

## **BLADE VIBRATION: A COMPARISON OF ON BEARING AND SHAFT TORSIONAL VIBRATION**

**Ahmed A. Gubran, Jyoti K. Sinha\***

School of Mechanical, Aerospace and Civil Engineering (MACE)  
The University of Manchester M13 9PL, UK  
ahmed.gubran@postgrad.manchester.ac.uk (ahmed.gurban1@gmail.com),  
jyoti.sinha@manchester.ac.uk

**Keywords:** Instantaneous Angular Speed (IAS), Blade Vibration, Blade Health Monitoring (BHM), Blade Faults, Shaft Torsional Vibration, Engine Order (EO).

***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 cracked conditions are studied on a small experimental rig using the on-bearing vibration and shaft torsional vibration 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 behaviour the blades. The observations suggest that the shaft torsion vibration can be extended to the non-intrusive method for the blade health monitoring (BHM) when compared with the on-bearing vibration. The paper presents the rig, experiments conducted and measurements, data analysis and the results.*

## 1 INTRODUCTION

Rotating blades are considered as the most common cause of failures in rotating machinery. The blade failure modes are normally occurred as a result of cracking due to unforeseen operating conditions and variable loads. Therefore the early detection of damage in the blades is essential to reduce the machine downtime and from the safety consideration. A number of research studies including the vibration-based methods can be found in the literature related to the blade damage detection. Different vibration-based methods found in the literature are basically includes the vibration measurement on turbine casing, torsional shaft vibration and the recent trend on the blade tip time (BTT) method [1-6]. The BTT [3-4] is receiving attention for the blade health monitoring (BHM) in the recent days, however the measurement procedure and data analysis are quite complex. Recent study [6] highlights the potential of the shaft torsion vibration for monitoring the blade vibration behaviour. In the present research study, the dynamics of the blades both in the healthy and cracked conditions are studies on a small experimental rig using the on-bearing vibration and shaft torsional vibration are measured using the accelerometer and the incremental shaft encoder. The instrumentations needed for the on-bearing and the shaft torsional vibration measurement are simple and non-intrusive. The purpose of the present study is to compare these 2 methods to bring out which of these methods is more effective for the purpose of the BHM. The experiments are conducted on a test rig having 8-bladed disc for healthy, blade looseness and the crack in a blade and data are recorded into the computer during the machine run-up. 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. The observations suggest that the shaft torsion vibration can be extended to the non-intrusive method for the blade health monitoring (BHM) when compared with the on-bearing vibration. The paper presents the rig, experiments conducted and measurements, data analysis and the results.

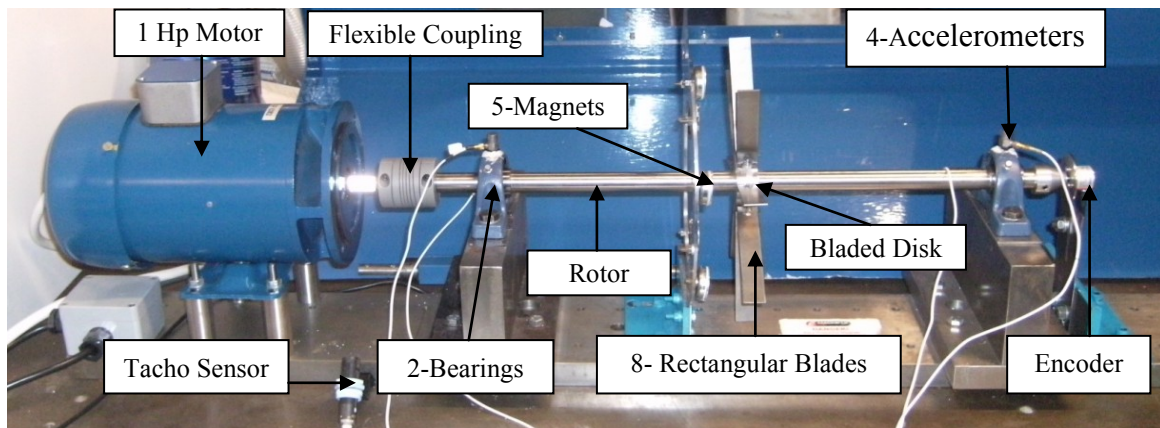


Figure 1: Photograph of the test rig.

