IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

# A review on vibration analysis of rotor with defective blade

**Mr.Sawant B.B**[1] **Prof.S.A.Sonawane**[2]

*1 PG Student, Design Engineering SKN SCOE,Korti -Pandharpur, Maharashtra, India*

*2 Assist.Professor,Dept.of Mechanical Engg, SKN SCOE,Korti -Pandharpur,Maharashtra, India*

**ABSTRACT :Competition and high quality requirements in the industries have necessitated the need for reliable rotating machines. This can be partly achieved by continuous monitoring of operation conditions to detect any fault before it causes serious problem or breakdown of rotating machines. The detection of faults in rotating blades via direct blade vibration measurements and analysis is somewhat difficult because blades often operate in a very harsh environment (gas turbine blades are rotating in high temperature and pressure environment). This paper presents indirect detection of blade faults from vibrations of a rotor-disk-blade system, which can easily be measured, using laboratory test-rig. A rotor, disk, 6 normal blades with different defects were designed. The modal parameters of the normal and defective blades were determined experimentally and by modal analysis using ANSYS. The results revealed that defective blades showed some distinct characteristics in the frequency domain, which can be used to identify blade faults in a bladed rotor-disk system**.

## I.INTRODUCTION

Vibration is a continuous cyclic motion of a structure or a component. A vibrating object moves to and fro, back and forth motion. We experience many an example in our daily life like vehicles driven on rough terrain vibrates. There are various ways we can tell that something is vibrating. We can touch a vibrating object and feel the vibration. We may also see the back and forth movement of a vibrating objects.

*Sources of vibration:*

1) Misalignment of couplings, bearings and gears.
2) Unbalance of rotating components.
3) Looseness, cracks
4) Deterioration of rolling element bearings
5) Gear wear
6) Eccentricity of rotating components such as "v "belt pulleys or gears

## II.LITERATURE REVIEW

*a.Present Theories & Practices:*

**B.O. Al-Bedooret *et. al.* [1]:** In present work,a review of Stability analysis of rotating blade bending vibration due to torsional excitation is presented in this paper. This paper studies the forced vibrations of a flexible rotating blade under the excitation of shaft torsional vibration. A reduced order nonlinear dynamic model is adopted, wherein the torsional vibration degree of freedom is substituted by a simple harmonic motion with a frequency that is function of the system rotating speed. The resulting system of second-order ordinary differential equation

**Yuhua Li, *et. al.* [2]:**This paper aims to develop a method that provides instantaneous speed information in the form of angular displacement. It addresses the general process and considerations that ensure effective measurement of instantaneous angular speed (IAS). The paper then presents two different techniques: one is based on a general-purpose data acquisition system, another uses pure software implementation. Both methods aim to maximise the use of hardware resources without incurring additional costs in the form of upgrades to the measurement system. Finally, an optimization of measurement system parameters for a reliable IAS measurement has been carried out based on measurement error analysis

**D. Knappett *et. al.* [3]:**In this paper correlation between Blade tip timing and strain gauge system to measure the vibration response of rotor blade is reviewed.This paper shows that both systems can be used with the finite-element model (FEM) to calculate the same amplitude-frequency level on the blade. This is provided that certain assumptions about the behavior of the blades are true and that the uncertainties within both measurement systems are considered. The paper also presents a novel way of reporting the data to give a visual display of the quality of the data.

**P. Charles, *et. al.* [4]:**This work presents an investigation of the diesel engine combustion related fault detection capability of crankshaft torsional vibration. The encoder signal, often used for shaft speed measurement, has been used to construct the instantaneous angular speed (IAS) waveform, which actually represents the signature of the torsional vibration. The paper discusses two typical experimental studies on 16- and 20-cylinder engines, with and without faults, and the diagnosis results by the proposed polar presentation method. The results were also compared with the earlier FFT-based method of the IAS signal.

**Zdzislaw Mazur, *et. al.* [5]:**In this paper the last-stage blades failure evaluation was carried out. The investigation included a metallographic analysis of the cracked blades, natural frequency test and analysis, blade stress analysis, unit's operation parameters and history of events analysis, fracture mechanics and crack propagation analysis. This paper provides an overview of this failure investigation, which led to the identification of the blades torsional vibrations near 120 Hz and some operation periods with low load low vacuum as the primary contribution to the observed failure.

