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Vibration analysis of a laminated composite beam based on virtual instrumentation using LABVIEW

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Abstract

Vibration response and its analysis is quite significant in understanding the behavior of a system. Vibrating systems produce complex time series waveforms which consist of many specific trends. These trends need to be properly extracted in order to develop methodologies for detecting system faults, its maintenance and vibration control. In the present analysis a laminated composite beam (Nylon sandwiched between Aluminum) in cantilever configuration is taken as the system model. LabVIEW is used to carry out various analyses from a range of algorithms such as standard frequency analysis, time-frequency analysis for time varying sound and vibration signals, quefrency analysis (FFT of the log of a vibration spectrum) for detecting harmonics, wavelet analysis and model based analysis for transient detection. Results of these algorithms are presented giving information for proper analysis and monitoring of the system model.

Keywords: Composite beam, Virtual Instrumentation, LabVIEW, Data acquisition, Dynamic analysis.

1. Introduction

Vibration occurs in almost every machine or structure and its analysis can be used for machine monitoring system. Vibration signals give a good indication of the internal defects of machines or structures and hence preventive action can be taken against their adverse effects. LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) can be used to acquire the vibration signals through its Data Acquisition (DAQ) card. Acquired signals can then be analyzed through various VIs available in the software to extract relevant information about the vibrating system and its faults. Required controlling action can then be implemented on the system accordingly [1].
Vibration analysis can be done in two ways; Time domain and Frequency domain. Time domain analysis gives the real time signal and extracts the signal characteristics like amplitude, time and phase characteristics. Information like amplitude, phase, power spectrum, Fast Fourier Transform (FFT), windowing action, filtering etc. are obtained by Frequency domain analysis [2]. This analysis gives additional and better information about the signal and the associated system model [3] as compared to time domain analysis.

K. B. Waghulde and Bimlesh Kumar [4] presented vibration analysis of cantilever smart structure by using piezoelectric smart material. M. Yuvaraja and M. Senthilkumar [5] studied vibration characteristics of a flexible GFRP composite beam using SMA and PZT actuators. She Tianli and Yang Xueshan [6] proposed the system of vibration signals measurement based on virtual instrument technology for seismographic vibration signals. Sunita Mohanta and Umesh Chandra Pati [7] presented monitoring and analysis of vibration signal based on virtual instrumentation in time domain and frequency domain.
Husain Mehdi et al, the maximum strength is found in composite GFRP instead of Aluminum and composite Nylon. Composite material has shown an improvement of mechanical properties when compared with individual materials, and the natural frequency found higher in the fifth mode shape for all composites [8, 9].

2. Experimental Setup

National Instruments provides various tools for advanced sound and vibration analysis [10]. These algorithms are

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based on time domain, frequency domain, time-frequency domain, quefrency domain (cepstrum), wavelet analysis and model based analysis. In the present analysis a composite beam (with known dimensions) of Nylon sandwiched between Aluminium is fabricated and is glued with two PZT (Lead-Zirconate-Titnate) patches at its upper and lower surfaces, acting as Sensor and Actuator, respectively. The beam is analyzed in cantilever configuration as shown in Fig. 1. A simulated signal of 50 Hz is generated in LabVIEW and is directed to the actuator patch through DAQ card as shown in Fig. 2. This vibration signal is then sensed through the sensor patch and is transmitted to software through Piezo sensing system for analysis and system monitoring. Various signal analyses results are obtained using different VIs (Algorithms) of LabVIEW.

