Vibrations of Composite material Beam and Shaft - Laser Vibrometer Vs Accelerometer

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Abstract

This paper presents a comparative study between accelerometer and laser vibrometer measurements aimed at quality measurements carried out on composite material shaft and beam. The experiments have been carried for different number of layers and fiber orientation of composite material beam. Results indicate the great influence of fiber orientation on the natural frequency of the beam. The measurements of laser are much clearer than that of the accelerometer. And other advantages of the laser vibrometer are checked while studying the vibrations of composite shaft.

Keywords: Vibration measurements, laser vibrometer, Accelerometer.

1 Introduction

Modern machinery is bound to fulfill increasing demands concerning durability as well as safety requirements. The concepts of a continuous on-line monitoring system with real time reporting offer the promise of improved knowledge of the condition of a machine and therefore fewer uncertainties in the operating decisions.

The vibration in rotating machinery is mostly caused by unbalance, misalignment, mechanical looseness, shaft crack and other malfunctions. Because of the global nature of the dynamic response of rotors, techniques for detecting damages based on the vibration characteristics of rotors have been gaining importance. As summarized by Hamidi et al. [1], several publications have proposed the use of several techniques such as the use of natural frequencies, mode shapes and frequency response functions for damage detection.

The existing methods are normally based on the use of accelerometers that have demonstrated a good performance in production processes, but installation may pose several problems. Other measurement techniques, like the laser vibrometer, offer the advantage of being a non contact method avoiding the intrusive character of the accelerometer. The single point laser vibrometer is, in fact, being employed nowadays to obtain fast, accurate on-line testing of products during the manufacturing process of an increasing range of appliances and devices.
Thus there are many advantages of using laser vibrometry and the research group intends to fully utilize the advantages of using for flexural and as well as for torsional vibrations

In the approach of structural dynamics, the accuracy depends on the quality of both experimental measurements and signal processing. Particularly, the quality of an approach of Structural Health Monitoring using experimental mode shape analysis (especially for small damage detection) is always dependent on the reliability and accuracy of sensors and also on the experimental sampling [2]. For this reason, original studies have been developed using a Laser Doppler Vibrometer (LDV) [3] or video analysis [4, 5]. Signal processing tools have recently been introduced such as continuous wavelet transform (CWT) [6] in order to detect and identify damage using mode shape data [7-10]. Pai et al. [11] have successfully identified the boundary effects in beams using spectral element analysis and LDV mode shape data. Morlier et al. [12] presented a complete approach to structural diagnosis, carried out on a simple structure. They have linked the structural dynamic behavior of beams and signal processing of mode shape (using CWT) in order to produce damage identification. As an application their method has been validated on a wooden portal frame using a scanning LDV apparatus.

Many authors [13-15] analyzed the information provided by the signals acquired with an accelerometer and a laser vibrometer that measure contemporary the vibrations of an electric motor. Further applications of LDV [16] include the vibration control of flexible bearings supported on smart bearings and elastodynamic model of a camshaft supported on journal bearings by Carlini and Rivola [17]. The present study experiments are carried out using both laser vibrometer and accelerometer for the rotor dynamic analysis of a composite material shaft. The effects of stacking/orientation of fibers and number of layers in a cantilever beam of composite material are also studied.

2 Experimental Details

2.1 Laser vibrometry

Laser vibrometer is a proven instrument for non-contact measurements of surface vibrations. The 5500 series Rotational vibrometeris (RLV) a variation on a non standard vibrometer that allows engineers to measure the rotational and translation vibration directly. The instrument uses two non-contact laser probes for dynamic acquisition of the angular vibration of rotating parts. Each laser probe is a separate laser interferometer, acquired, independent of the shape of the measurement object at the same time translation vibration is virtually eliminated. The 5500 series has a frequency range of 0 Hz to 10 KHz, providing enough bandwidth for even the most demanding measurement tasks.

The optical measurement principle for the rotational vibrometer is based on laser interferometry. Use of the RLV is not limited to cylindrical parts. By using a special differential measurement process with two laser beams, independently of the shape of the object under investigation, only the rotational movement component is acquired and translational vibrations are predominantly suppressed.

Apart from the dynamic rotational vibration quantities ω and ϕ, the average RPM value up to 20000 is acquired. The construction and the various sensor head stand-off distances of 550mm and 650mm simplify making measurements on drive parts that are difficult to access. However, the accuracy of a measurement is affected by the optical alignment.

