# Comparison of On-Bearing and On-Casing Vibration for Blade Health Monitoring in Rotating Machine

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**Abstract** Rotating blades are considered as the most common cause of failures in rotating machinery. In the present research study, the dynamics of the blades both in the healthy and crack conditions are studies on a small experimental rig using the on-bearing and on-casing vibration, which are measured using the accelerometer on bearing pedestals and on casing cover towards on blades. The measured vibration 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 blade(s) dynamics behavior. The observations suggest that the on-bearing and on-casing vibration measurements can be extended to the non-intrusive method for the blade health monitoring (BHM). Comparative study between the on-bearing and on-casing vibrations on the simple experimental rig further allow to understand which method is more effective for blade damage detection.

**Keywords** Blade vibration · Blade health monitoring (BHM) · Blade faults · Engine orders (EO's) · Order tracking

## 1 Introduction

Rotating blades are considered as the most common cause of failures in rotating machinery which is nearly 42 % of the total failures for gas turbines [1]. The blade failures normally occurred as a result of crack due to unexpected operating conditions and also due to variable of external loads. For this reason, the early detection of damage in the blades is important to reduce the machine downtime, maintenance

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overhead and from the safety consideration. The vibration based monitoring is the most accepted technique used in condition monitoring of the rotating machines. Different vibration-based methods are attempted for the blade health monitoring (BHM) can be found in the literature which includes the vibration measurement on turbine casing, torsional shaft vibration, etc. [2–6]. The recent study [2] also highlights the potential of the use of shaft torsional vibration for monitoring the blade vibration behavior. A number of studies are found in the literature to understand blade excitation and estimation of blade natural frequencies in order to detect blade health condition [7–10]. In this study, the dynamics of the blades both in the healthy and crack conditions are studies on a small experimental rig using the on-bearing and on-casing vibration measurement techniques, which are measured signals using the accelerometers. The instrumentations needed for the on-bearing and on-casing vibration measurement are simples and non-intrusive. The main purpose of this study is to compare between these 2 methods in order to bring out which of these methods is better for the BHM. The experiments are conducted on a test rig having 8-bladed disc for blade conditions; healthy, crack in one blade and crack in two blades and the acceleration data are recorded into the computer during the machine run-up and stored for a further signal processing analysis. The measured vibration data which is obtained by accelerometers from both positions, front bearing pedestal in vertical direction and on casing towards the blades in the mid way between two bearings are analyzed using Fast Fourier Transform (FFT) and by computing the responses at different engine orders (EO's) related to the blade resonance frequencies and their higher harmonics to understand the dynamic behavior of the blades under different blade fault cases.

## 2 Test Rig

A small test rig was designed and manufactured for the proposal study is as it shown in Fig. 1. The rig details, dimensions and material properties are discussed in [2, 3]. Initially shaft-disc-blades system is designed and analysed using the finite element (FE) model constructed in ABAQUS code to understand the natural frequencies and mode shapes of the shaft-disc-blades system to determine the suitable dimensions for the rig. Figure 2 shows the pre-design mode shapes and natural frequencies of shaft-disc-blades system. Small mistuning among the 8 blades is also introduced into the FE model. Blades frequencies were estimated in the range of 184.5–201.65 and 289.49 Hz for the rotor. The rig was then manufactured using the dimensions in accordance to this model. Modal tests were also conducted on the blades and shaft to know the natural frequencies and compare with the FE prediction during design stage.

