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Operational Modal Analysis of a Plate to Determine the Modal Characteristics Using Unmeasured Random Excitation

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ABSTRACT: Conventional modal testing requires a known excitation force in order to extract the modal properties. One particular challenge using this technique is that it can be experimentally complex because of the need for artificial excitation and it also does not represent actual operational condition. The present study had successfully applied a real time modal testing technique for plate using unmeasured random excitation to extract modal properties like damping, shape and frequency. The technique only employed two sensors which consist of a two IEPE accelerometers. The measured response data was extracted using Frequency Domain and Time Domain OMA. In Time Domain OMA, SSI (Stochastic Subspace Identification) technique is used to simultaneously extract multiple mode and having slight errors in estimating the higher modes. Moreover, it requires more accelerometers to connected the structure for simultaneously acquiring the time wave form. Frequency domain technique using least squares complex frequency domain (LSCF) method proved to be better for higher modes and it supported roving techniques which will help to capture the response by using only two accelerometers..

KEYWORDS: operational modal analysis, modal parameters, plate, Radom excitation, LSCF, SSI.

I. INTRODUCTION

Over recent decades, modal testing and analysis has been widely applied for aerospace structures, mechanical and civil engineering in determining and optimizing the dynamic characteristics of the structures. Frequency Response Functions (FRFs) which is the ratio of the response (output) signal over the excitation (input) signal is calculated and the frequency peak amplitudes are identified as possible modes. However, traditional EMA has limitation whereby FRFs would be very difficult or even impossible to be measured within the operational condition. In this case, Operational Modal Analysis (OMA) or also named as ambient or output-only analysis is a suitable technique to be applied. It does not require special boundary conditions, measurements are in-situ, uses natural excitation and can be performed simultaneously with other testing.

The objective of OMA is to identify the modal properties of a system which are the frequency resonances, damping and mode shapes by using only output measured responses and without knowledge of the inputs. applications include bridges, roads, buildings as well as automotive such as cars and engines. In bridges, the vibration modes induced by traffic and wind are of interest, while in automotive, the resonances from engine run-up as well as investigation of on-the-road body vibrations in the development of new cars are among the objectives of conducting OMA. To ensure good modal data is attainable, three specific requirements for the excitation must be fulfilled which are the power spectra of the input forces are broadband and smooth; the input forces are uncorrelated; and distributed over entire structure.

II. MATERIALS AND METHODS

1.Plate: The plate is made of aluminium (Al) having Young's Modulus 68.91GPa. The accelerometers are fix on the plate to acquire the signal. Fig showed the aluminium plate.

Table 1: Dimensions of plate

Shape	Rectangle
Length	240mm
Width	50mm
Thickness	20mm

Fig1: Al thin plate model

2.Accelerometers: The accelerometer is used to measure the response from the structure. The accelerometers are IEPE (Integrated electronics piezo-electric). The accelerometer used is TEA110 series having sensitivity of 100mV/g use for general purpose measurements.

Fig 2: Accelerometers

3.NI 9234 Module: The NI 9234 is a four-channel dynamic signal acquisition module for making high-accuracy measurements from IEPE sensors. The NI 9234 delivers 102 dB of dynamic range and incorporates Integrated Electronics Piezoelectric (IEPE) signal conditioning at 2 mA constant current for accelerometers and microphones.

Fig 3: NI 9234 Module

4. NI cDAQ-9171 chassis: The NI cDAQ-9171 is chassis to mount the module. The chassis is connected to system by Ethernet cable.

Fig 4: NI cDAQ-9171 chassis

5. ModalVIEW R2 software: ModalVIEW software is designed for you easily to acquire multi-channel vibration signals from a machine, or the static or dynamic loading of a mechanical structure by utilizing data acquistion hardware. After obtaining a set of time histories, it can animate the response of a structure and show you the structure's vibration behavior at once. It helps you to extract and visualize useful modal parameters information from acquired time- and frequency-domain experimental data.

III. METHODOLOGY

In this case, the technique was demonstrated using two types of excitation, i.e. LSCF and SSI. Data were recorded using the same response transducers whereby the accelerometers was roved to measure at dedicated points on the plate. For random tapping, spanner are used to continuously tap on the plate. The plate was kept of a foam to simulate free-free boundary conditions. There will be a low frequency rigid body mode less than 100Hz which will be ignored. The accelerometers were placed only on the centre line of the beam and excitation was given only in the direction of accelerometer axes. This will only result in the excitation of bending modes. Other modes like torsional are neglected in this study.