2.2 Experimental setup

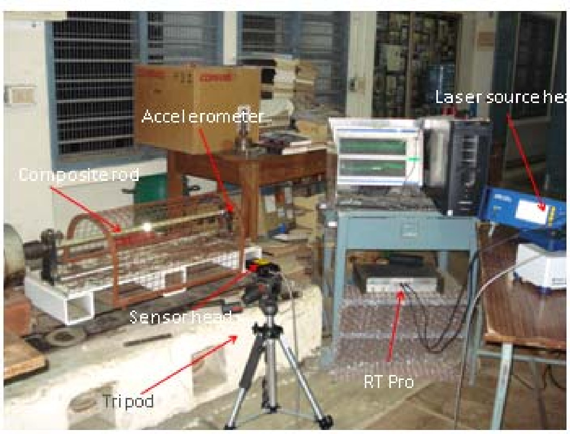


Fig. 1: The experimental setup for composite Shaft

This paper analyses the information provided by the signals acquired with an accelerometer and a laser vibrometer that measure contemporary the vibration of composite material shaft and a cantilever beam. The measurement process consists of basically in accelerating the motor to keep it rotating at constant speed for several seconds and finally stop it. The vibration signal are acquired and analyzed. There is no problem for mounting the sensor in beam but in rotating case installation of the accelerometer causes the problem. So the accelerometer is mounted on the bearing and laser gun passing at the middle of the shaft. Figure 1 shows the experimental setup. The composite shaft of 20 mm diameter is made of glass epoxy. The cantilever beam experimental setup is shown in Fig.2.

Fig. 2: The experimental setup for composite beam

2.3 Instrumentation and method

All the measurements were taken on the bearings in radial direction. In every measurement both the accelerometer and the vibrometer signal were acquired. In cantilever beam the gap between the both sensors is 10mm.

The transducer employed was a precision Quartz shear Icp accelerometer, with sensitivity of 100mv/g and frequency range 0.5000 to 10000 Hz. The single point laser beam vibrometer is hold by tripod which has isolated pads. The gap between the sensor head and the measuring object is 600mm. The controller demodulates the vibration signal from the optical head and provides an analogue voltage proportional to the velocity or displacement of surfaces. The sensitivity was fixed 200mm/s, the maximum signal bandwidth is 0 to 20 KHz, and the maximum velocity is 2m/s.

The amplified analogue signals from the accelerometer and the vibrometer are then acquired by means of 16 bit acquisition board. Data is sampled in the time domain with a sampling of 5000 Hz that provides a useful frequency range. A "dewesoft" program, especially developed for this purpose activates and controls both the functioning of the rotor & beam and the acquisition board and processes the signals.

3 Results and Discussion

The results of the free vibrations of a cantilever beam with different number layers and fiber orientations of composite material; and the free and forced vibrations of the composite shaft are discussed in the following sections. In the results the measurements of laser and accelerometer are compared to find the efficient and accurate way of measurement in case of composite structural vibrations.

3.1 Measurements on Beam

The measurements were taken for different orientation of glass epoxy composite beam (0-90, 45-45) with different number of layers such as 5, 8, and 12 layers.

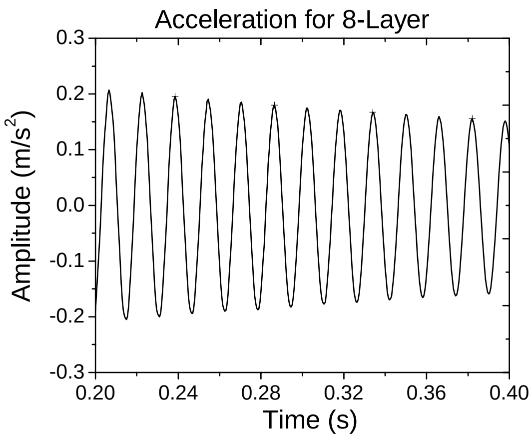
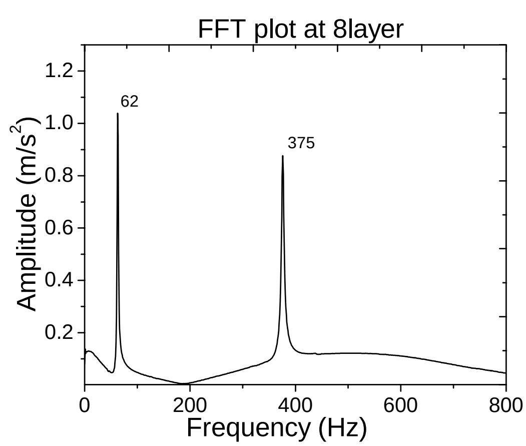


