Vibration Analysis of Rotor using Cracks with Various Depth and Positions

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Abstract: *A strong interest has developed within the past several years in the dynamic behavior of Turbo machinery with cracked shafts. Vibration investigation of a damaged structure is one approach for fault diagnosis. Vibration diagnosis, as a non-destructive detection technique, has recently become of greater importance. Cracks in vibrating component can initiate catastrophic failures. The presences of Cracks change the physical characteristics of a structure which in turn alter its dynamic response characteristics. Therefore there is need to understand dynamics of cracked structures. Crack depth and location are the main parameters for the vibration analysis. A crack on a beam element introduces considerable local flexibility due to the strain energy concentration in the vicinity of the crack tip under load. In the present study, vibration analysis is carried out on a simply supported rotor shaft with open transverse crack, to study the response characteristics. It is verified from simulation analysis that the presence of crack decreases the natural frequency and amplitude of vibration. The mode shapes also changes considerably due to the presence of crack.*
Keywords — *Vibration investigation, crack, natural frequency, amplitude.*

I. Introduction

Rotating machinery is very common in the industry. Accurate prediction of dynamics of rotating shafts is necessary for a successful design. The vibratory phenomena associated to this kind of machine have been intensively studied to assure the best operational condition of the rotating machinery. The dynamic behaviour of structures, in particular, that of a rotor, containing cracks is a subject of considerable current interest. Cracks are among the most encountered damage types in the structures. Cracks in rotating parts may be hazardous due to static or dynamic loadings, so that crack detection plays an important role for structural health monitoring applications.

The most common structural defect is the existence of a crack. Cracks are present in structures due to various reasons. The presence of a crack could not only cause a local variation in the stiffness but it could affect the mechanical behaviour of the entire machine to a considerable extent. Cracks may be caused by fatigue under service conditions as a result of the limited fatigue strength. They may also occur due to mechanical defects. Another group of cracks are initiated during the manufacturing processes. Generally they are small in sizes. Such small cracks are known to propagate due to fluctuating stress conditions. If these propagating cracks remain undetected and reach their critical size, then a sudden structural failure may occur. Hence it is possible to use natural frequency measurements to detect cracks.

Most of researchers studied the effect of single crack on the dynamics of structures. However in actual practice structural members such as beams are highly susceptible to transverse cross-sectional cracks due to fatigue. Therefore to attempt has been made to investigate the dynamic behaviour of basic structures with crack systematically. The objective is to carry out vibration analysis on a simply supported rotor shaft with and without crack. Simulation has been done in free-free condition. With this modal analysis natural frequencies are calculated for various modes. In first phase of the work a single transverse surface cracks are included in developing the analytical expressions in dynamic characteristics of structures.

II. Vibration Theory

A. Vibration

Vibration is both useful and harmful for engineering systems. The main cause of failures in rotating machineries is vibration. Due to faulty design and poor manufacture there is unbalance in the machines which causes excessive and unpleasant stresses in the rotating system because of vibration. The vibration causes rapid wear on machine parts such as bearing and gears. Excessive vibration is dangerous for human beings. Mostly in rotating machineries vibration is the main cause for several forms of failures. Vibrations in rotating machinery cause many problems such as fatigue of the rotating components, excessive noise, or transmission of vibration to the supporting structure.

B. Natural Frequency

When no external force acts on the system after giving it an initial displacement, the body vibrates. These vibrations are called free vibrations and its frequency as natural frequency. It is expressed in rad/sec or Hz.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{g}{\Delta}}$$

where,

f_n – natural frequency
g – Acceleration due to gravity
Δ – Static deflection

The natural frequencies of a structure are the frequencies at which the structure naturally tends to vibrate if it is subjected to a disturbance. For example, the strings of a piano are each tuned to vibrate at a specific frequency.

III. PROPERTIES

Length of the shaft, L = 0.5m
Diameter of the shaft, D= 0.02m
Density = 7800 Kg/m^3
Modulus of elasticity = 2.08x 10^{11}N/m^2
Central mass = 5.5 Kg
Poisson's Ratio = 0.3
Rotor end condition = both end fixed by flexible bearing.
Crack position ratio X/L= 0-0.5
Crack depth ratio a/D= 0.1–0.4
Location of force X_f /L = 0.04-0.5
Magnitude of force, F = 15N
Where,
A - Crack depth.
X - Crack position from the left support end.
X_f - Location of force from the left support end.

IV. DESIGN OF ROTOR BEARING SYSTEM

Here deep groove ball bearing was selected.
From PSG data book page no. 4.12,
for D_1 = 19mm
Maximum permissible speed = 20000 rpm.
For this specification SKF 6003 was selected.
Minimum diameter of shaft d = 17mm.
Breadth of the bearing, B = 10mm.