**S. Madhavan, *et. al.* [6]:**This paper describes the problems concerning turbine rotor blade vibration that seriously impact the structural integrity of a developmental aero gas turbine. Experimental determination of vibration characteristics of rotor blades in an engine is very important from fatigue failure considerations. The blades under investigation are fabricated from nickel base super alloy through directionally solidified investment casting process. The blade surfaces are coated with platinum aluminide for oxidation protection. A three dimensional finite element modal analysis on a bladed disk was performed to know the likely blade resonances for a particular design in the speed range of operation. Experiments were conducted to assess vibration characteristics of bladed disk rotor during engine tests. Rotor blade vibrations were measured using non-intrusive stress measurement system, an indirect method of blade vibration measurement utilizing blade tip timing technique. Abnormalities observed in the vibration characteristics of the blade tip timing data measured during engine tests were used to detect the blade damage.

**Guai Yeu Kae, *et. al.* [7]:**This study involved the use of vibration analysis and dynamic testing of blades for failure detection. Current field inspections of blades are based on visual inspections only, and the intent here was to use impact testing of the blades during these inspections to determine cracked blade (from the vibration response). Vibration impact tests were undertaken using decommissioned turbine blades with and without cracks in the laboratory. Four common crack patterns were deliberately induced to the turbine blades to investigate changes in the blades normal mode response. Finite element analysis (FEA) of the blades was also undertaken. FEA results were correlated to experimental results and these results showed that each crack pattern was unique and significant changes were found in higher modes. Dynamic vibration analysis was also undertaken in a laboratory test rig fitted with rotating model straight blades.

**Ahmed A. Gubran, *et. al.* [8]:**In the present research study, the dynamics of the blades both in the healthy and cracked conditions are studied on a small experimental rig using the on-bearing vibration and shaft torsional vibration which are measured using the accelerometer and the incremental shaft encoder. The measured vibration and encoder data are analyzed by computing the responses at different engine orders (EOs) related to the blade resonance frequencies and their higher harmonics to understand the behavior of the blades.

**Ahmed A. Gubran, *et. al.* [9]:**In this study, a number of experiments on an experimental rig with a bladed disk were conducted using 2 types of blades (long and short blades) with healthy but mistuned blades and with different faults simulation in the blades. The paper presents the experimental setup, simulation of blade faults, experiments conducted, observations and comparison of results between the long and short blades with and without faults

**A.Rama Rao, *et. al.* [10]:**The paper is about a proposed innovative method of detecting the presence of blade vibration in operating turbine. The method is based on vibration analysis of the turbine casing. The casing vibration also includes the signals associated with the blade passing frequency (BPF) component. When the rotating blades vibrate, the analysis of changes in the BPF is a novel way of diagnosing blade vibrations. Signals captured from operating plants have been analysed and blade vibrations detected.

## II.FINDINGS

1) There is necessity of blade health monitoring for preventive maintenance.
2) It has been observed that blade faults in gas turbines cause up to 42% of engine failures, the highest of all failure modes.
3) Under dynamic vibration analysis natural frequency of blade will change if defect is present on the rotating blade.
4) Blade tip time (BTT) method is used for the blade heath monitoring (BHM) in the recent days, however the measurement procedure and data analysis are quite complex.
5) When the rotating blades vibrate, the analysis of changes in the BPF is a novel way of diagnosing blade vibrations.
6) Torsional vibration of rotating shaft can also detect the fault in rotating blade.

## III.DESIGN OF EXPERIMENT

*a. Objectives*

1. To design and develop experimental test rig for torsional vibration analysis of rotating shaft.
2. To analyze the vibration response characteristics for healthy blade and defective blade with mistuned effect, blade root looseness and crack on the blade.
3. To analyze vibration response characteristics of healthy and defective blade for variable speed.
4. To study effect of various defect on blade natural frequency at different speed.

*b. Methodology:*

**1) Selection of blade rotor:**

An six blade rotor is selected for the experimental study. The parameters will be decided with respect to rotor.

**2) Preparing Defective sample blade:**

The artificial defects are introduced separately on rotor blade. The defects on the blade are made at different location.

**3) Deciding the running situations:**

The parameters like change in speed range of shaft, size of defect on defective blade, different defect locations in a blade are decided which can be applied on the rotor-blade system during test.

*c. Faults simulation and experiments:*

Three different blade faults were simulated for the experiments. These conditions of blade are:

(a) Case 1: Healthy blades with mistuned effects
(b) Case 2: Blade root looseness
(c) Case 3: Crack on blade(s)

**(a) Case 1: Healthy blades with mistuned effects:**

The healthy blade with mistuned effect for the blades is tested initially where the variation in the 1st natural frequencies observed. It is the most likely condition of the healthy blades in any rotating machines like the steam turbines, gas turbines, etc.