Fig. 3: Time response of accelerometer Measurement for 8-layer (0-90)



. Fig. 4: FFT of accelerometer measurement for 8 layer (0-90)

The free vibration measurements using the laser vibrometer and accelerometer are taken close to the free end of the cantilever beam. The time signals are measured for beams of different layers and fiber orientations.

The natural frequencies in each case of the layers and fiber orientation are estimated using the modal testing. The FRF plots are not shown here, but with phase plots together could find the natural frequencies in each case. Both accelerometer and laser measurements yielded identical results. These are shown in Table 1 for the first three modes of bending.

Some typical results for 8-layer (0-90) case are presented here. Figure 3 shows the time plot and Fig. 4 shows the corresponding FFT, in the case of accelerometer. Similarly, the measurements taken using laser

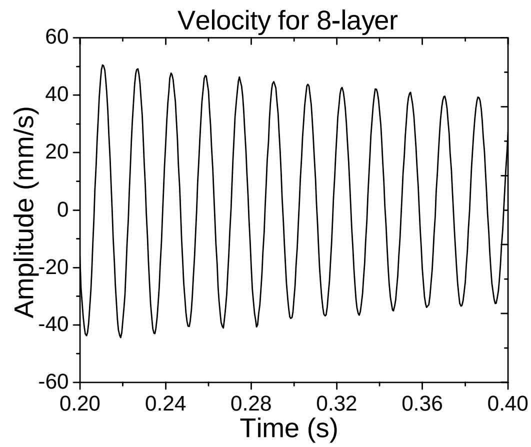


Fig. 5: Time response of Laser measurement for 8-layer (0-90)

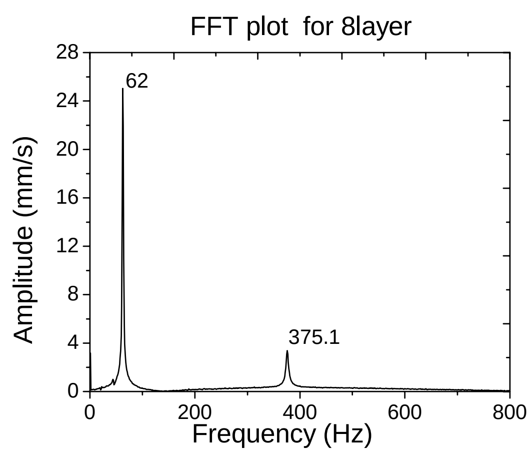


Fig. 6: FFT of Laser measurement for 8-layer (0-90)

Table-1: Natural frequencies of composite beam

S.No.	No. of Layers	Orientation	Natural Frequency (Hz)		
			I	II	III
1	12	[0/90]	92	623.5	1625
2	8	[0/90]	62	375	1050
3	5	[0/90]	30.3	176	352.5
4	12	[45/-45]	63	408	952
5	8	[45/-45]	44	260	578
6	5	[45/-45]	40	251	680

vibrometer are in shown in Figs. 5 & 6 for time response and FFT respectively. It can be observed that the FFT plots of laser measurements are much clearer as compared to that of accelerometer.

The result indicate that if there is any fault/damage in the beam the change in FFT will be of more evident. Thus the laser measurements will more useful in identifying the defect, although both methods estimate the same natural frequencies.

The results from Table 1 clearly indicate that there is a great influence of stacking/fiber orientation on the natural frequencies. It is observed that the natural frequency increases with number of layers. Also observed is that, for the same number of layers, the natural frequency of the angle ply laminate is lower than the cross ply laminate cases. This is due to fact that in the angle ply laminate the contribution of matrix is higher than that in cross ply laminate.