## 2 EXPERIMENTAL SETUP

The experimental test rig is shown in Figure 1 [6] which is located in the dynamics Lab at the school of MACE at the University of Manchester. The test rig mainly consists of (a) 1 HP driver 3-phase motor B56, (b) Two SKF type YS 20 TF, ball bearings, (c) a Steel shaft of diameter 20mm, (d) a bladed disc with eight rectangular blades, (e) a flexible coupling between the motor shaft and the rotating rig shaft addition to measurement devices were installed on the rig which consists of (f) a rotary shaft encoder for torsional vibration signal measurement,

(g) an accelerometer for measuring vibration signals on bearing pedestals. The rig photograph in Figure 1 also includes the mounting of vibration accelerometers and the encoder.

The modal testing is also conducted on the test rig and on each blade by the Impulse-Response modal test method [7]. An instrumented hammer (PCB-0860C03) and a small accelerometer (PCB-325C33) are used for this purpose. The experimentally identified first natural frequencies of the blades are in the range of 123.75Hz to 128.75Hz [6]. The small deviation in blades natural frequencies showing the presence of the blade mistuned effect due to the blade manufacturing and/or fitting.

### 3 FAULTS SIMULATION AND EXPERIMENTS

Three different conditions of blade faults were simulated for the experiments. These conditions of blade faults are, Healthy with mistuned effects, Blade root looseness and Crack on a blade. Experimentally faults simulation in blades are discussed in the following sections and also summarized in Table 1. Figure 2 shows blades position with the tachometer sensor location.

