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Research Article

Vibration Based Condition Assessment of Rotating cracked shaft using changes in critical speed and RMS Velocity response functions

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Abstract

Many rotor dynamic system consist of shaft/rotor elements that are highly liable to transvrse cross sectional cracks due to fatigue. The early detection that can be provided by an effective vibration monitoring and analysis technique is efficient. Two theoretical analyses, global and local asymmetry crack models, are utilized to identify characteristics of the system response that may be directly attributed to the presence of a transverse crack in a rotating shaft. The work reported in this paper is part of an ongoing research on the experimental investigations of the effects of cracks and damages on the integrity of structures, with a view to detect, quantify with the study of some parameter such as critical speed, RMS velocity. As crack initiates and propagates, Critical speed and RMS Velocity changes accordingly and that can be monitored with condition monitoring technique. Therefore the change in Critical speed and RMS Velocity is effective way to identify the crack .In this paper review of these two parameter carried out for effective identification of crack in a Rotor-shaft system.

Keywords: *Condition monitoring, Crack Detection, Fracture, Rotating Machinery*

1. Introduction

In previous few years, major efforts have been devoted to developing non-destructive techniques for damage identification in structures. As rotating machinery designed in such way that it operates at higher efficiency ;operating speed, power and load are increased as weight and dimensional tolerance are decreased. The result is significantly increased level of operating stress in modern rotating machinery. As a consequence, many practical rotor dynamic systems contain shaft/rotor elements that are highly susceptible to transverse cross-sectional cracks due to fatigue. To accurately predict the response of a system to the presence of a transverse crack, an appropriate crack model is essential. Once the crack is included in the system model, unique characteristics of the system response can be identified and attributed directly to the presence of the crack. These predicted indicators then serve as target observations for monitoring systems [Itzhak Green, 2005] .To investigate the use of the 2X and 3X super-harmonic frequency components for detecting the presence of a single transverse breathing crack in a non-linear rotor system. This procedure is based on the detection of the super-harmonic frequency components of the non-linear dynamical behavior at the associated sub-critical resonant peaks.[A.K.Darpe,K. Gupta, 2003] The stability of a rotor system presenting a transverse breathing crack is studied by considering the effects of crack depth, crack location and the shaft's rotational speed. The harmonic balance method, in combination with a path-following continuation procedure, is used to calculate the periodic response of a non-linear model of a cracked rotor system. [Jean-Jacques Sinou, 2007] A comprehensive survey of available literature on damaged structures was carried out by [G.M. Owolabi, 2007], to determine the current state of the crack detection technology. The paper discussed the various methods used for structural integrity monitoring of nuclear power plants, large civil engineering structures, rotating machinery, etc.

A more comprehensive survey was presented later by [Jinhee Lee. 1997]. This survey reviewed the numerous technical literatures available on detection, sizing and location of structural damage via vibration-based testing. It categorized the various methods available for crack detection according to the measured data and analysis techniques. A comprehensive survey of available literature Flexural vibrations of a rotor system with transverse or slant crack is analyzed under torsional excitation by numerical simulation and experiment. Numerical results show that combination frequencies of the rotating speed and the torsional excitation frequency are prominent in the flexural responses of a slant-cracked rotor, but too weak to be identified for a transverse-cracked rotor. In order to verify the results, an experimental setup is installed to simulate the cracked rotor system and a special structure is

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*Corresponding author: Vaibhav J Suryawanshi designed to exert the torsional excitation on the cracked rotor [Yanli Lin, 2009]. In recent years, significant efforts have been devoted to developing non-destructive techniques for damage identification in structures. The work reported in this paper is part of an ongoing research on the experimental investigations of the effects of cracks and damages on the integrity of structures, with a view to detect, quantify their effect by identifying some parameter such as critical speed and RMS velocity.

2. Overview of Cracks

There consist of two stages in crack development; crack initiation and crack propagation. The former caused by mechanical stress raisers, such as sharp keyways, abrupt cross sectional changes, heavy shrink fits, dents and grooves and/or metallurgical factors, such as flows, fretting, and forging. The latter stage, namely crack propagation, can accelerate the growth rate under different conditions; operating faults generated during sustained surging in compressors negative sequence current or grounding faults in generators and coupled turbine, the presence of residual stresses in the rotor material, thermal stresses, and environmental conditions, such as presence of corrosive medium. Cracks can be classified based on their geometry and orientation as follows: cracks perpendicular to the shaft axis are known as transverse cracks and cracks parallel to the shaft axis are known as longitudinal cracks; cracks at an angle to the shaft axis are known as slant cracks; cracks that open and close, when the affected part of the material is subjected to alternating stresses known as breathing cracks; cracks that primarily remain open are known as gaping cracks or notches; cracks that open on the surface are known as surface cracks; cracks which are not visible on the surface are known as subsurface cracks [Mohammad A, 2010]. An effective detection and identification of cracks occurring in the rotor-shafts is a very important task for reliable and safe exploitation of modern heavily affected rotating machines. Thus, recent advances in machinery dynamics, fracture mechanics and dynamic diagnostics have to be employed to build proper mechanical models and algorithms necessary for thorough investigations and monitoring of these defects [T. Szolc, 2009].