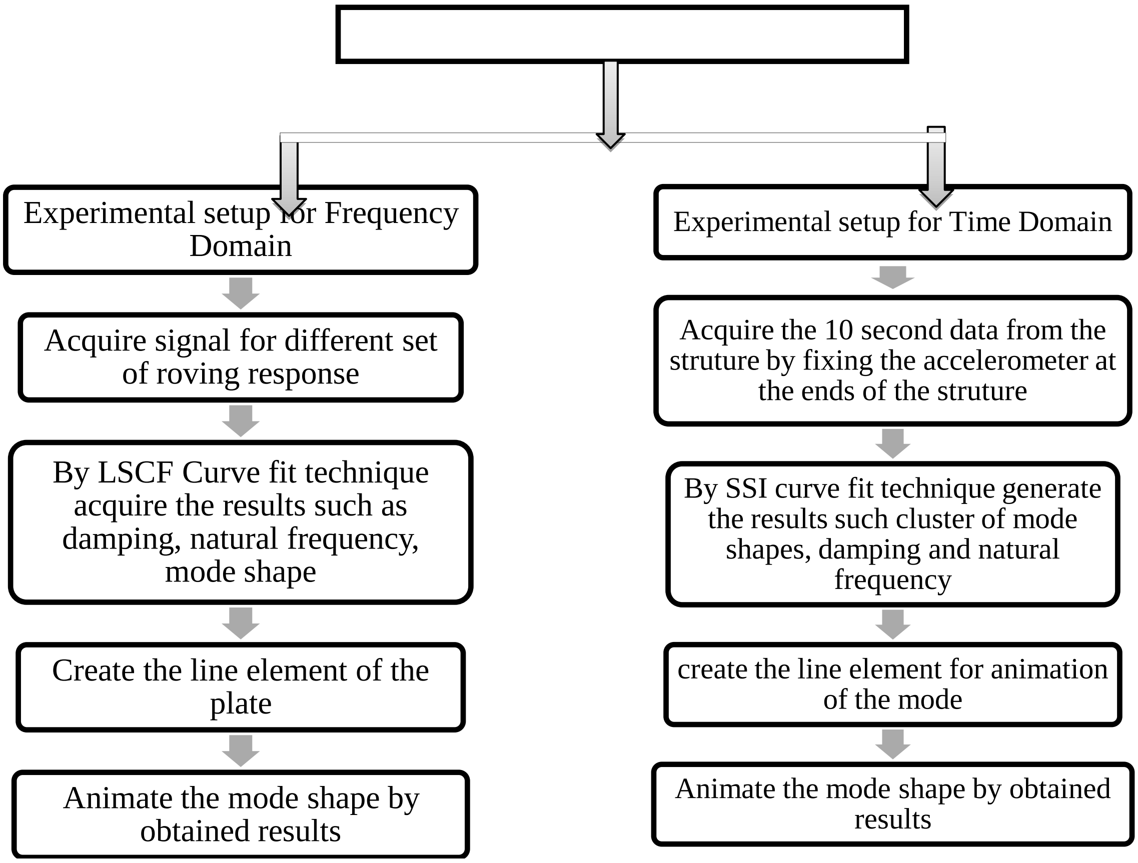
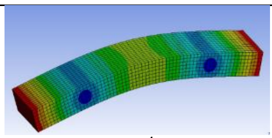
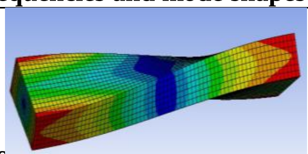
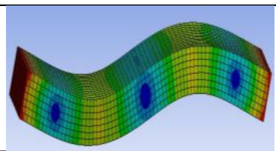
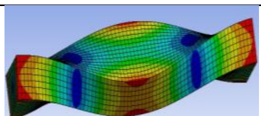
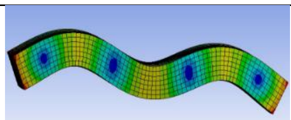
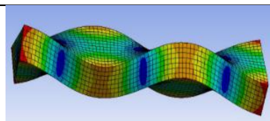


Fig 5: Methodology Flow Chart

IV. RESULTS AND DISCUSSIONS

FE RESULT: The first five natural frequencies and the corresponding mode shapes of the model are extracted using Ansys are shown in Table 1. It can be seen that the first six modes of the plate are in the frequency range of 1960.6 Hz to 13832 Hz. It should be noted that the boundary condition is free-free and hence there will be six zero frequency rigid body modes. These are not included in the results for brevity.