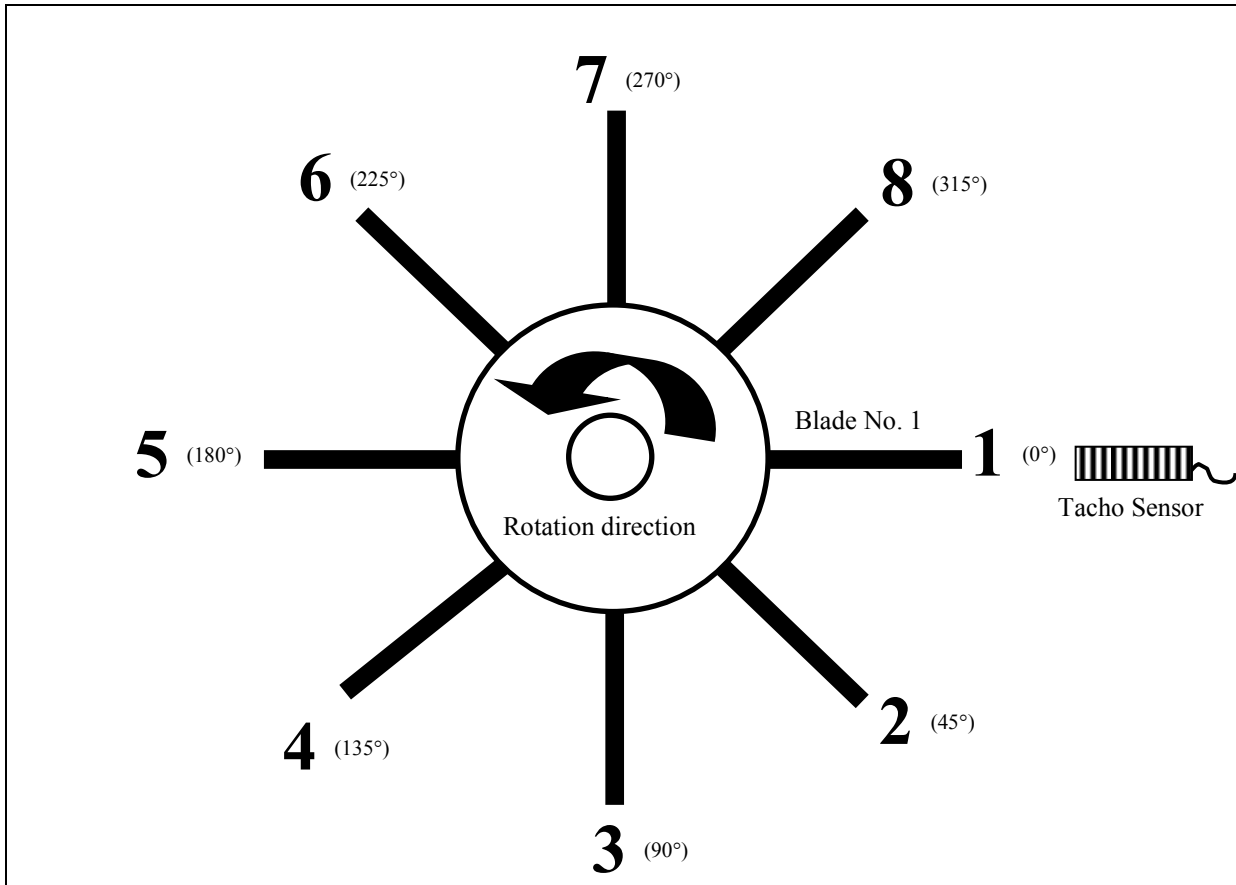


Figure 2: Schematic diagram of the blade positions with respect to the tachometer sensor.

Case	Description	Blade No.
1	Healthy blade with mistuned effect	—
2	Blade root looseness	1
3	Crack on blade	2 & 4

Table 1: Blade faults conditions.

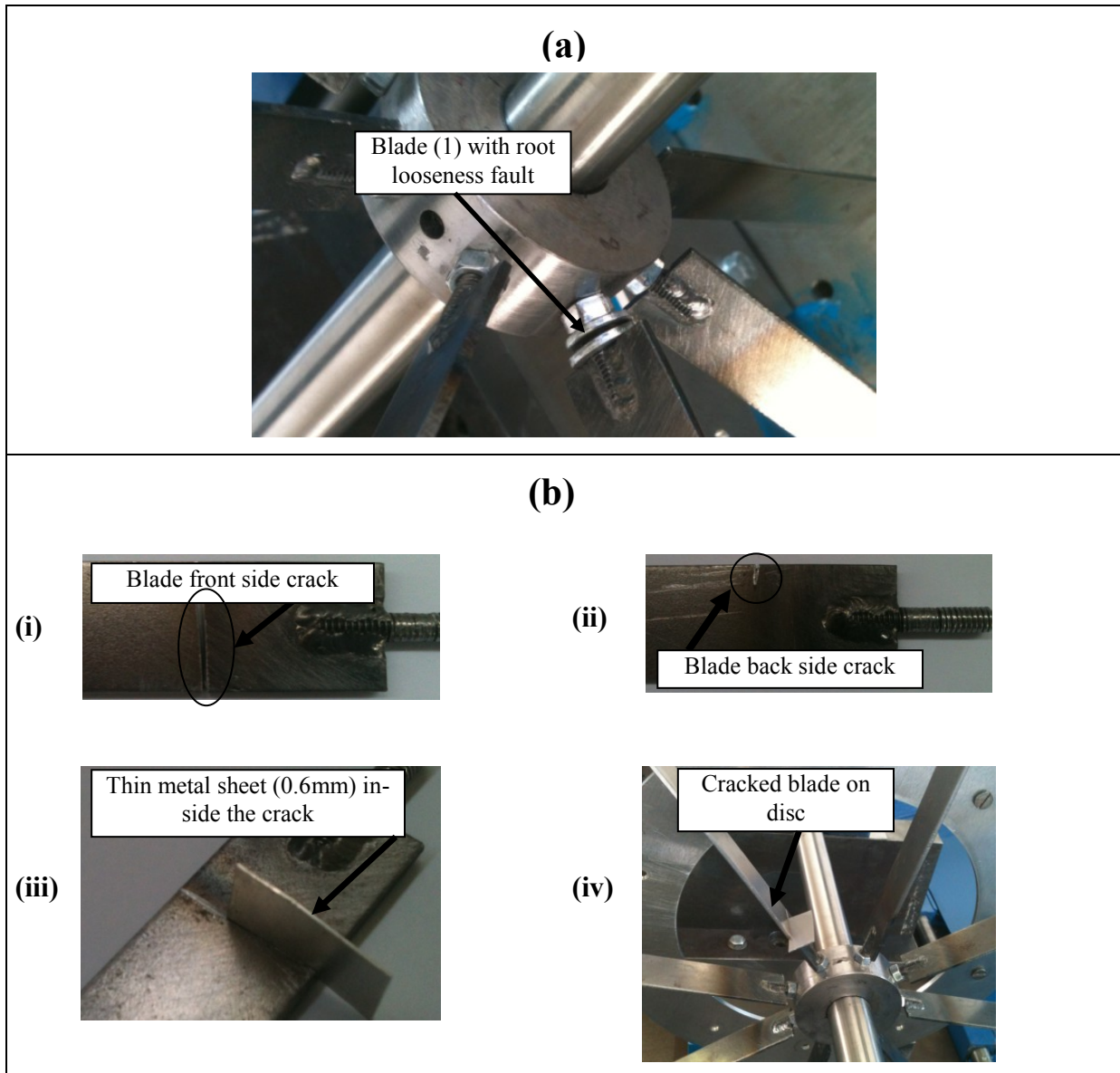


Figure 3: Blade faults simulation: (a) Root looseness, (b) Crack: (i) front side of a crack, (ii) back side of a crack, (iii) a very thin metal sheet in crack, (iv) Cracked blade location on bladed disc on rig.

