

THE INFLUENCE OF LOCATION AND DEPTH OF CRACKS ON THE DYNAMIC CHARACTERISTICS OF ROTORS DURING RUN-UP CONDITION

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ABSTRACT

Rotating machines are widely used in various industrial sectors. Their dynamic characteristics are normally given a lot of thought throughout the design process, especially when crack incidence is taken into account. The influence of a transverse crack in a rotor system on its dynamic behavior was explored in this study. To identify the dynamic parameters of a rotor in terms of vibration responses, natural frequencies, and critical speed, the job entails constructing a numerical model based on displacement-based finite element technique. In building the model, varied fracture depths at different positions along the rotor were taken into account. To test the validity of the developed approach, a numerical example of a rotor system was used. The numerical results demonstrate a distinct shift in the cracked rotating machine's vibration responses, natural frequencies, and critical speed. The size and form of the alteration were discovered to be a function of crack volume and location. The findings suggest a potential tool for an on-line diagnosis and monitoring system.

Keywords: Cracked rotor, Rotating machine, Rotor dynamics, Critical speed.

INTRODUCTION

Turbines, compressors, pumps, jet engines, and other rotating gear are subjected to varying stress conditions, making crack development inevitable. Their critical speeds and vibration responses in reaction to fracture onset are always key concerns. The undamaged natural frequencies of the rotor are represented by critical speeds. One of the key concerns that frequently lead to catastrophic failure in real-world operation situations is cracks forming in spinning machinery. Rotor failure occurs when the cross-section of the rotor that is not affected by the crack becomes insufficient to withstand the imposed load. When the crack reaches a critical size, it will fail quickly. Transverse cracks and longitudinal cracks are the two types of fractures that can be classified based on their geometries. Transverse cracks run parallel to the rotor shaft axis, whereas longitudinal cracks run perpendicular to the shaft axis. Transverse cracks are the most prevalent and dangerous because they weaken the spinning shaft by causing local flexibility in the rotor stiffness by concentrating strain energy in the crack zone. As a result, various studies have focused on such fissures.

The vibration-based technique was used in a large portion of the published literature on identifying and diagnosing rotor cracks. There are two types of signal-based and model-based approaches to this technology. Spectrum analyzers, proximity probes, and phase reference are used in signal-based methods to measure and monitor. Model-based strategies mimic cracked rotor behavior during operation using numerical or analytical models, and then connect the observed vibration pattern with the presence of a fracture at specific locations on the rotor.

The fundamental concerns include modeling cracked rotor dynamics and analyzing their dynamic response. In this case, a suitable mathematical model for the broken rotor is necessary for accurate dynamic response prediction. In this field of study, a great number of studies have been completed, and numerous notable achievements have been produced.

To the best of our knowledge, most studies primarily focus on evaluating alternative ways to analyze dynamic behavior of rotors with crack incidence, with limited research on analyzing the fractured rotor's instantaneous reaction during machine run-up. As a result, the focus of this study is on the dynamic behavior of a broken rotor during machine startup, taking into account varied crack depths and locations. The Timoshenko beam element was used, which had two nodes and four Degrees of Freedom (DOFs) per node.

Gyroscopic moments, translational and rotary inertia, and transverse shear deformations are all taken into account. To introduce the transverse fracture on the rotating shaft, an analogous beam element model is used. In addition, the model takes into account the rotary machine's geometry as well as the bearing supports' flexibility. To evaluate the dynamic behaviour of the broken rotor system, simulations for numerical examples are used. The impact of various fracture depths and placements on dynamic characteristics is thoroughly explored. The findings of this study may be useful for rotating machine designers, as well as for rotating machinery health monitoring and diagnosis [1-7].

MATERIALS AND METHODS

Mathematical model for a cracked rotor

In order to undertake dynamic analysis in the design of modern machines, modeling and simulation techniques are widely used in the design stages and analysis of rotor-bearing systems. As a result, possible issues can be identified early in the design process. To address the issue of dynamic behavior of rotary machines in the presence of cracks, a finite element approach was used to construct a displacement-based computer model.

The rotor, which generates or transmits electricity from one location to another, is the most important component of any rotating machine. A spinning shaft carries various machine parts such as turbine wheels, impeller wheels, and gears in the rotor. In general, the rotor is not completely rigid, and in some situations, it is rather flexible. Two or more bearings can be used to support the rotor. Bearing location, stiffness, and damping qualities all play a part in determining dynamic performance.

The spinning shaft was modeled with a Timoshenko-type beam that took into account shear, rotational inertia, and the influence of gyroscopic coupling. Mass, polar, and diametric mass moments of inertia are added into typically stiff discs. Linear springs and dashpots can be used to model bearings. Finite element modeling approaches can be used to determine the rotor-bearing system matrix.

Modeling the cracked section

In this research, the transverse crack in a rotating shaft is modeled as a circular segment within the cracked beam element. Consequently, the crack influence can be expressed as the reduction in the element second moment of area at the crack position (Figure 1).

Fig. 1. Modeling cracked beam section

Where h and W refers to depth and width of the crack respectively, θ is the angle proportional to crack depth and denotes the radius of the shaft.

