Vibration Analysis of Rotating Shaft with Longitudinal Crack

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Abstract— Shafts are the components which are subjected to the hardest conditions in high performance rotating equipment used in the process and utility plants like high speed compressors, steam and gas turbines, generators and pumps etc. Although when shafts are operated in different type of conditions then serious defects can appear, but these are much suspected to cracks because of the rapidly fluctuating nature of stresses. The development of crack changes dynamic behavior of rotor system. It decreases the strength of object or material. When shaft rotates then due to defect the vibration response of the rotating shaft will more or less change. 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. This paper gives the vibration analysis of rotating shaft with different crack location & with different shaft speeds.

Key words: Dynamic behavior, condition monitoring, vibration monitoring, vibration analysis

I. INTRODUCTION

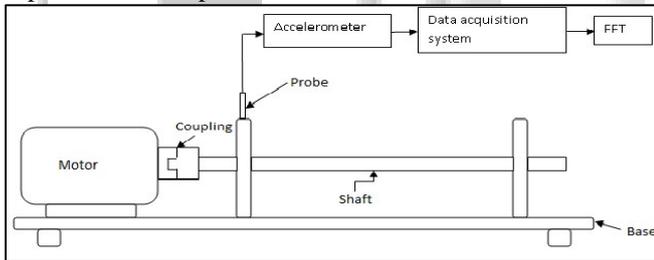For studying the vibration response of rotating shaft an experimental set up can be made as follows:

Fig. 1: 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. For our experiment we choose the shaft of working length 600mm, diameter 21mm & material MILD steel. The crack is of width 0.5mm, depth 21mm & the length as generated by these dimensions. The bearing of SKF 6204 is used.

For our study we take five shafts, one healthy & other with different crack location for studying the vibration response of shaft, some terms like fundamental train frequency, varying compliance frequency are important.

A. 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:

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

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

B. 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:

$$VC = N \times FTF$$

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

II. VIBRATION ANALYSIS

We take the readings of shaft at 500, 1000, 1500& 2000rpm. One shaft is healthy & other containing the longitudinal crack at location 225mm& 370mm from bearing 1& bearing 2 respectively.

The rotational frequency & varying compliance frequency for above speeds is tabulated as follows:

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

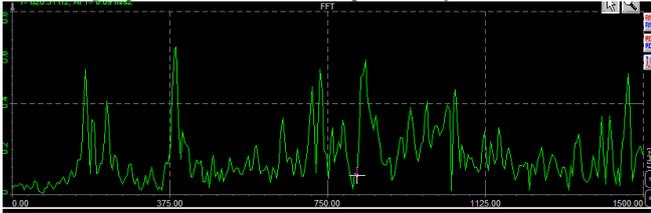Table 1: Rotational frequency & varying compliance frequency for different speed

A. Case-I: Healthy shaft at bearing 1:
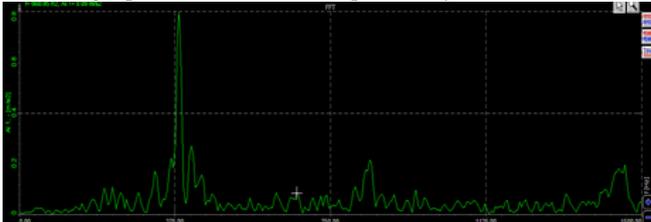
1) The graph obtained at 500rpm is as follows:
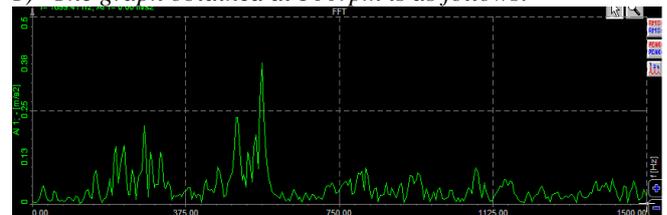
Here we get the max. Peak at Vc =0.232 m/s^2.

2) *The graph obtained at 1000rpm is as follows:*

Here we get the max. Peak at Vc =0.62 m/s².

3) *The graph obtained at 1500rpm is as follows:*
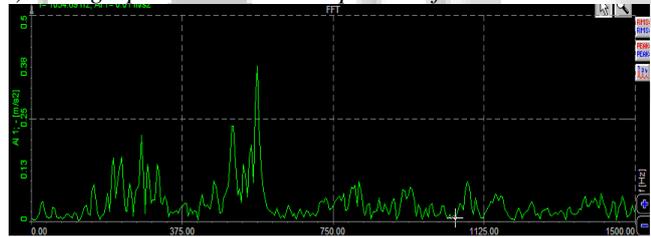

Here we get the max. Peak at Vc =0.970 m/s².