3. Source of vibration in rotating machine Element

3.1 Manufacturing Faults

Departures from perfect geometry are the main items in this category. These faults occur in the geometry of a bearing, shafts, rotors, pulley, coupling, and gear during manufacturing. These include out of roundness of inner or outer race, lack of sphericity of balls, and unequal ball diameters in case of bearing, lack of surface finish in a shaft etc. A possible secondary cause is lack of uniformity in materials of all mention elements of rotating machine, e.g. varying local modulus due to inclusions etc. [Jinhee Lee, 2009]

3.2 Faulty Application, Installation or Operation

Some faults in this classification result directly in imperfect rolling motion, others have obvious mechanical effects. The former category includes assembly misalignment of shaft, race distortion, as well as brinelling of the bearing races (caused, by overloading or impact either during assembly or operation). Looseness or similar faults produce direct mechanical impact effects, [Jean-Jacques Sinou, 2007], Poor or inadequate lubrication can lead to friction and sticking with irregular motion or vibration. At the highly stressed Hertzian contact area, if there is no separating layer or lubricant, the contacting surfaces will weld together and then be broken or sheared apart. Since the contact area is very small only a trace of lubricant is required but this trace is essential (the main purpose of greater oil supply is to remove heat from the bearing preventing deterioration of components due to overheating). Wear particles or other minute debris in the oil produce vibration effects similar to defective lubrication since very small particles can penetrate the lubricant film effectively resulting in metal to metal contact.

3.3 Deterioration of Rotating Components in Service

Continued repetitive loading of a rotating component such as shaft, bearing, coupling will lead to surface fatigue, manifested as pitting, spalling or flaking of races, balls or rollers. Other progressive surface damage mechanisms include corrosion, ‘fretting, abrasive wear (due to contaminants in the oil or some other external source), and other wear mechanisms associated with defective lubrication. All these faults can be regarded as departures from ideal rotating geometry and depending on whether they occur in the inner race, outer race, ball or roller, generate vibration with the same characteristic periodicities, or repetition frequencies as geometric irregularity. Early detection and evaluation of this progressive type of damage which if continued leads to total rotating component failure, is the prime reason for monitoring shaft, bearing, coupling vibration.[G.M. Owolabi, 2003]

4. Other Vibration Sources

4.1 Acoustic Emission

Acoustic emission is generated by very small scale plastic deformation or crack propagation in high stress regions. Slip, dislocation movements, or fracture release energy manifested as a propagating stress wave. In rotating, shaft, the high stress levels are found in highly regions just near the crack propagates. Significant acoustic emission levels thus provide an indication of sub-surface fatigue crack growth, likely to be followed soon after by surface failure such as pitting or spalling.

4.2 External Vibration

Measurements of shaft vibration are complicated because part of the signal detected may be generated elsewhere in the machine. It is often difficult to distinguish the external sources from intrinsic shaft vibration, especially as the shaft form the transmission path between vibrations originating on the rotating assembly and the stationary bearing housing or machine casing where sensors are located.

5. Experimental verification

Experimental setup the validity of the proposed method is testified by an experimental set up of rotor system with three disks, as shown in Fig.1 shows the photo of the experimental setup and the experimental test rig used for measuring the first three frequencies of the rotor system. The axis is D = 0.020 m column cross-section. And L = 0.490m long (support long).Dimensions of the three disks are of diameters d =0.120 m and thicknesses t = 0.016 m. The corresponding material properties are: E =2.06 x 1011 N/m2, ρ = 7860 kg/m3 and m = 1.4 kg. The positional dimensions of the experimental set up are: l1= 0.145m and l2 = 0.100 m and l3 = 0.10 0m. In the experiment, four specimens are used including one intact (uncracked) rotor. The cracked specimens, shown in Fig. 2, are made using a numerically controlled wire-cut electrical discharge machine with extra fine molybdenum filament and its diameter dimension is 0.2mm.A fine slit made in the rotor is visible and wider than any fatigue crack and should be treated as an open crack. A hammer is used to impulse the rotor system. Input signals are sampled with sensors mounted on the bearing pedestal.