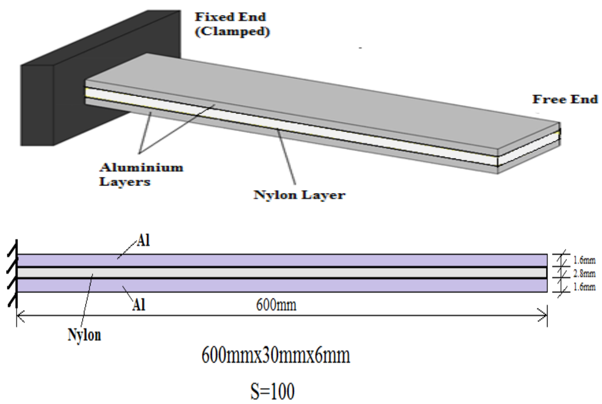
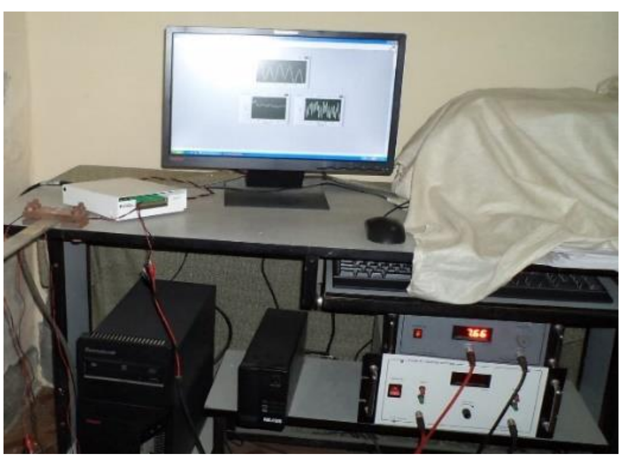
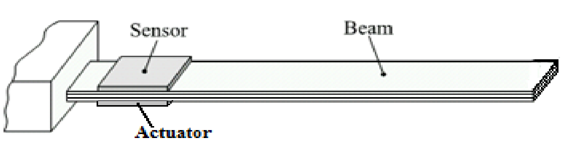


Figure 1: Aluminum-Nylon Laminated Composite Beam



(a)



(b)

Figure 2: (a) Experimental Setup, (b) PZT Sensor and Actuator attached to the Beam and

3. Results and Discussions

Following results are obtained for the composite beam through Sound and Vibration analysis palette of LabVIEW for a 50 Hz excitation. Fig. 3 simply shows the excitation signal amplitude as sensed by the piezo sensing system through sensor patch attached to the upper surface of the beam as shown in Fig. 2.

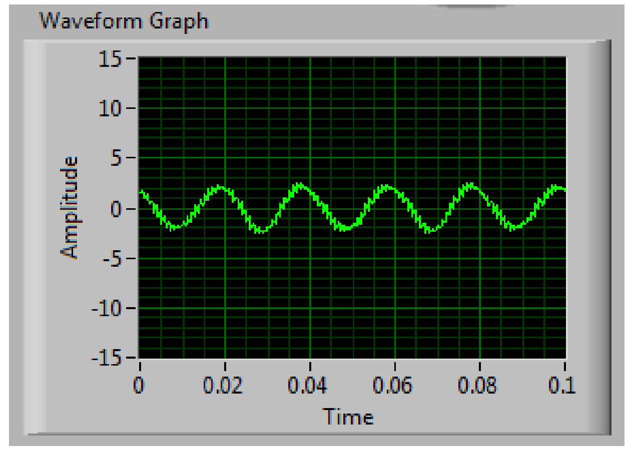


Figure 3: Waveform Graph,

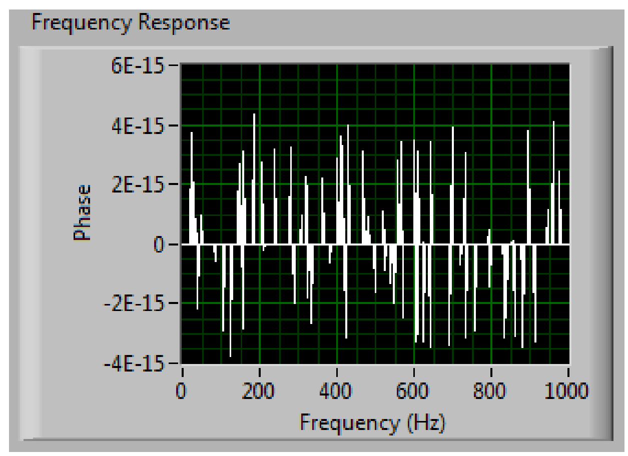


Figure: 4 Phase-Frequency Graph

3.1 Frequency Analysis

Frequency analysis is a common method for analyzing vibration signals. The most basic type of frequency analysis is an FFT, or Fast Fourier Transform, which converts a signal from the time domain into the frequency domain. The product of this conversion is a power spectrum and shows the energy contained in specific frequencies of the overall signal. Fig. 4 and Fig. 5 show Phase vs Frequency and Amplitude vs Frequency graphs (FFT), respectively.

There are many limitations of just using frequency analysis because its results, such as a power spectrum contain only the frequency information of the signal. They do not contain time information. This means that frequency analysis is not suitable for signals whose frequencies vary over time.

