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VALIDATION OF VIBRATION ANALYSIS OF ROTATING SHAFT WITH LONGITUDINAL CRACK

[1] S. A. Todkar, [2] M. D. Patil, [3]S. K. Narale, [4]K. P. Patil
[1,2,3,4] Department of Mechanical FTC College of Engineering & Research,
Sangola (Maharashtra), India.
todkarsagar01@gmail.com

***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.**

***Index Terms* — Validation of longitudinal crack, Vibration analysis, Vibrational response, Online condition monitoring.**

I. 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: 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.

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:

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

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

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

II. LITERATURE REVIEW:

S.K. Georgantzinos et al - Shafts are amongst components subjected to perhaps the most arduous working conditions in high performance rotating equipment used in process and utility plants. Although usually quite robust and well designed, shafts in operation are sometimes susceptible to serious defects that develop without much apparent\ warning. They are prime candidates for fatigue cracks because of the rapidly fluctuating nature of stresses, the presence of numerous stress raisers and possible design or manufacturing flaws. The growth of cracksin the rotating components can cause severe accidents if undetected. The earlier the time of crack detection, the smaller the effort, and expenses for repair. Cracks that always remain open are known as gaping cracks.

A.C. Chasalevris, et al -The coupling phenomenon of different vibration modes of a cracked shaft has been reported over the past two decades. This investigation focuses on the coupled bending vibrations, particularly under the presence of two cracks. Even if this kind of coupling in general was known and expected, the past investigations focused on the coupling of longitudinal and bending or on the torsional and bending vibrations. The main conclusions of this investigation could be summarized as follows:

(a)When the two cracks are in phase, then the coupling phenomenon becomes stronger; meanwhile, if the two cracks are opposite, then the coupling turns weaker.
(b) The coupled response in the horizontal plane under vertical excitation is maximized when the crack is rotated by 900 in reference to the vertical plane. This is the result of the value of the local coupled compliance, which is maximized at this rotational angle.
(c) The experimental procedure proved that the deeper crack makes the coupling phenomenon more intense. This situation depends, of course, on the relative angular position of the cracks.

JeslinThalapil,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.

A. READINGS OF VARIOUS DEPTH

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)

III. VALIDATION ON MINITAB:

Regression Analysis: D versus F
Case- 1

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	26.870	26.870	6.84	0.120
F	1	26.870	26.870	6.84	0.120
Error	2	7.858	3.929		
Total	3	34.727			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.98216	77.37%	66.06%	10.14%

Coefficients

Term	Coef	SECoef	T-Value	P-Value	VIF
Constant	-1.62	4.17	-0.39	0.735	
F	23.26	8.89	2.62	0.120	1.00

Regression Equation

D = -1.62 + 23.26 F

Case- 2

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	32.301	32.301	26.62	0.036
F	1	32.301	32.301	26.62	0.036
Error	2	2.427	1.213		
Total	3	34.727			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.10151	93.01%	89.52%	84.29%

Coefficients

Term	Coef	SECoef	T-Value	P-Value	VIF
Constant	-7.74	3.29	-2.36	0.143	
F	21.63	4.19	5.16	0.036	1.00

Regression Equation

D = -7.74 + 21.63 F

Case- 3

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	26.923	26.923	6.90	0.120
F	1	26.923	26.923	6.90	0.120
Error	2	7.805	3.902		
Total	3	34.728			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.97547	77.53%	66.29%	0.00%

Coefficients

Term	Coef	SECoef	T-Value	P-Value	VIF
Constant	0.85	3.25	0.26	0.819	
F	4.21	1.60	2.63	0.120	1.00

Regression Equation

D = 0.85 + 4.21 F

Case- 4

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	28.096	28.096	8.47	0.101
F	1	28.096	28.096	8.47	0.101
Error	2	6.631	3.316		
Total	3	34.727			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.82089	80.90%	71.36%	

Coefficients

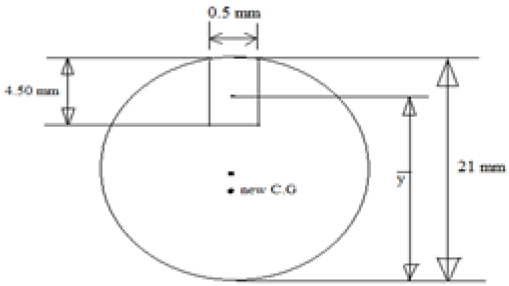
Term	Coef	SECoef	T-Value	P-Value	VIF
Constant	0.55	3.04	0.18	0.874	
F	3.13	1.08	2.91	0.101	1.00