### 3.1 Blade root looseness

The blade root looseness is also simulated by put 2 free loose washers on the root of blade 1 as per the Case 2 in Table 1. Figure 3(a) shows the root looseness simulation.

### 3.2 Blade crack simulation

A small cut on blade by width of 0.6 mm using a thin saw was made on 2 blades at different locations. A very thin metal sheet placed on blade cut using adhesive glue from one side of cut so that breathing of crack in the blade can be realized during vibration. The crack made on the 2 blades is shown in Figure 3(b).

### 3.3 Experiments conducted

The vibration experiments have been carried out for all cases listed in Table 1 (i.e., Healthy, Blade root looseness and Crack blade). The experiments are conducted during the machine

run-up from 600RPM (10 Hz) to 1800 RPM (30 Hz). The run-up rate was kept equal to 40 RPM/s. The data were then collected at 50000 Samples/s and stored into the PC for the further signal processing analysis.

#### 4 DATA ANALYSIS

First of all the encoder data during the machine run-up are converted into the shaft instantaneous angular speed (IAS) [5] and then tacho signal into the machine speed. The order tracking at different engine orders (EO's) are then carried out using the tacho speed signal for both IAS and on-bearing vibration signals. The order tracking of the IAS and vibration signals at EO5 and EO10 clearly show the blade resonance (BR) region and its 2<sup>nd</sup> harmonics respectively. They are typically shown in Figures 4 and 5. Figures 4 and 5 compared the order tracked responses at EO5 and EO10 in the BR region for both shaft torsional vibration (IAS signal) and the on-bearing vibration signal respectively for the healthy, blade looseness and blade crack conditions.

#### 5 OBSERVATIONS AND RESULTS

It is observed from Figure 4(a) & (b) that the Case 1 Healthy blades with mistuned effect has amplification around the frequency 115Hz (23Hz x 5) to 135Hz (27Hz x 5) confirms the excitation of the blade resonance (BR) during the machine run-up in both on-bearing vibration and shaft torsional vibration using the accelerometer and the incremental shaft encoder respectively. The amplification of the BR region seems to be in a banded form due to the mistuned effect. The higher harmonics of the banded BR region (2xBR) has also been observed in the EO10 shown in Figures 5(a) & (b) even for the healthy condition. Possibly the mistuned effect in the blades could be the reason for the appearance of the higher harmonics even for the healthy case (Case 1).

Case 2 is the blade root looseness at the blade 1. The addition of 2 loosely held washers at the root has not affected the natural frequency of the blade 1 significantly but their EO5 and EO10 responses in Figures 4(c) & (d) and Figures 5(c) & (d) respectively, shows significantly different behaviour compared to the healthy blades in Case 1. Here the 1xBR region shows distinct multiple peaks instead of a single banded peak around 1xBR region for the Case 1 for the healthy as seen in Figures 4(c) & (d). The higher harmonics 2xBR in Figures 5(c) & (d) also show multiple peaks.

Case 3 is the test related to the crack in two blades 2 and 4. Once again the distinct multiple peaks in the (1xBR and 2xBR) regions related to the EO5 and EO10 responses respectively are observed in Figures 4(f) and 5(f) for the shaft torsional vibration. On-bearing data in Figures 4(e) and 5(e) shows single banded peak in harmonics regions (1xBR and 2xBR) but much different than healthy condition.

It is observed that both measurement techniques, on-bearing vibration and shaft torsional (IAS) vibration, gave a good indication to detect blade health conditions. Hence the presence of the distinct multiple peaks in the BR region and its higher harmonics can be considered as the feature of the BHM. However the shaft IAS signal seems to be giving much better indication compared to the on-bearing vibration.