3.2 Measurements on composite shaft

The measurements of laser vibrometer and accelerometer are compared in the case of vibrations of a composite material shaft in this section. The composite shaft is made of unidirectional glass epoxy, and having 20mm diameter. From the FRF and phase plots (not shown here) of the modal testing, the first bending natural frequency of composite material shaft-bearing system has been estimated as 3725 rpm. Hence the composite shaft is run at different speeds below and above the critical speeds.

At each speed rotor is rotor is kept at steady for some seconds and measurements are taken. The typical results for the case of shaft speed of 3300 rpm are discussed here. Figure 7 shows the time plot and Fig. 8 shows the corresponding FFT in case of accelerometer. Similarly, the measurements taken using laser vibrometer are in shown in Figs. 9 & 10 for time response and FFT respectively. The peaks in FFT indicate the running speed of 56 Hz (around 3300 rpm) and its harmonics.

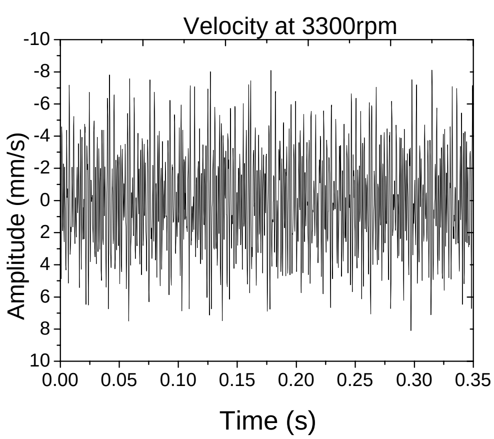


Fig. 7: Time response of integrated accelerometer Measurement at 3300 rpm

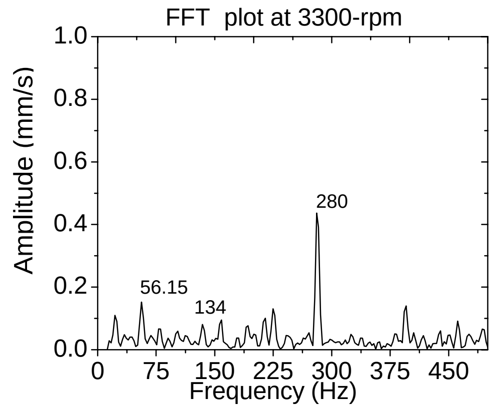


Fig. 8: FFT of accelerometer measurement at 3300 rpm

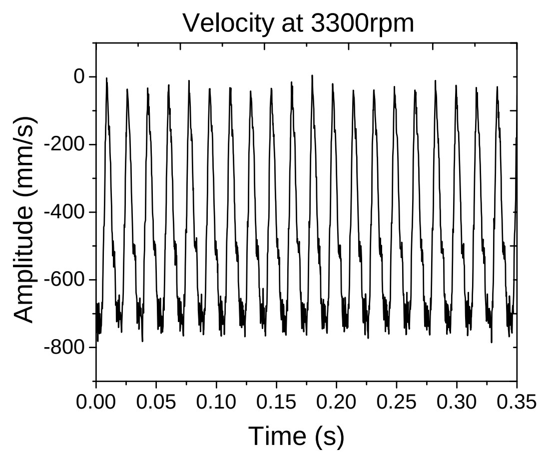


Fig. 9: Time response (velocity) of Laser measurement at 3300 rpm

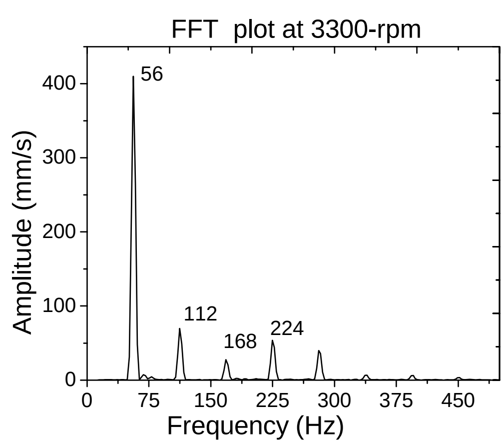


Fig. 10: FFT of Laser measurement at 3300 rpm

Also the time domain plots in displacement measured with both type of sensors are shown in Figs. 11&12. From all the plots, particularly FFT, the laser measurements are clearer as compared to that of accelerometer as in the case of beam. Also the accelerometer is kept on the bearing, while the laser measurements are taken on the shaft. Hence the FFT of accelerometer (Fig.8) readings is having several other peaks, while that of the laser (Fig.10) indicate only clear harmonics of running speed (56 Hz).