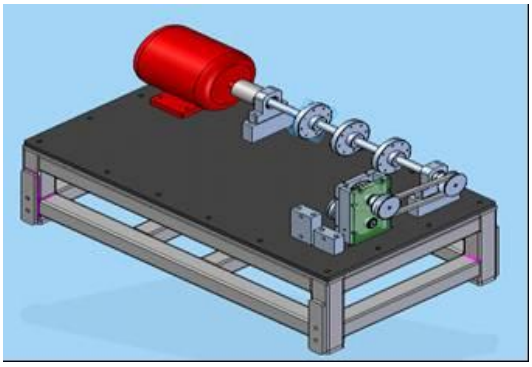

Fig.1 Experimental setup

Fig.2 Cracked specimen

6. Experimental Results and Discussion:

To simulate four types of cracks, specimens with crack depths of 4mm, 5mm, and 6mm at distances of 33 and 44 mm respectively. By using the FFT analyzer analysis is done on the above experimental set up by using accelerometer. Graphs for intact rotor and crack at distance 33mm and 44mm for crack depth 4mm as shown below:

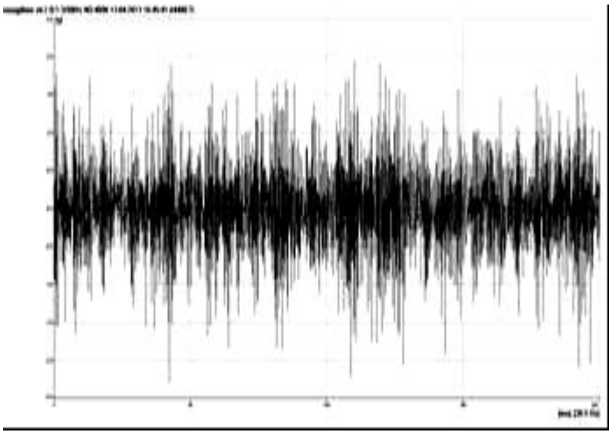

Fig.3 Time spectrum for intact rotor

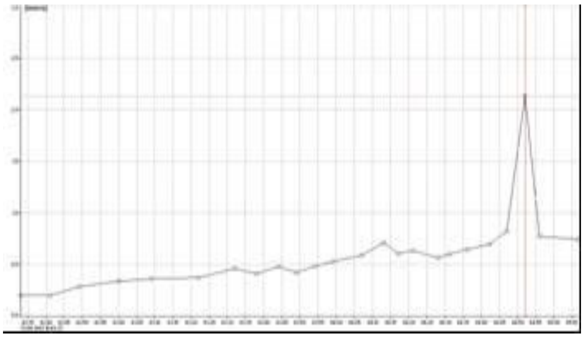

Fig.4 RMS velocity spectrums for intact rotor for run up Condition

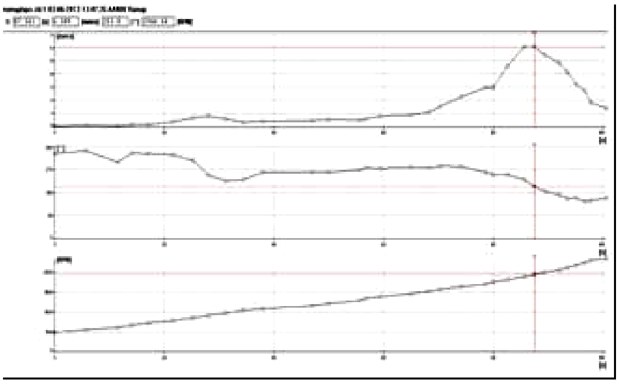

Fig.5 RMS Velocity Spectrum for Crack Position 33 mm from Rotor and crack depth 4mm