#### 6 CONCLUSIONS

In this paper the measured shaft IAS signal from the encoder data and acceleration signal data from bearing pedestals during the 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) Healthy with mistuned effects, (b) Blade root looseness and (c)

Blade crack. The shaft IAS signal and on-bearing vibration signal when order tracked with the EO5, EO10 and its higher multiples shows the existence of the Blade Resonance (BR) and its higher harmonics for all the 3 cases. The appearance of the multiple peaks during the machine run-up is observed to be useful for the BHM. It has also been observed that the shaft torsional (IAS) vibration give much better results than the on-bearing vibration. Now it is plan to test methods with different size of blades and the number of blades and possibly with more number of stages.

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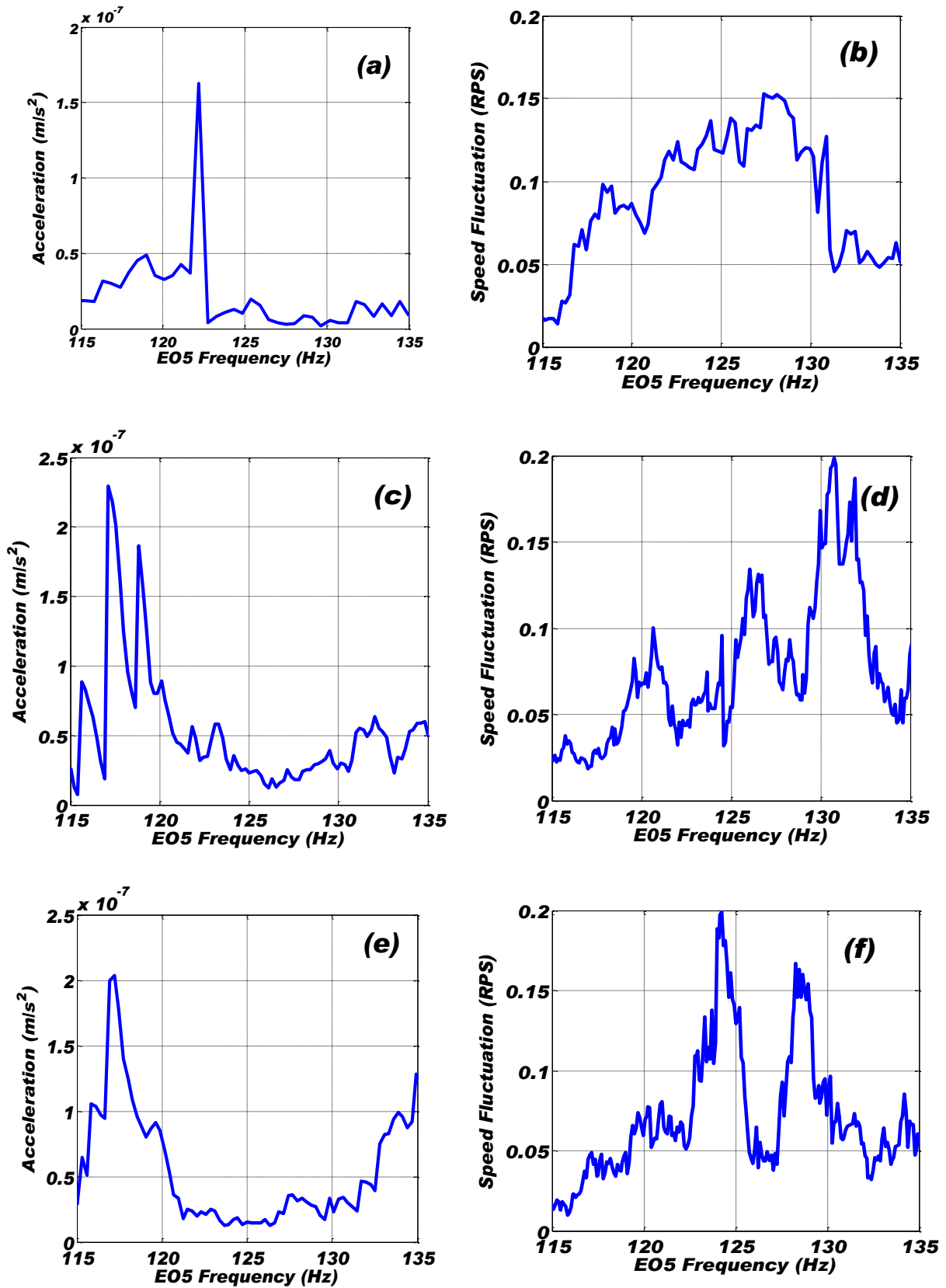


Figure 4: Measured data for engine order spectra of EO5: Figures, (a), (c) and (e) Accelerometer data for healthy, Blade looseness and crack in blade respectively; Figures, (b), (d) and (f) Encoder data for healthy, Blade looseness and crack in blade respectively.