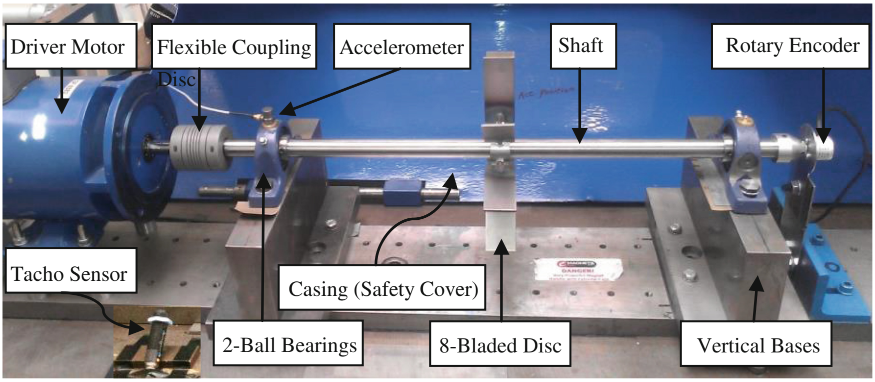


**Fig. 1** Photograph of the test rig

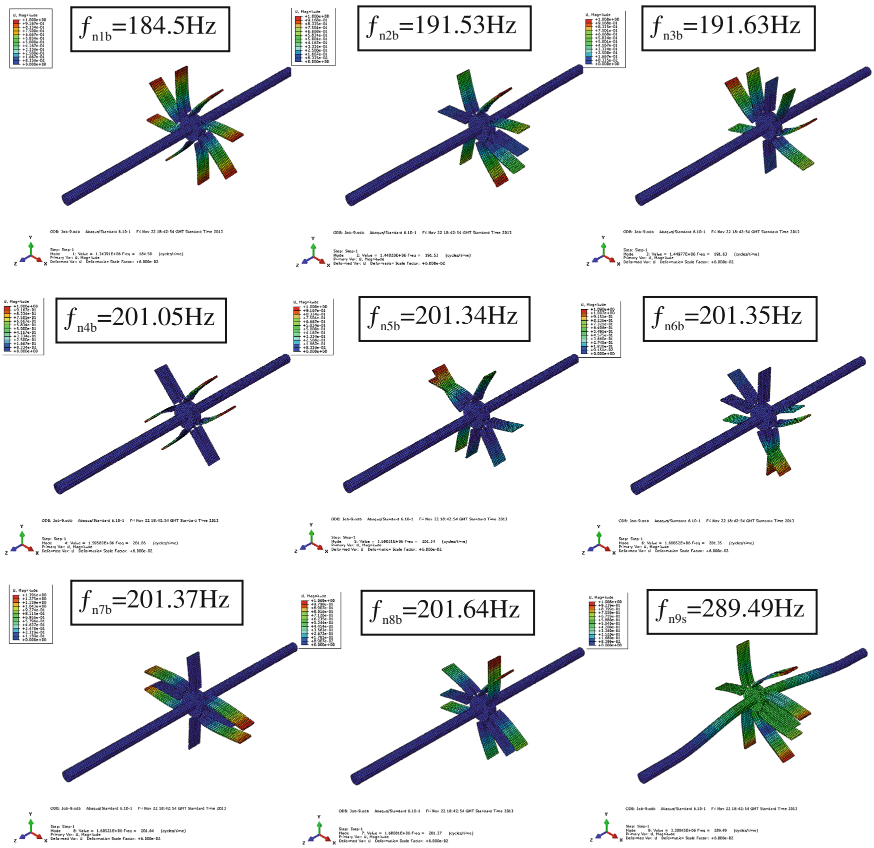


**Fig. 2** Mode shapes and natural frequencies of shaft-disc-blades system using Finite Element (FE) method

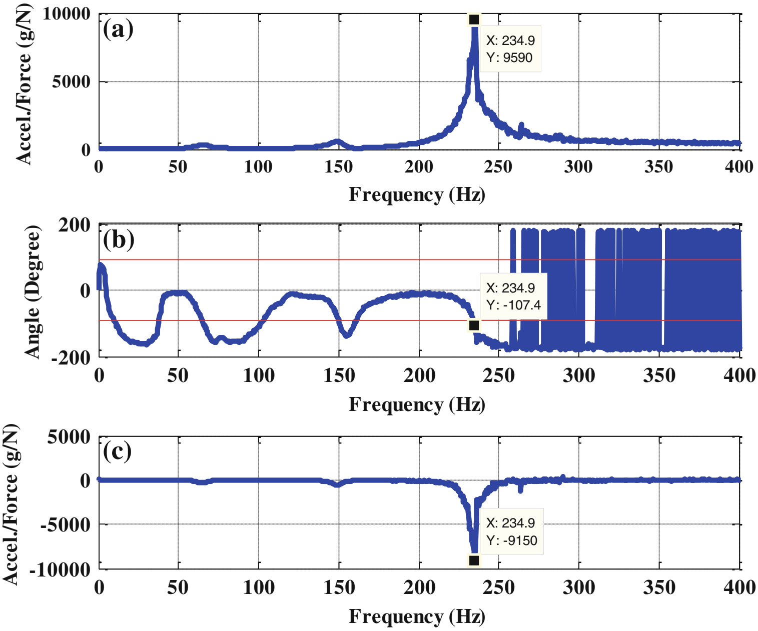


**Fig. 3** A typical FRF plots of blade first natural frequency at 234.90 Hz: **a** Amplitude, **b** Phase and **c** Imaginary part