Regression Equation

D = 0.55 + 3.13 F

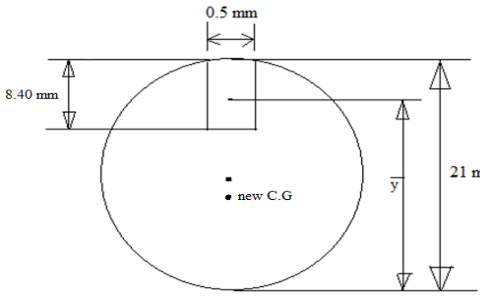
IV. CALCULATION OF CENTRE OF GRAVITY:

A. For depth 4.50 mm



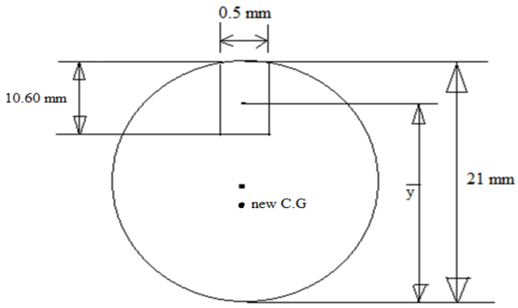
$$\bar{y} = \frac{A_1Y_1 - A_2Y_2}{A_1 - A_2}$$
$$= \frac{\frac{\pi}{4}\times 21^2 \times 10.5 - 0.5\times 4.5\times 18.75}{\frac{\pi}{4}\times 21^2 - 0.5\times 4.5} = 10.4461\ mm$$

B. For depth 8.40 mm



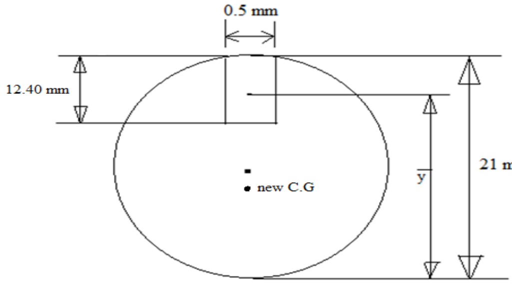
$$\bar{y} = \frac{A_1Y_1 - A_2Y_2}{A_1 - A_2}$$
$$= \frac{\frac{\pi}{4}\times 21^2 \times 10.5 - 0.5\times 8.40\times 16.80}{\frac{\pi}{4}\times 21^2 - 0.5\times 8.40} = 10.4227\ mm$$

C. For depth 10.60 mm



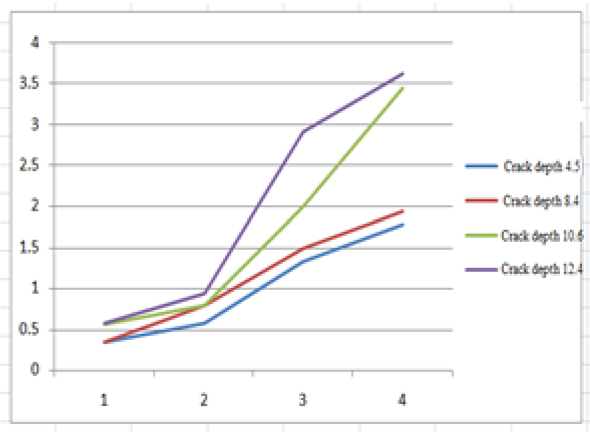
$$\bar{y} = \frac{A_1Y_1 - A_2Y_2}{A_1 - A_2}$$
$$= \frac{\frac{\pi}{4}\times 21^2 \times 10.5 - 0.5\times 10.60\times 15.70}{\frac{\pi}{4}\times 21^2 - 0.5\times 10.60} = 10.4192\ mm$$

D. For depth 12.40 mm



$$\bar{y} = \frac{A_1Y_1 - A_2Y_2}{A_1 - A_2}$$
$$= \frac{\frac{\pi}{4}\times 21^2 \times 10.5 - 0.5\times 12.40\times 14.80}{\frac{\pi}{4}\times 21^2 - 0.5\times 12.40} = 10.4216\ mm$$

GRAPH OF ABOVE TABLE:



CONCLUSION

1) Amplitude of vibration depends on crack depth; it is different for different crack depth.

2) As depth of crack increases, amplitude of vibration also increases.

3) AS PER MINITAB

By using regression equation we can find out unknown depth at known frequency and speed.

4) AS PER CENTRE OF GRAVITY

- Because of crack centre of gravity shifted to lower side of original centre of gravity.
- As depth of crack increases, centre of gravity shifted to lower side of original centre of gravity.

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