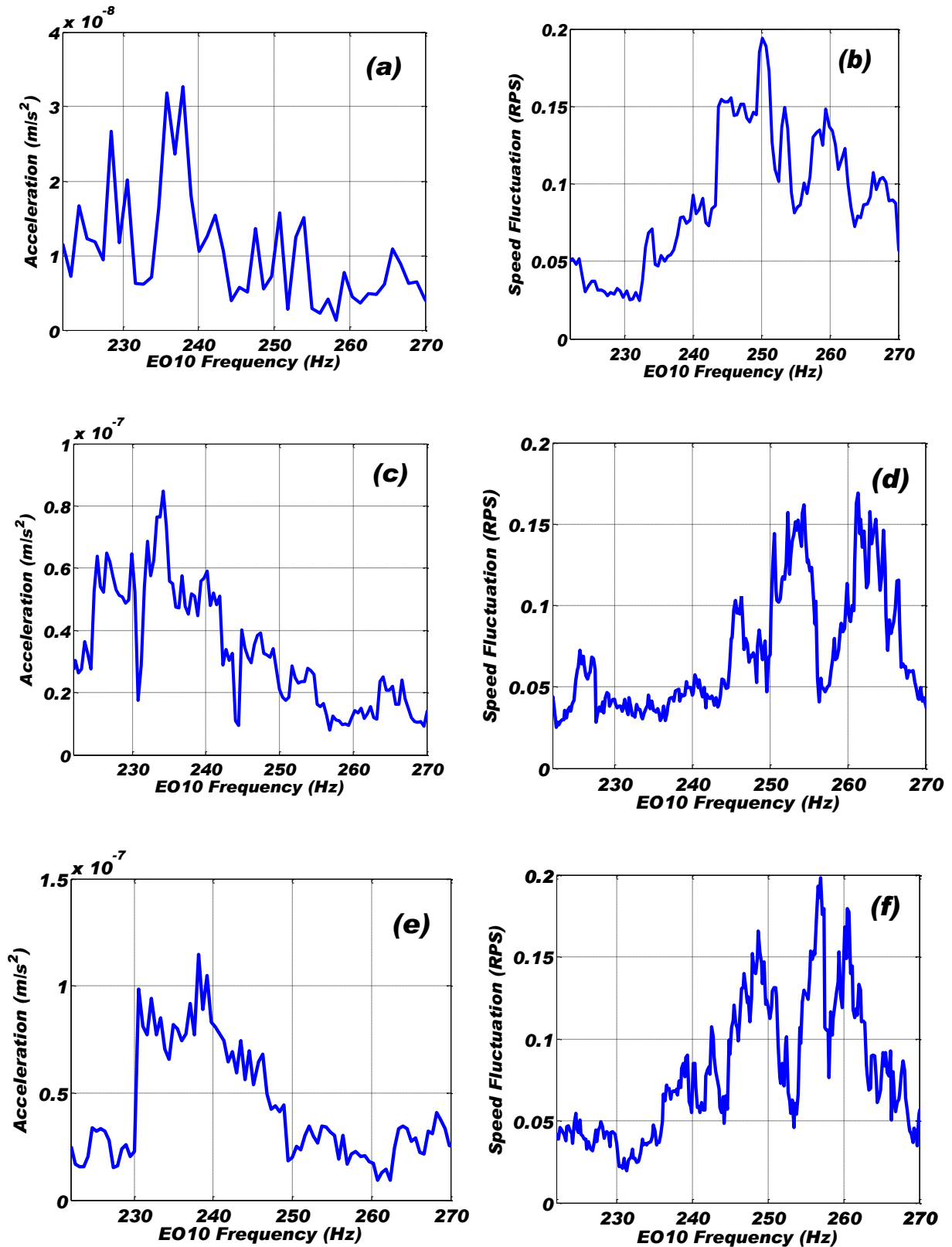


Figure 5: Measured data for engine order spectra of EO10: Figures, (a), (c) and (e) Accelerometer data for healthy, Blade looseness and crack in blade respectively; Figures, (b), (d) and (f) Encoder data for healthy, Blade looseness and crack in blade respectively.