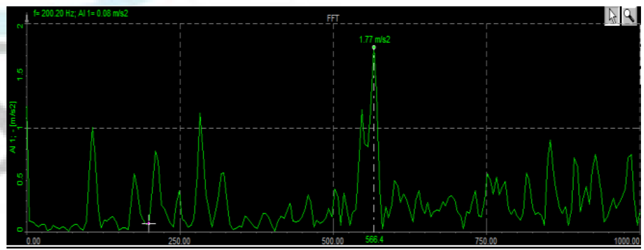
Case 2-crack location at 370mm from bearing 1, depth 4.20 & speed 1000rpm



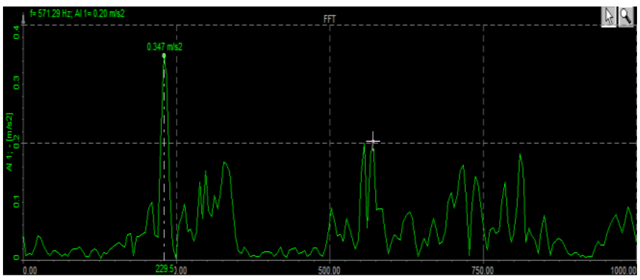
Case 3-crack location at 370mm from bearing 1, depth 4.20 & speed 1500rpm



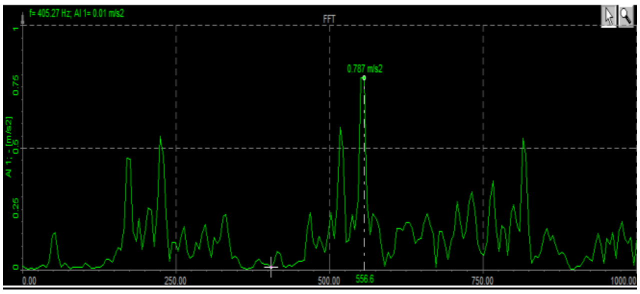
Case 4-crack location at 370mm from bearing 1, depth 4.20 & speed 2000rpm



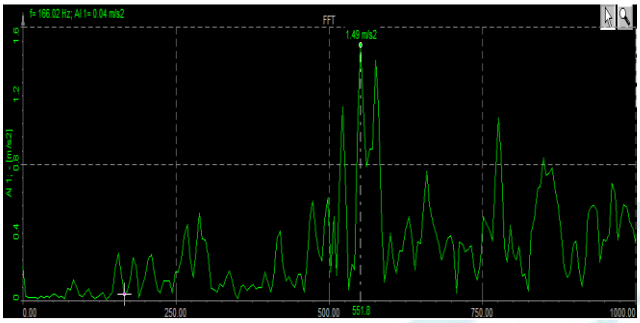
Case 5-crack location at 370mm from bearing 1, depth 8.40 & speed 500rpm



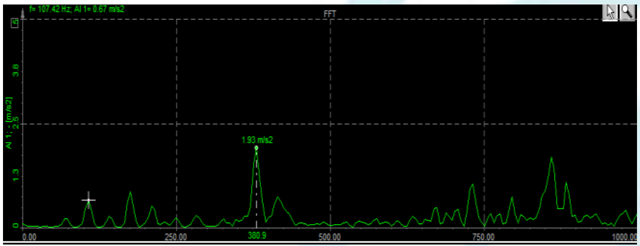
Case 6-crack location at 370mm from bearing 1, depth 8.40 & speed 1000rpm



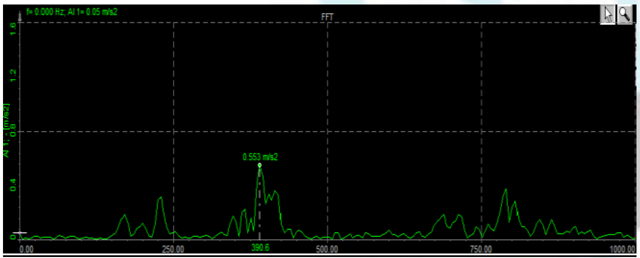
Case 7-crack location at 370mm from bearing 1, depth 8.40 & speed 1500rpm



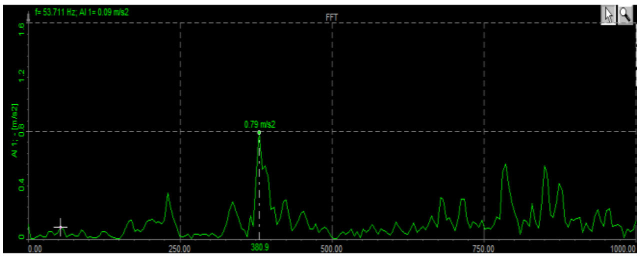
Case 8-crack location at 370mm from bearing 1, depth 8.40 & speed 2000rpm



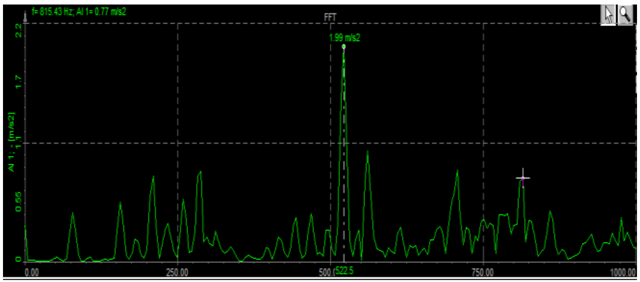
Case 9-crack location at 370mm from bearing 1, depth 10.60 & speed 500rpm