4) *The graph obtained at 2000rpm is as follows:*
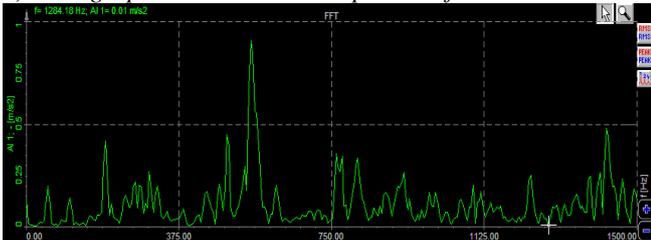

Here we get the max. Peak at Vc =1.18 m/s².

B. *Case-II: Shaft with crack at 225mm:*
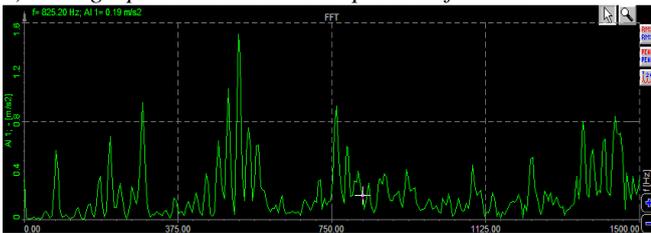
1) *The graph obtained at 500rpm is as follows:*

Here we get the max. Peak at Vc =0.363 m/s².
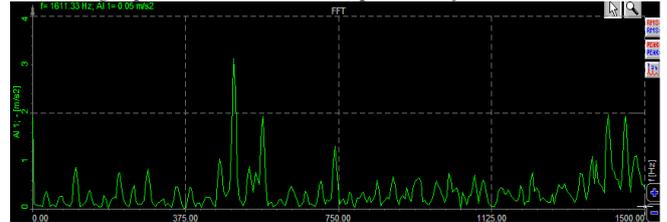
2) *The graph obtained at 1000rpm is as follows:*

Here we get the max. Peak at Vc =0.907 m/s².

3) *The graph obtained at 1500rpm is as follows:*
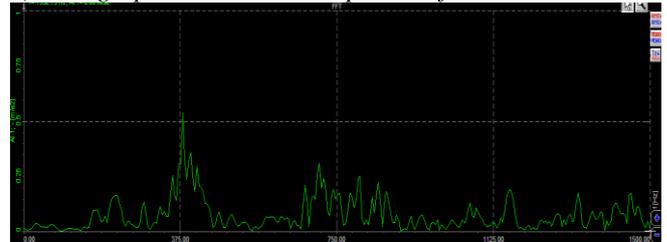

Here we get the max. Peak at Vc =1.51 m/s².

4) *The graph obtained at 2000rpm is as follows:*
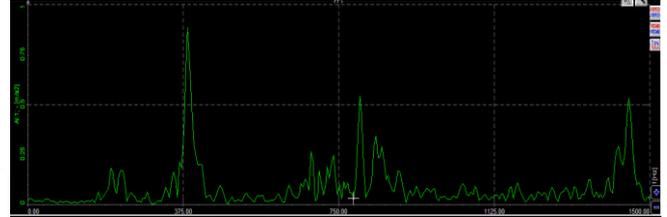

Here we get the max. Peak at Vc =1.78 m/s².

C. *Case-III: Shaft with crack at 370 mm:*
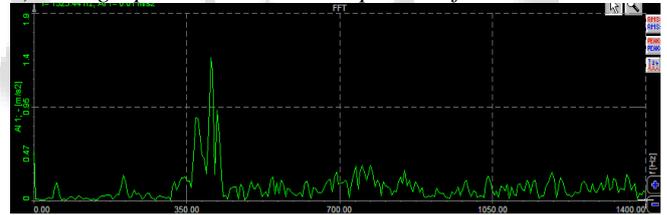
1) *The graph obtained at 500rpm is as follows:*

Here we get the max. Peak at Vc =0.547 m/s²

2) *The graph obtained at 1000rpm is as follows:*

Here we get the max. Peak at Vc =0.824 m/s².

3) *The graph obtained at 1500rpm is as follows*

Here we get the max. peak at Vc =1.25 m/s²

4) *The graph obtained at 2000rpm is as follows:*
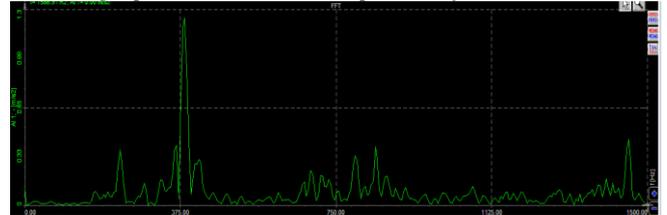
Here we get the max. peak at Vc =1.49 m/s²

From the above graphs it is clear that maximum peak is obtained nearly at the varying compliance frequency. The maximum amplitudes from all the above graphs can be tabulates as follows:

Crack location from bearing 1	Rotation speed in RPM			
	500	1000	1500	2000
Intact Shaft	0.230 m/s²	0.627 m/s²	0.97 m/s²	1.180 m/s²
225mm	0.363 m/s²	0.907 m/s²	1.51 m/s²	1.780 m/s²
370mm	0.547 m/s²	0.824 m/s²	1.25 m/s²	1.49 m/s²

Table 2: Maximum amplitude for different crack location

D. Case-II: Healthy shaft at bearing 2

1) The graph obtained at 500rpm is as follows:

Here we get the max. peak at Vc =0.216 m/s^2.
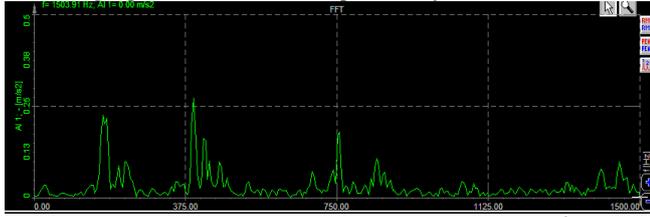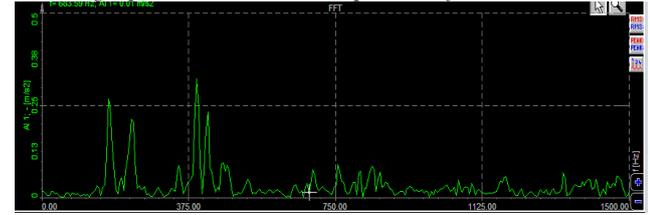
2) The graph obtained at 1000rpm is as follows:

Here we get the max. peak at Vc =0.30 m/s^2.

3) The graph obtained at 1500rpm is as follows:

Here we get the max. peak at Vc =0.822 m/s^2.

4) The graph obtained at 2000rpm is as follows:

Here we get the max. peak at Vc =1.07 m/s^2.

E. Case-II: Shaft with crack at 225mm at bearing 2

1) The graph obtained at 500rpm is as follows:

Here we get the max. peak at Vc =0.33 m/s^2.
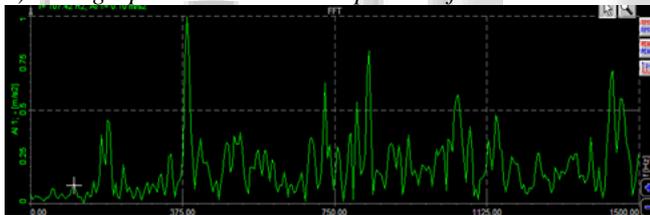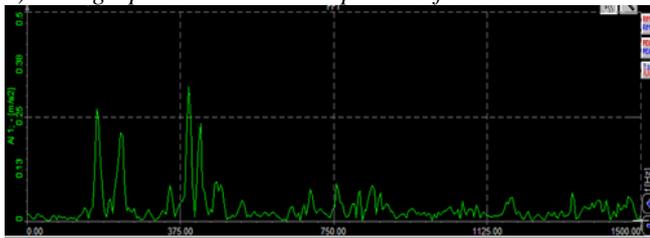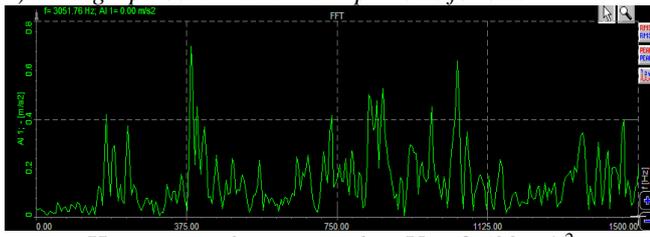
2) The graph obtained at 1000rpm is as follows:

Here we get the max. peak at Vc =0.699 m/s^2

3) The graph obtained at 1500rpm is as follows:

Here we get the max. peak at Vc =1.38 m/s^2.

From the above graphs it is clear that maximum peak is obtained nearly at the varying compliance frequency. The maximum amplitudes from all the above graphs can be tabulates as follows:

Crack location from bearing 2	Rotation speed in rpm			
	500	1000	1500	2000
Inatct shaft	0.216 m/s^2.	0.30 m/s^2.	0.822 m/s^2.	1.07 m/s^2.
225mm	0.33 m/s^2.	0.699 m/s^2.	1.38 m/s^2.	1.64 m/s^2.

III. CONCLUSION

1) As speed of shaft increases, amplitude of vibration also increases.
2) Maximum peak obtained nearly at varying compliance frequency.
3) Amplitude of frequency depends on crack location; it is different for different crack location.
4) In above case study 225mm crack location gives nearly high amplitude as compared to other crack location for the respective speed.

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