## 3 Modal Testing

The modal testing for blades has been conducted on the test rig by the Impulse-Response modal test method [11]. The experimentally identified first mean natural frequencies of the eight blades are 235.47 Hz with small deviation ±5.53 Hz due to blade mistuned effect due to the blade manufacturing and/or fitting. A typical frequency response function (FRF) plot of magnitude, phase and imaginary, it shows the blade frequency peak at 234.90 Hz as shows in Fig. 3.

## 4 Experiments and Fault Simulation

The experiments are conducted during the machine run-up from speed of 600 RPM (10 Hz) to 1800 RPM (30 Hz). The run-up rate was for kept equal to 40 RPM's. The data were then collected at 30,000 Samples/s and the data stored on PC for further signal processing analysis in the MatLab.

Three different conditions of blade faults were simulated for the experimental tests. These conditions of blade health conditions are healthy with mistuned effects, crack in one blade and crack in two blades. Experiments conducted are summarised in Table 1.

**Table 1** Blade faults conditions

| Case | Description | Blade no. |
|---|---|---|
| 1 | Healthy blade with mistuned effect | |
| 2 | Crack in one blade | 5 |
| 3 | Crack in two blades | 5 and 7 |

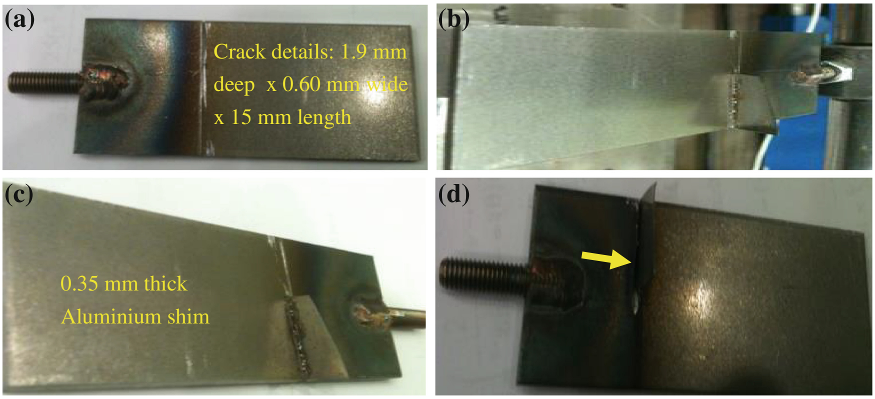


**Fig. 4** Blade faults simulation: **a** Crack dimensions, **b** Cracked blade with shim location on bladed disc on rig, **c** shim in cracked adhesive side, **d** shim in crack non adhesive side

The three conditions of blade conditions were discussed in details in the references [2, 3]. A photograph of blade fault simulation is shown in Fig. 4. The vibration experiments were carried out for all fault cases listed in Table 1.

## 5 Data Analysis, Observation and Discussion

The measured vibration signals from on-bearing and on-casing acceleration signals are processed with the different engine orders (EO's) accelerations to understand the appearance of blade resonances and its dynamics behavior. The accelerometer locations on the bearing and casing are shown in Fig. 5. Typical measured acceleration signals for the on-bearing and on-casing vibration are shown in Fig. 6. The processed measured vibration acceleration signals for the EO10 and EO20 for both on-bearing and on-casing vibrations are shown in Figs. 7, 8, 9 and 10 for all cases. The EO10 is likely to contain the first resonance frequencies of blades and its 2nd harmonics in the EO20. Figures 7a–c and 8a–c) related to the EO10 are shown in the frequency range 220 Hz to 260 Hz related to the first blade resonance (1 × BR) frequency band and it's higher harmonics (2 × BR) in Fig. 9a–c and 10a–c for both on-bearing and on-casing measurements for the easy comparison.