3.2 *Quefrency Analysis*

Quefrency or cepstrum analysis is the FFT of the log of a vibration spectrum. The term "cepstrum" is derived from "spectrum" by reversing its first four letters. The independent variable on the x-axis of a cepstrum is called "quefrency", analogous to the independent variable of a power spectrum as "frequency". "Quefrency" gets its name by replacing the first three letters of "frequency" with its second three letters.

Quefrency is a measure of time but not in the sense of time domain. While a frequency spectrum or FFT reveals the periodicity of a time domain measurement signal, the cepstrum reveals the periodicity of a spectrum. A cepstrum is often referred to as a spectrum of a spectrum. Cepstrum analysis is especially useful for detecting harmonics. Harmonics are periodic components in a frequency spectrum and are common in machine vibration spectra. Figure shows the cepstrum for the given vibration signal.

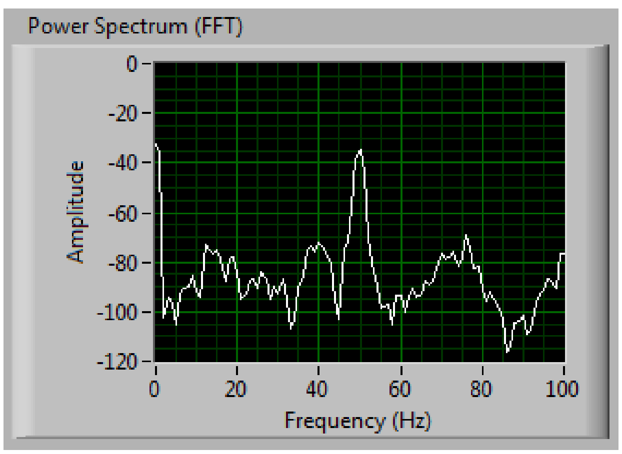


Figure 5: Power Spectrum (FFT)

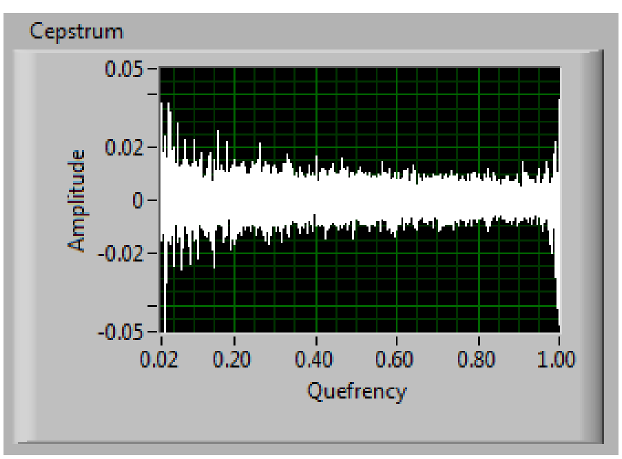


Figure 6: Quefrency (Ceptrum) Analysis

3.3 *Model Based Analysis*

Model based analysis compares the vibration signal to a linear model of the signal and returns the error between the two which makes it useful for detecting transients. Autoregressive modeling analysis is the use of a linear model, the AR model. The AR model represents any sample in a time series as the combination of the past samples in the same time series. The linear combination ignores any noise and transients in the signal.

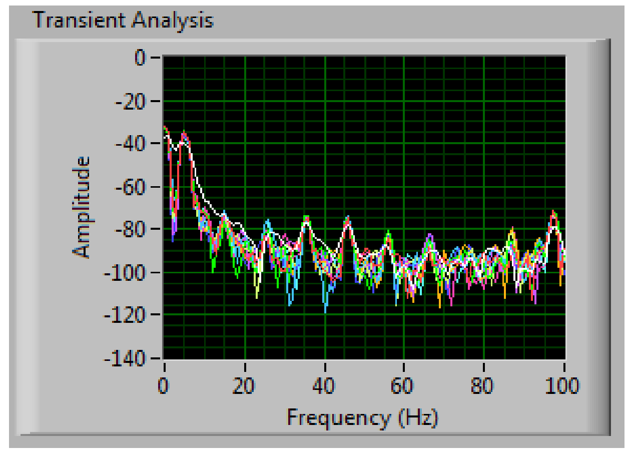


Figure 7: Transient Analysis

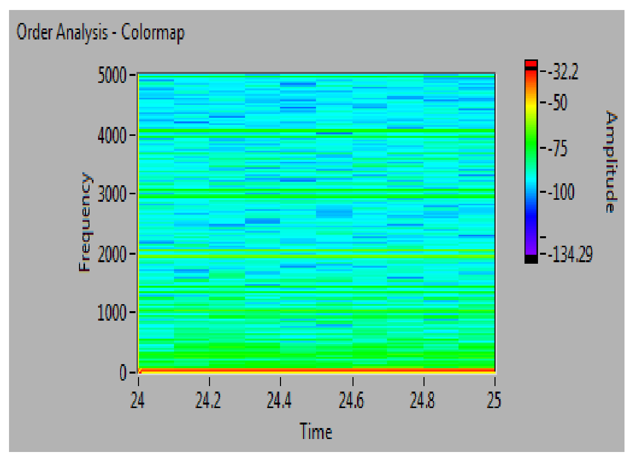


Figure 8: Order Analysis (Colormap)