The angle (θ) can be found as in below:

(1)

Consequently, for a given crack depth, the area of the cracked segment () can be determined by:

(2)

The moment of inertia of the cracked segment () can be defined as given below:

(3)

The effective moment of inertia of the cracked beam element () can then be calculated by:

(4)

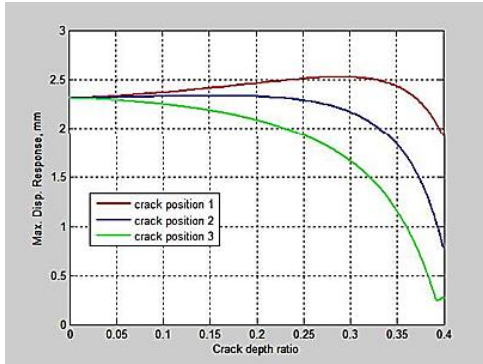


Fig. 5. Maximum displacement response for a wide range of crack depth ratios.

The findings of the displacement responses, frequency responses, and, as a result, the machine critical speed are obtained in each case of fracture positions, as detailed below.

The frequency and displacement responses obtained for fracture position 1 (10 mm distance from the left bearing support) are shown in Figures 6 and 7, respectively (Figures 6, 7A and 7B).

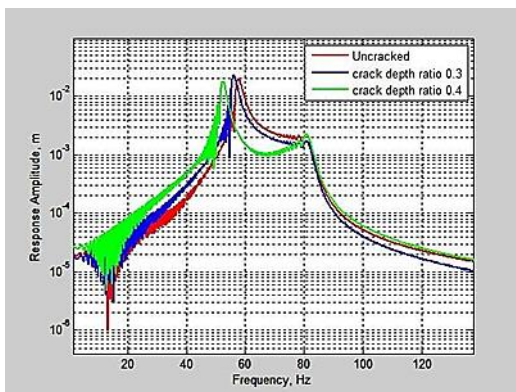


Fig. 6. Frequency response during rotor running up for crack position 1

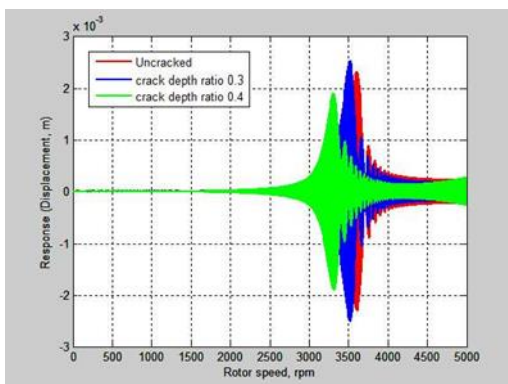


Fig. 7A. Displacement response during rotor running up for crack position 1

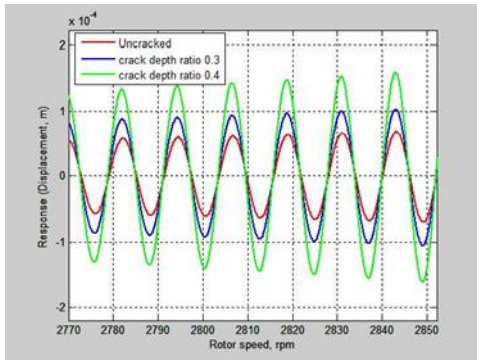


Fig. 7B. Displacement response during rotor running up for crack position 1

For crack position 2 (30 mm distance from the left bearing support), the results obtained for frequency and displacement responses are depicted respectively (Figures 8, 9A and 9B).

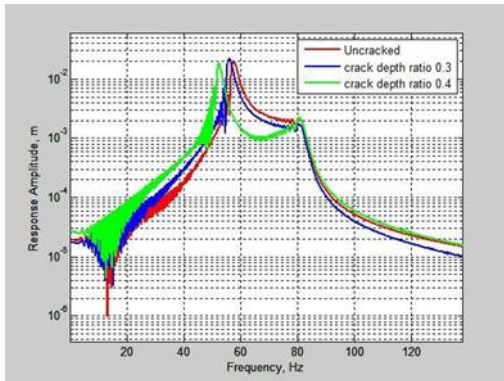


Fig. 8. Frequency response during rotor running up for crack position 2

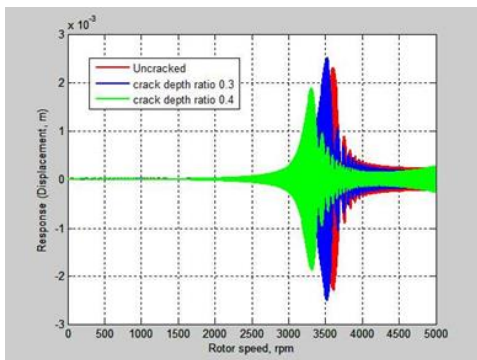


Fig. 9A. Displacement response during rotor running up for crack position 2

Fig. 9B. Displacement response during rotor running up for crack position 2
For crack position 3 (50 mm distance from the left bearing support), the results obtained for frequency and displacement responses are presented respectively (Figures 10, 11A-11C).

Fig. 10. Frequency response during rotor running up for crack position 3

Fig. 11A. Displacement response during rotor running up for crack position 3