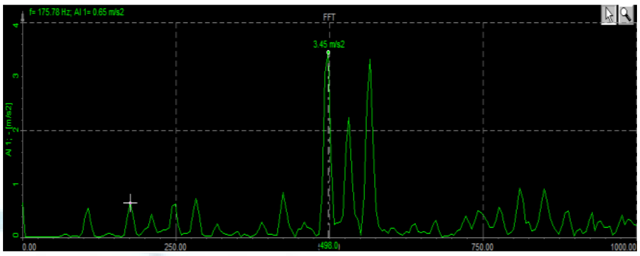
Case 10-crack location at 370mm from bearing 1, depth 10.60 & speed 1000rpm



Case 11-crack location at 370mm from bearing 1, depth 12.40 & speed 1500rpm



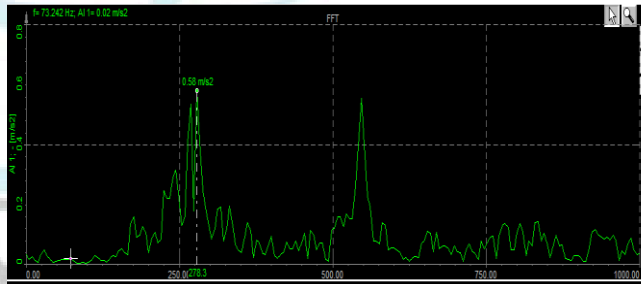
Case 12-crack location at 370mm from bearing 1, depth 10.60 & speed 2000rpm



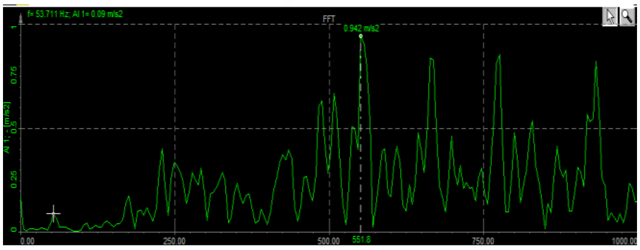
Case 13-crack location at 370mm from bearing 1, depth 12.40 & speed 500rpm

Mild Steel (For bearing 1)

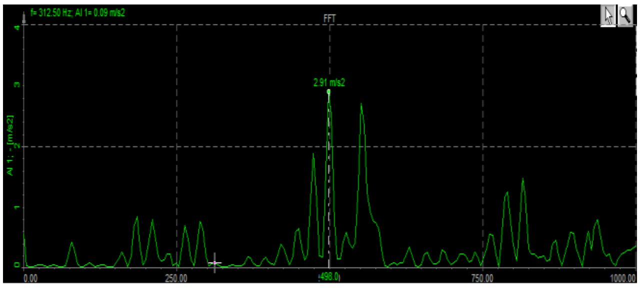
Crack location from bearing 1	Rotation speed in rpm			
	500	**1000**	**1500**	**2000**
370(4.50)	0.342(m/s^2)	0.573(m/s^2)	1.33(m/s^2)	1.77(m/s^2)
370(8.40)	0.347(m/s^2)	0.787(m/s^2)	1.49(m/s^2)	1.93(m/s^2)
370(10.60)	0.553(m/s^2)	0.79(m/s^2)	1.99(m/s^2)	3.45(m/s^2)
370(12.40)	0.58(m/s^2)	0.942(m/s^2)	2.91(m/s^2)	3.62(m/s^2)



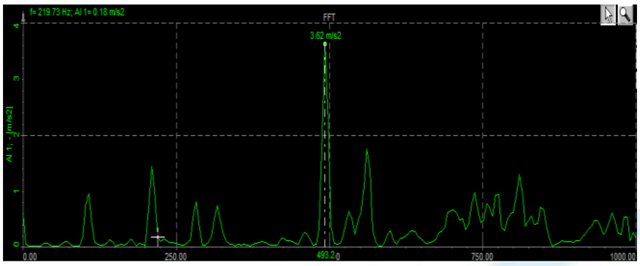
Case 14-crack location at 370mm from bearing 1, depth 12.40 & speed 1000rpm



Case 15-crack location at 370mm from bearing 1, depth 10.60 & speed 1500rpm

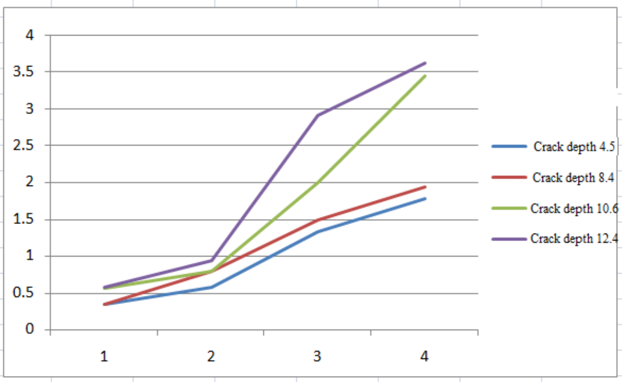


Case 16-crack location at 370mm from bearing 1, depth 12.40 & speed 2000rpm



Readings of Above Cases:

Graph of Above Table:



4. Conclusion

1) As speed of shaft increases, amplitude of vibration also increases.
2) Amplitude of vibration depends on crack location; it is different for different crack location.
3) Amplitude of vibration depends on crack depth; it is different for different crack depth.
4) As depth of crack increases, amplitude of vibration also increases.

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