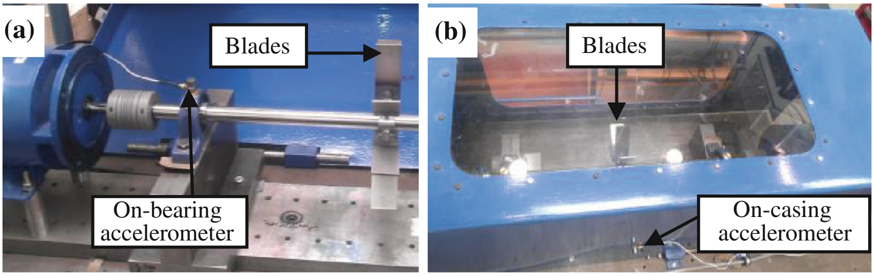


**Fig. 5** Measurement locations on test rig: **a** On-Bearing, **b** On-Casing

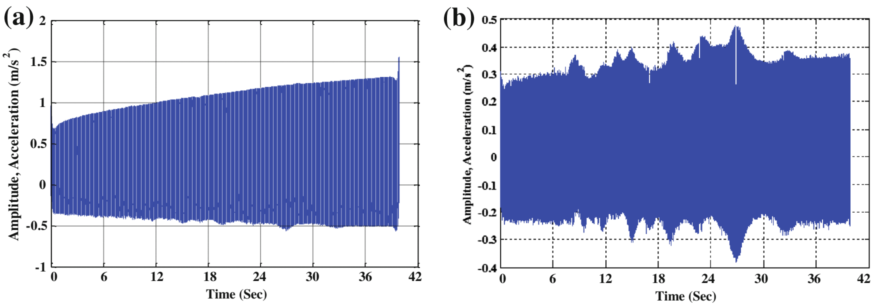


**Fig. 6** Typical measured acceleration signals at machine run up from 600 to 1,800 RPM: **a** On-Bearing, **b** On-Casing

The results was obtained from on-bearing and on-casing vibration for blade conditions of Healthy blades with mistuned effect, crack in 1 blade and crack in 2 blades are discussed and compared on the Table 2.

From the comparison in the Table 2, it is observed that the on-bearing measurements gave a good indication for the cases of more than one crack in blades on bladed disc. Hence the presence of the distinct multiple peaks in the BR region and its higher harmonics for cases of 2 cracked blades or more can be considered as the feature of the BHM. On the other hand, the on-casing signal seems to be given much better blade resonance responses but no indication for BHM when comparing 3 cases.

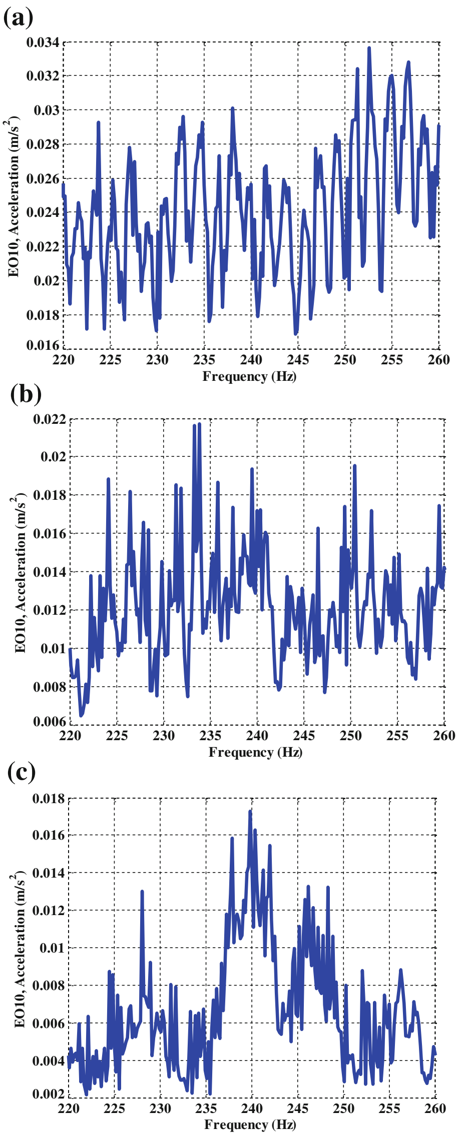


**Fig. 7** On-Bearing acceleration measured data for engine order spectra of EO10: **a** healthy, **b** crack in one blade and **c** crack in 2 blades