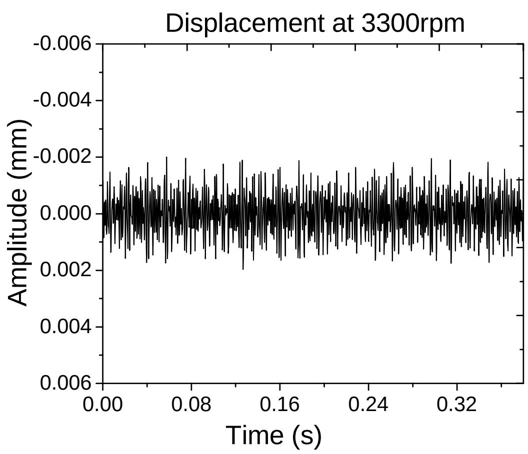


Fig. 11: Time response of integrated accelerometer Measurement at 3300 rpm

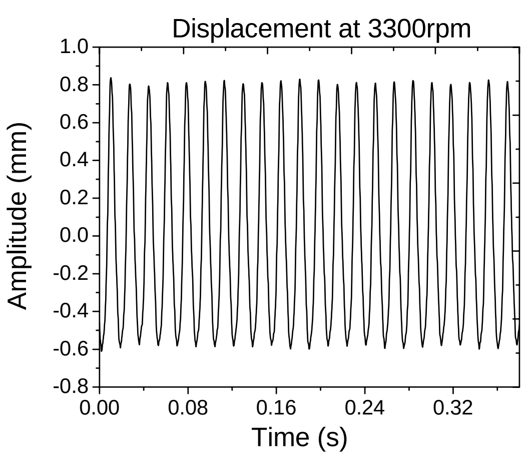


Fig. 12: Time response (displacement) of Laser measurement at 3300 rpm

The figures 13 and 14 show the unbalance response plots of composite shaft. These bode plots are generated by joining the peak responses at different speeds. As expected the responses peaks in both cases at the critical speed of 3725 rpm.

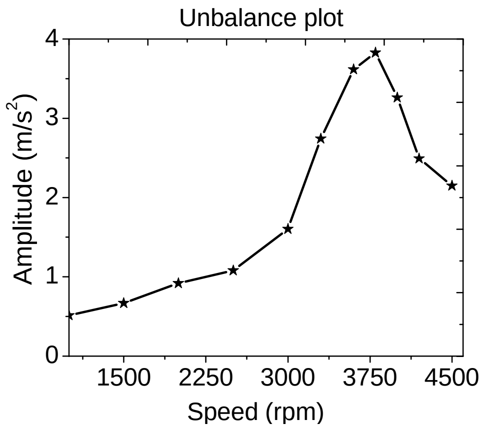


Fig. 13: Unbalance response of shaft using accelerometer measurement

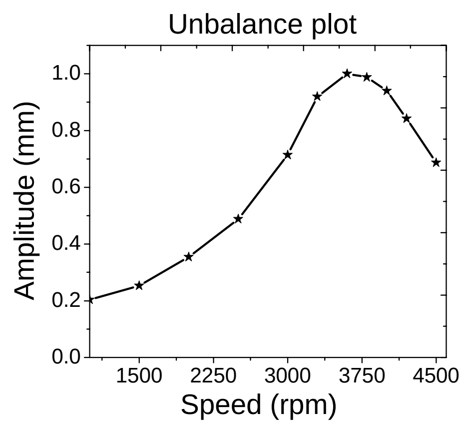


Fig. 14: Unbalance response of shaft using laser measurement

4 Summary

The experimental results of composite material beam and shaft have been discussed in the present study. The vibration analysis has been done using both laser vibrometer and accelerometer. The results of composite beam clearly indicate that there is a great influence of stacking/fiber orientation on the natural frequencies. For the same number of layers, the natural frequency of the angle ply laminate is lower than the cross ply laminate cases. The advantages of the laser compared to accelerometer are observed. However, the laser vibrometer is very expensive compared to the accelerometer. Thus considering this point, the accelerometer measurements are very much comparable particularly in the case of beams.

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