A. Calculation of torque

From PSG data book page no. 1.11
For C15 steel, tensile strength = 340 N/mm^2
Yield strength = 190 N/mm^2
Shear stress [τ] = 250 Kg/cm^2

We know Torque

$$T = \frac{\pi}{16} d^3 [\tau]$$

Where , d - Minimum diameter of the shaft
τ - Design stress

Here T= 27434.391 N-mm

We know power

$$P = \frac{2\pi NT}{60}$$

Where, N - speed of shaft in rpm

Here P = 1.646 KW

The modelling of rotor shaft was done. The crack was modelled with a depth ratios of 0.1, 0.2, 0.3, and the position of ratios 0.1, 0.2, 0.3, 0.4 from the left end of the support. Finally, we obtained the V-shaped open transverse crack. The model was imported into simulation software in IGES file format.

V. RESULT AND DISCUSSION

TABLE I VARIATION OF FREQUENCIES AT DIFFERENT RELATIVE CRACK DEPTHS WHEN RELATIVE CRACK LOCATION AT X/L=0.1

Crack Depth ratio (a/D)	Mode 1 Frequency Hz	Mode2 Frequency Hz	Mode3 Frequency HZ
0	120.09	121.1	485.74
0.1	119.71	120.98	485.39
0.2	119.66	120.75	485.32
0.3	118.86	120.72	484.64

TABLE II VARIATION OF FREQUENCIES AT DIFFERENT RELATIVE CRACK DEPTHS WHEN RELATIVE CRACK LOCATION AT X/L=0.2

Crack Depth ratio (a/D)	Mode 1 Frequency Hz	Mode2 Frequency Hz	Mode3 Frequency HZ
0	120.09	121.1	485.74
0.1	119.77	121	485.62
0.2	119.57	120.8	485.44
0.3	119.05	120.09	484.92

TABLE III VARIATION OF FREQUENCIES AT DIFFERENT RELATIVE CRACK DEPTHS WHEN RELATIVE CRACK LOCATION AT X/L=0.3

Crack Depth ratio (a/D)	Mode 1 Frequency Hz	Mode2 Frequency Hz	Mode3 Frequency HZ
0	120.09	121.1	485.74
0.1	119.91	121.03	485.68
0.2	119.69	120.9	482.7
0.3	119.55	120.72	479.44

TABLE IV VARIATION OF FREQUENCIES AT DIFFERENT RELATIVE CRACK DEPTHS WHEN RELATIVE CRACK LOCATION AT X/L=0.4

Crack Depth ratio (a/D)	Mode 1 Frequency Hz	Mode2 Frequency Hz	Mode3 Frequency HZ
0	120.09	121.1	485.74
0.1	119.96	121.08	484.72
0.2	119.48	120.94	480.59
0.3	119.09	120.71	472.86