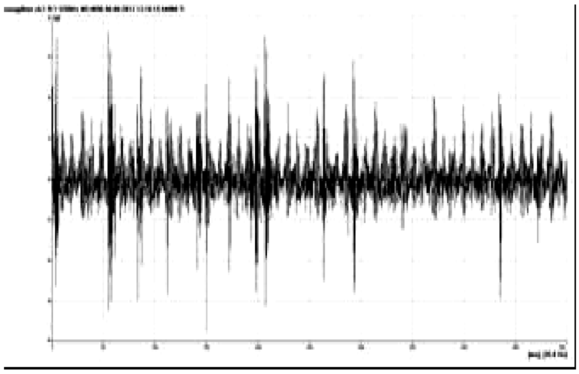

Fig.6 RMS Velocity Spectrum for Crack Position Rotor and crack depth 4mm

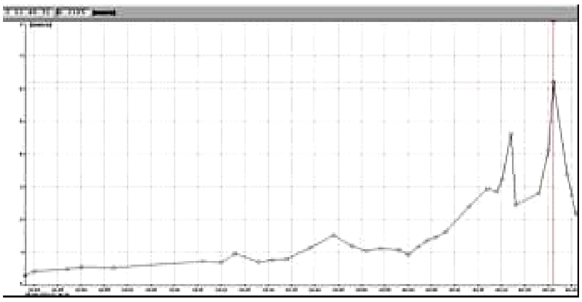

Fig.7 RMS Velocity Spectrum for Crack Position 33 mm from Rotor and crack depth 4mm

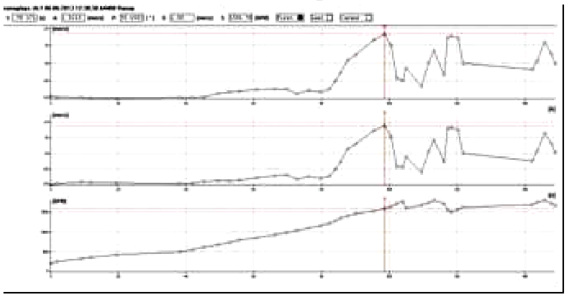

Fig.8 RMS Velocity Spectrum for Crack Position 33 mm from Rotor and Crack Depth 4 mm at Run Up Condition

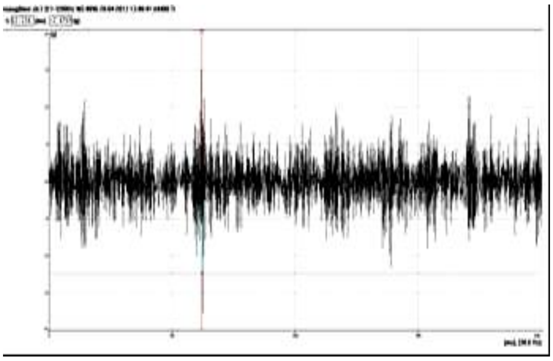

Fig.9 Time spectrum for crack position 44 mm from Rotor and crack depth 4mm

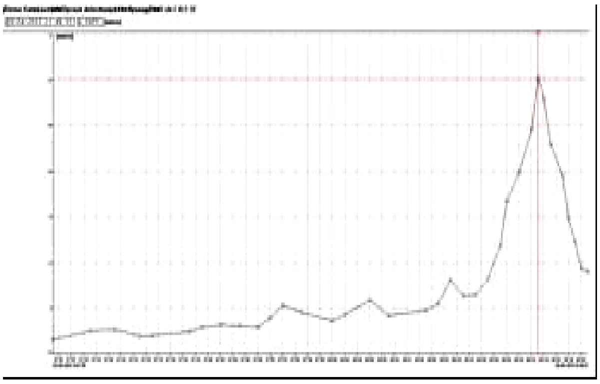

Fig.10 RMS Velocity spectrum for crack position 44 mm and Crack depth 4 mm

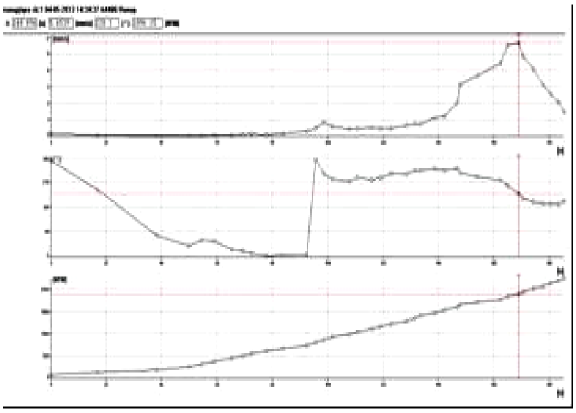

Fig.11 RMS velocity for 44mm crack location and 4mm Depth

From experimental set up different readings are taken for analysis and from that few observation made as follow:

Table 1 FFT readings for analysis of critical speed and RMS velocity of rotor system

From all observations made above some results are plotted and discussed below:

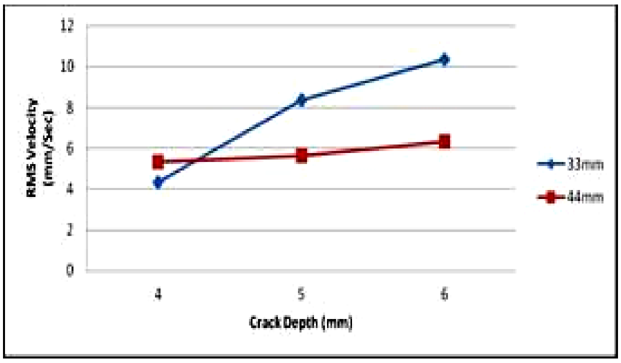

Fig. 12 RMS Velocity (mm/Sec) Vs Crack Depth at Run-up condition

Table 1 FFT readings for analysis of critical speed and RMS velocity of rotor system

			Crack position 33 mm			Crack Position 44 mm		
			Crack Depth			Crack Depth		
	Conditions	Intact rotor	4 mm	5 mm	6 mm	4 mm	5 mm	6 mm
RMS velocity(mm/sec)	Run-up	2.13	4.35	8.35	10.3	5.35	5.65	6.35
Critical speed(rpm)	-	1922	1600	1579	1575	1892	1890	1885
velocity(mm/sec)	1000 rpm	0.235	0.385	0.412	0.452	0.332	0.401	0.532

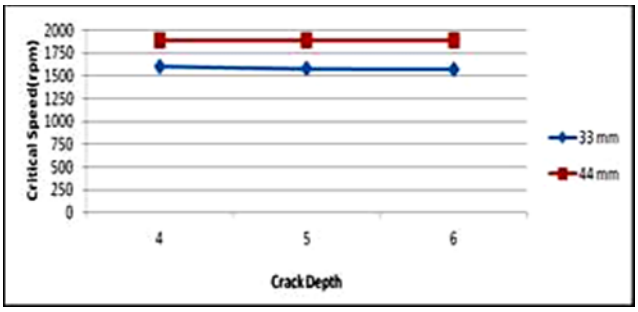

Fig.13 Critical SPEED (rpm) Vs Crack Depth (mm)

Conclusion

This method of identifying parameter such as critical speed and RMS velocity gives positive identification on structure. Critical speed decreases with increase in crack depth .Lower the critical speed as the crack closer to disc. Higher the critical speed as crack away from the disk.RMS velocity increases as crack depth increases.

References

Itzhak Green, (2005), Crack Detection in a Rotor Dynamic System by Vibration Monitoring—Part I: Analysis, Georgia Institute of Technology, ASME.

A.K. Darpe,K. Gupta(2003), Experimental investigations of the response of a cracked rotor to periodic axial excitation", Journal of Sound and Vibration, 260,265–286 .

Jean-Jacques Sinou (2008), Detection of cracks in rotor based on the 2x and 3xsuper-harmonic frequency components and the crack–unbalance interactions, Communications in Nonlinear Science and Numerical Simulation 13 2024–2040.

Jean-Jacques Sinou (2007), Effects of a crack on the stability of a non-linear rotor system, International Journal of Non-Linear Mechanics 42 959 – 972

G.M. Owolabi (2003), Crack detection in beams using changes in frequencies and amplitudes of frequency response functions, Journal of Sound and Vibration 265 1–22.

Yanli Lin (2009), Numerical and experimental investigations of, Flexural vibrations of a rotor system with transverse or slant crack, Journal of Sound and Vibration 324 107–125.

Jinhee Lee (2009) , Identification of multiple cracks in a beam using vibration amplitudes, Journal of Sound and Vibration 326 205–212.

A.S. Sekhar (2004), Model-based identification of two cracks in a rotor system, Mechanical Systems and Signal Processing 18 977– 983, IEEE Std. 802.11, 1997.

T. Szolc (2009), Damage identification in vibrating rotor-shaft systems by efficient sampling approach, Mechanical Systems and Signal Processing 23 1615–1633

Mohammad A (2010), General harmonic balance solution of a cracked rotor-bearing-disk system for harmonic and sub-harmonic analysis: Analytical and Experimental approach, International Journal of Engineering Science 48 921–935.

H.B. Dong (2009), X.F. Chen, Rotor crack detection based on high-precision modal parameter identification method and wavelet finite element model, Mechanical Systems and Signal Processing 23 869–883.

E. Viola (2007), Free vibration analysis of axially loaded cracked Timoshenko beam structures using the dynamic stiffness method, Journal of Sound and Vibration 304 124–153..