**Fig. 8** On-Casing acceleration measured data for engine order spectra of EO10: **a** healthy, **b** crack in one blade and **c** crack in 2 blades

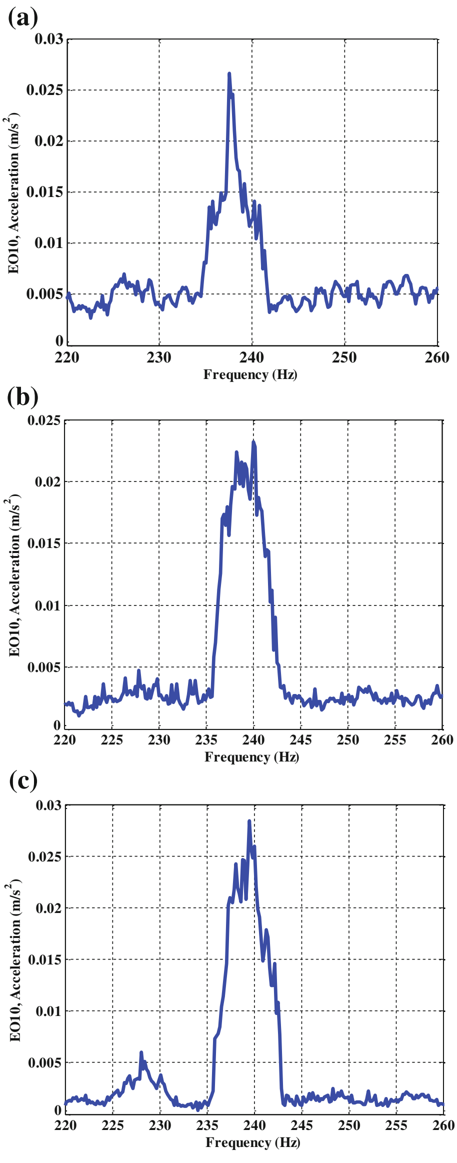

**Fig. 9** On-Bearing acceleration measured data for engine order spectra of EO20: **a** healthy, **b** crack in one blade and **c** crack in 2 blades

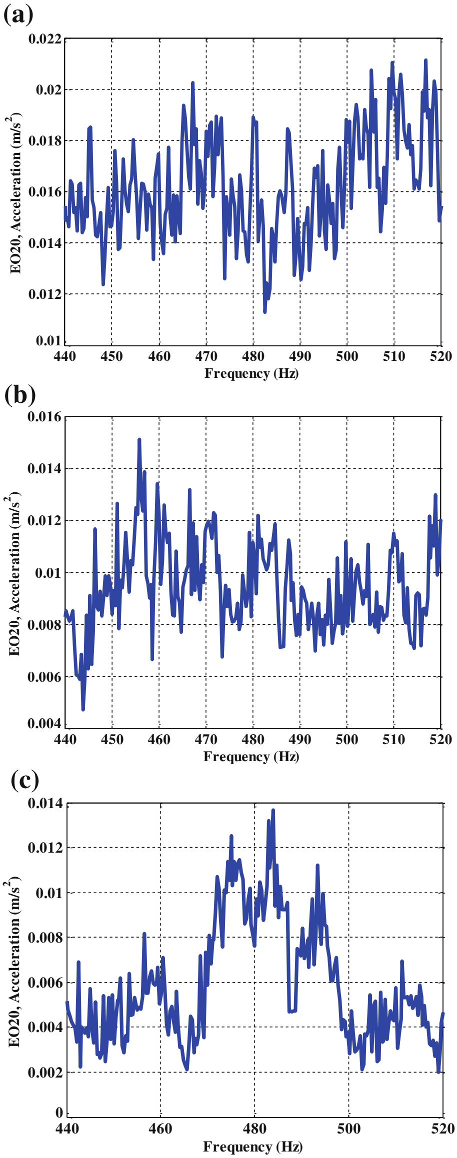

**Fig. 10** On-Casing acceleration measured data for engine order spectra of EO20: **a** healthy, **b** crack in one blade and **c** crack in 2 blades