When comparing a new measurement signal to the AR model, the modeling error corresponds to the noise and transients not recorded in the linear combination model. Fig. 7 shows the result for transient detection in the given vibration signal.

3.4 *Order Analysis (Colormap)*

A colormap is a three-dimensional display of a sound or vibration spectrum as a function of time or speed. The spectrum can be a frequency or order spectrum. By default, this plot displays frequency against time. Red portions of the colormap indicate areas of strong amplitudes. Yellow portions show areas of lesser amplitude than red ones. Similarly green and blue portions show areas of even lesser amplitudes than yellow portions. Fig. 8 shows colormap for the present case of vibration analysis.

3.5 Wavelet Analysis

Wavelet analysis is appropriate for characterizing machine vibration signatures with narrow band-width frequencies lasting for a short time period. Wavelets are used as the reference in wavelet analysis and are defined as signals with two properties: admissibility and regularity. Admissibility means that a wavelet reference, or mother wavelet, must have a band-pass-limited spectrum. Admissibility also means that wavelets must have a zero average in the time domain which implies that wavelets must be oscillatory. Regularity means that wavelets have some smoothness and concentration in both the time and frequency domains, which means that wavelets are oscillatory and compact signals. Fig. 9 and Fig. 10 respectively show Analytic wavelet Transform and Continuous Wavelet Transform for the given vibration signal.

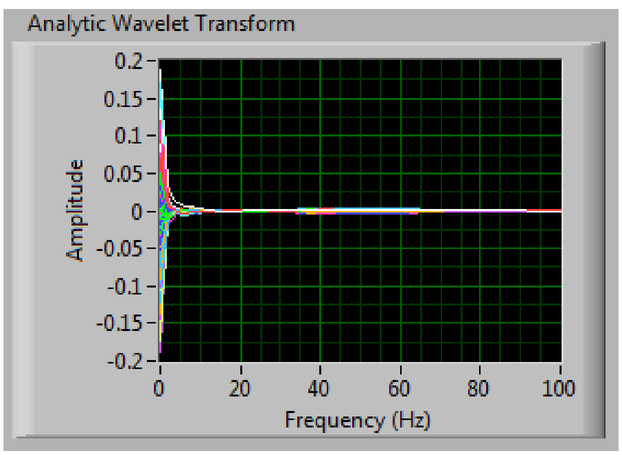


Figure 9: Analytic Wavelet Transform

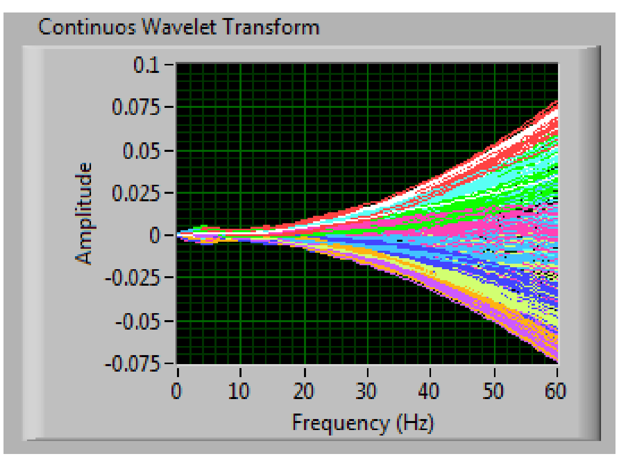


Figure 10: Continuous Wavelet Transform

4. Conclusion

Results of analysis and monitoring of vibration signal in terms of time domain and frequency domain are presented in this paper. In time domain analysis, it is difficult to find the defective region in the structure. Harmonics of vibration signal are not clearly obtained from displacement graph which is in time domain. So, frequency domain or power spectrum analysis of vibration signal is performed. From the two different analyses it is found that frequency domain analysis gives more information about the structure and helps in implementing control action more effectively.

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