**(b) Case 2: Blade root looseness:**

If the blades are not properly mounted and assembled on the shaft disc then the blades root may be loose that could result in rubbing during machine operation which may lead to the failure. Hence this root looseness fault is simulated by putting 2 free loose washers on the root of Blades 1 and 4 separately.

**(c) Case 3: Crack on blade(s):**

A small cut on blade of 0.6 mm width by a thin saw was made on 2 blades but at different locations. The crack made on the 2 blades is shown in Fig and the cracked blades in the rig in Fig. Here, a total of 4 tests were conducted for the cracked blade case to understand the dynamic behaviour of crack blade(s) in different combinations; crack in a single blade but different location, crack in 2 blades simultaneously and the impact on the dynamic behavior when a crack blade,is tested after 100 min of machine operation

*d. Designing The Experimental Test Rig For Measurement Of Vibration Data:*

Experimental setup shown in Fig.1 consists of: (a) 1/2 hp 3-phase motor, (b) two ball bearings, (c) a steel shaft, (d) a bladed disc with six rectangular blades, and (e) a flexible coupling between the motor shaft and the rotating rig shaft. The signatures of the vibration will be collected for various running parameters using the FFT analyzer which is available at SKN COE, Korti,Pandharpur and has an accelerometer as a sensor. The sensor will be directly attached to bearing outer race. The readings will be obtained in the form of displacement, velocity and acceleration with respect to time and frequency. The signatures obtained will be analysed to formulate the results. The results will then tabulated and will be presented in the form of graphs.

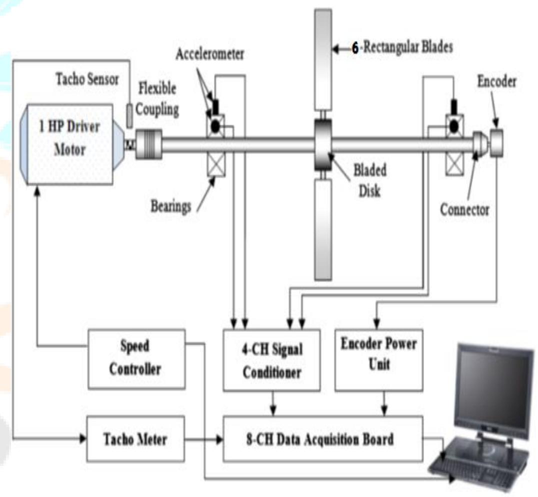


Fig.1 The experimental setup of the blade test system.

**TABLE I**

SHAFT–DISK–BLADES DATA:

| Part | Property | Value |
|---|---|---|
| **Shaft** | Material | Stainless steel |
| | Length | 500mm |
| | Diameter | 20mm |
| **Disc** | Material | Steel |
| **Blade (6 numbers)** | Material | Steel |
| | Length | 110mm |
| | Width | 20mm |
| | Thickness | 02mm |

***e. Modal Testing:***

Modal testing has been conducted on the test rig for the six blades in order to determine blade natural frequencies by using the Impulse-Response modal test .Each blade was excited using an instrumented hammer and the vibration responses were measured using a tiny accelerometer weighing just 0.5 g. The blades natural frequencies were identified using the frequency response functions (FRF) calculated from the measured force and acceleration data. The experimentally identified first natural frequency for each blade .A small deviation in blade natural frequencies showing the presence of the blade mistuned effect due to possibly small deviation in blade manufacturing and/or fitting.

*f. Experiments Conducted:*

The vibration experiments have been carried out for all cases (i.e., Healthy, Root looseness and Crack blade). Initially the experiments were conducted at different constant shaft speeds but the excitation of the shaft torsional vibration was not observed to be significant, hence the further experiments were conducted during the machine run-up from 600 rpm (10 Hz) to 1800 rpm (30 Hz). The run-up rate was kept equal to 40 rpm/s. The measured analogue signals by the encoder and tacho sensors were then collected at 50,000 Samples/s and stored into the PC for the further signal processing.

*g. Expected Conclusion:*

In this study the measured vibration signal during machine transient operation was used to understand the dynamics of the rotor blades with and without faults. Experiments were conducted for the 3 different blade conditions: (a) Case 1: Healthy with mistuned effects, (b) Case 2: Blade root looseness and (c) Case 3: Blade crack.

Hence the present observations are definitely encouraging and can be extended further for the BHM. The instrumentation cost and the signal processing are also not exorbitant and can be easily extended to any industrial applications. More experiments are also underway with multistage bladed discs to enhance confidence levels of the present observations.

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