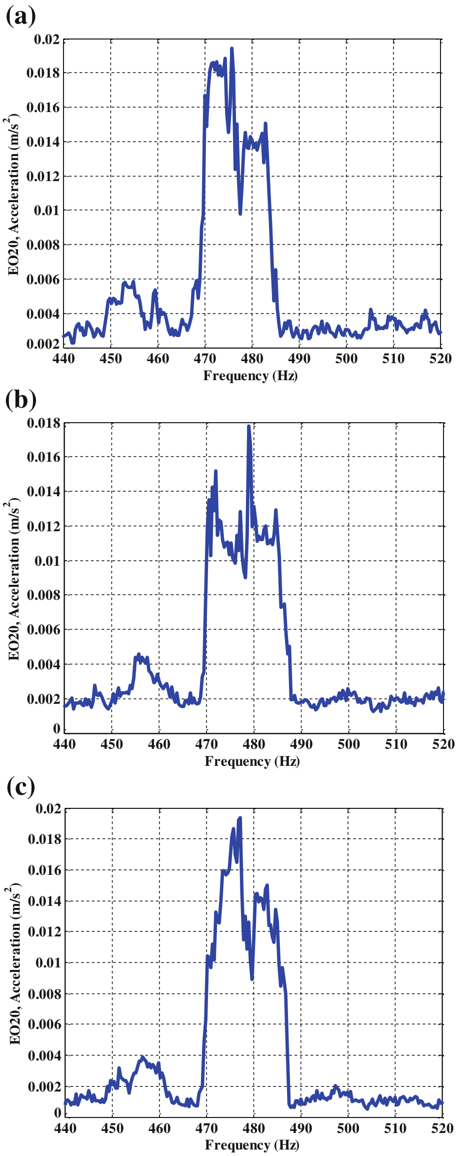

**Table 2** Comparison of the results between on-bearing and on-casing vibrations

| Blade condition | On-bearing vibration | On-casing vibration |
|---|---|---|
| Case 1: healthy with mistuned effect | There are no responses in the blade resonance regions of (1 × BR) and their higher harmonics (2 × BR). As shown in Figs. 7a and 9a respectively | There are a one distinct peak around the frequency 238 Hz confirms the excitation of the blade resonance of (1 × BR) and also at (2 × BR). As in Figs. 8a and 10a |
| Case 2: Crack in one blade | Also, here no BR and no changes in the harmonics regions of (1 × BR and 2 × BR) compared to the healthy case condition in both Engine orders EO10 and EO20. As shown in Figs. 7b and 9b respectively | There are no changes in the blade behavior related to EO10 & EO20 in (1 × BR and 2 × BR) regions compared to healthy condition. Which are appears only single distinct peak as shown in Figs. 8b and 10b respectively |
| Case 3: Crack in two blades | There is a distinct multiple peaks in the (1 × BR and 2 × BR) regions related to the EO10 and EO20 responses respectively. As shown in Figs. 7c and 9c | It's the same to the case 2, which are no changes in the blade harmonics regions of (1 × BR and 2 × BR) for both EO10 and EO20 compared to the healthy case. As shows in Figs. 8c and 10c |

## 6 Conclusion

In this paper the measured vibration data was obtained from on-bearing pedestals and on-casing towards to blades during the machine run-up was used to understand the dynamics behavior of rotating blades with and without faults. Experiments were conducted for three different types of blade conditions, (a) Healthy with mistuned effects, (b) crack in 1 blade and (c) crack in 2 blades. From the results observed that on-casing vibration when order tracked with EO10 and their higher harmonic EO20 shows the existence of BR in all 3 cases. The appearance of the multiple peaks only observed in Case 3 (crack in 2 blades) compared to single peak in Case 1 (healthy) and it could be useful for the BHM, only when crack in 2 blades or more in bladed disc. Note that the on-casing signal seems to be given much better blade resonance responses but unfortunately no indication for BHM when comparing 3 cases in the present experimental rig.

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