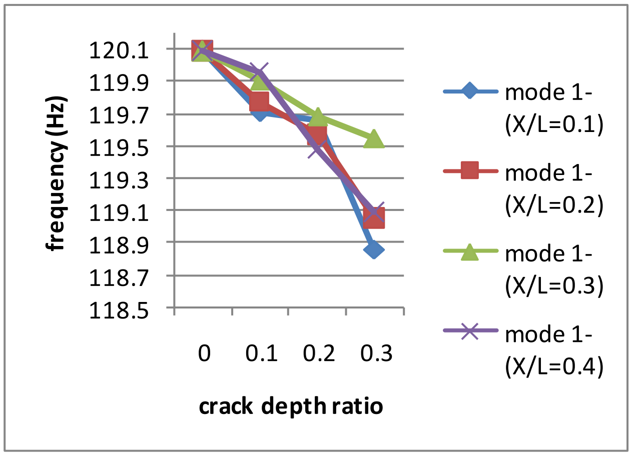

Fig. 1 Comparison of natural frequencies at Mode 1

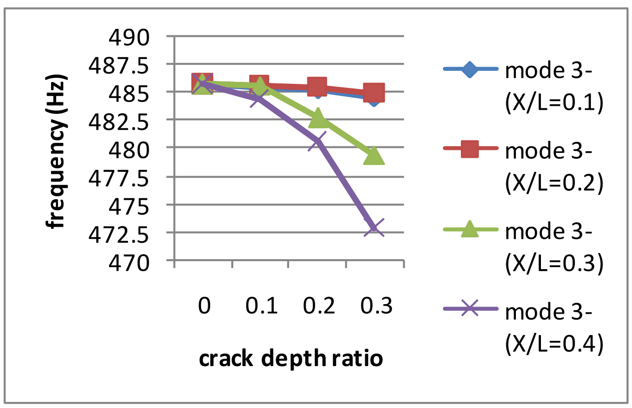

Fig. 2 Comparison of natural frequencies Mode -2

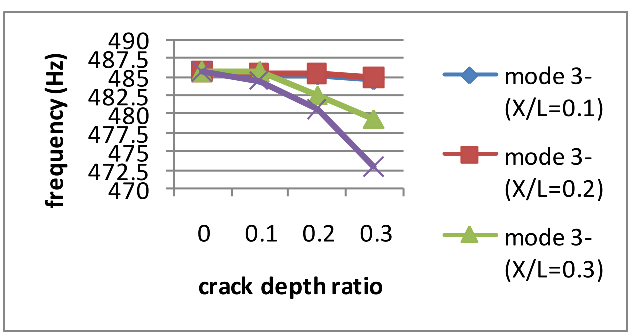

Fig. 3 Comparison of natural frequencies at Mode -3

TABLE IV COMPARISON OF MAXIMUM AMPLITUDE AT CRACK LOCATION(X/L=0.1)

Crack Depth ratio (a/D)	Maximum amplitude at X_f /L = 0.15	Maximum amplitude at X_f /L = 0.25	Crack Depth ratio (a/D)
0	4.28×10^{-6}	8×10^{-4}	0
0.1	4.03×10^{-6}	7.92×10^{-4}	0.1
0.2	4.02×10^{-6}	7.79×10^{-4}	0.2
0.3	4.00×10^{-6}	7.75×10^{-4}	0.3

TABLE V COMPARISON OF MAXIMUM AMPLITUDE AT CRACK LOCATION(X/L=0.2)

Crack Depth ratio (a/D)	Maximum amplitude at X_f /L = 0.15	Maximum amplitude at X_f /L = 0.25	Crack Depth ratio (a/D)
0	4.28×10^{-6}	8.00×10^{-4}	0
0.1	4.158×10^{-6}	7.979×10^{-4}	0.1
0.2	4.1×10^{-6}	7.857×10^{-4}	0.2
0.3	4.06×10^{-6}	7.825×10^{-4}	0.3

TABLE VI COMPARISON OF MAXIMUM AMPLITUDE AT CRACK LOCATION(X/L=0.3)

Crack Depth ratio (a/D)	Maximum amplitude at X_f/L = 0.15	Maximum amplitude at X_f /L = 0.25	Crack Depth ratio (a/D)
0	4.27×10^{-6}	8.00×10^{-4}	0
0.1	4.15×10^{-6}	7.97×10^{-4}	0.1
0.2	4.1×10^{-6}	7.85×10^{-4}	0.2
0.3	4.06×10^{-6}	7.82×10^{-4}	0.3

TABLE VI COMPARISON OF MAXIMUM AMPLITUDE AT CRACK LOCATION(X/L=0.4)

Crack Depth ratio (a/D)	Maximum amplitude at X_f /L = 0.15	Maximum amplitude at X_f /L = 0.25	Crack Depth ratio (a/D)
0	4.28×10-6	8.00×10-4	0
0.1	4.23×10-6	8×10-4	0.1
0.2	4.2×10-6	7.92×10-4	0.2
0.3	4.19×10-6	7.89×10-4	0.3

The first three natural frequencies corresponding to various crack locations and depths are calculated. The fundamental mode shapes and corresponding amplitude of vibration for transverse vibration of cracked and uncracked shaft are tabulated and compared. Result also discussed in graphical form. It shows that there is an appreciable variation between natural frequency of cracked and uncracked simply supported rotor shaft. With increase in mode of vibration this difference increases. The simulation results indicate that the deviation between the fundamental mode shapes of the cracked and uncracked rotor is always sharply changed at the crack location. The simulation results obtained by analysis software.

From the simulation results we can understand that

- When there is a presence of crack in the rotor shaft there is variation in the natural frequency and amplitude.
- When the crack location is constant but the crack depth increases:
- The natural frequency and amplitude of the shaft decreases for a single crack.
- When the crack location increases, but the crack depth is constant
- The natural frequency and amplitude increases which is compared from the tables.
- If the crack located near the supports the frequency and amplitude decreases and Vice versa.

VI. CONCLUSIONS

The vibration behavior of rotor with open transverse crack in various position and depth was studied under free condition. The modal analysis was done and six modes of frequencies are calculated using simulation. It is shown that the natural frequency changes substantially due to the presence of cracks. The changes depending upon the location and size of cracks. The position of the cracks can be predicted from the deviation of the fundamental modes between the cracked and un cracked rotor shaft.

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