Table 2. Natural frequencies and mode shapes obtained from FE

 **1960.6 Hz (1st Bending)**	 **4569.6 Hz (1st Torsion)**	 **5119.3 Hz (2nd Bending)**
 **9170.6 Hz (2nd Torsion)**	 **9373.9 Hz (3rd Bending)**	 **13832 Hz (3rd Torsion)**

FREQUENCY DOMAIN RESULT

Example of time histories of the measured response is shown in Fig.5 and must display time decay behaviour. For random excitation, it was found the first mode occurs at the frequency of 1952.566Hz and damping range 0.626. The first 3 natural frequencies were tabulated in Table 3 and showed that while the bending modes are in excellent agreement between the random tapping and LSCF techniques, the torsional modes are not.

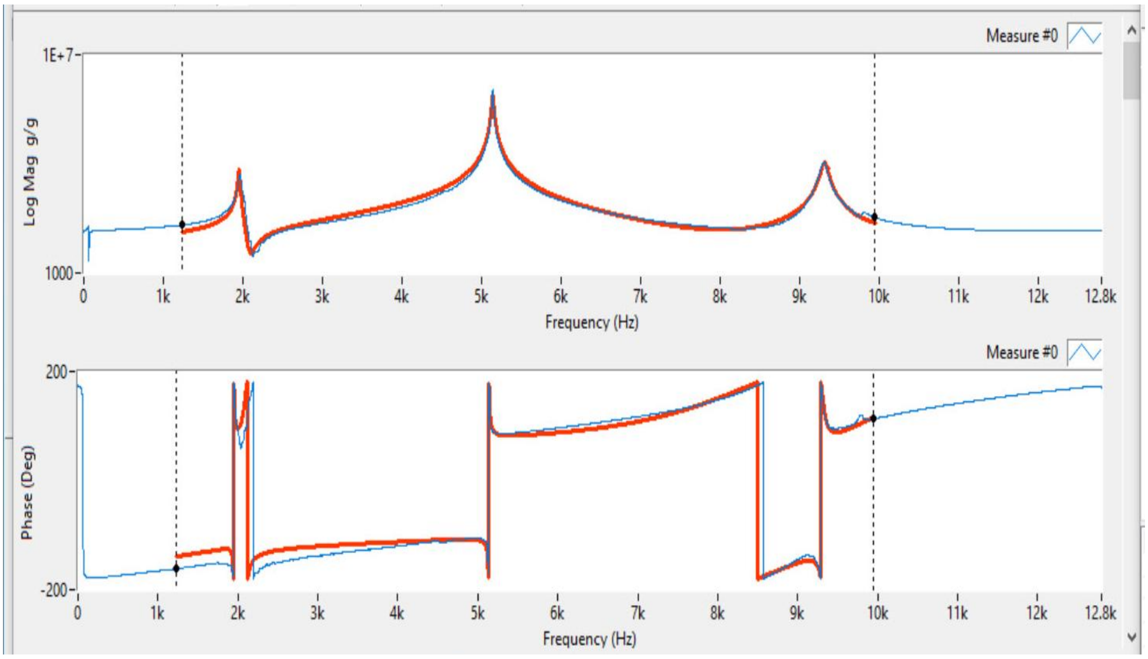


Fig 5: Frequency domain histories of the measured response

Table 3: Frequency Domain Results

Mode index	Natural frequency(Hz) from FDD	Damping(%)	Shape	FE result (Hz) from table 2
1	1952.566	0.626	1st bending	1960.6
2	5142.176	0.247	2nd bending	5119.3
3	9315.370	0.463	3rd bending	9373.9

The identification of the modal frequencies from random tapping and LSCF excitations were presented in typical FDD plots as shown in Fig. 5. The FDD plot for random tapping is smoother and displayed more prominent peaks corresponding to the natural frequencies of the plate. To ascertain that peaks do represent the modal peaks, the mode shapes at those peaks are to be examined. and if it is complex, then that particular peak are ruled out. However, in this case, predicting the mode shapes prior to testing via finite element analysis is necessary. For heavier structures, the quality of the FDD can be improved by conducting single testing as opposed to roving test through the use of multiple accelerometers.

TIME DOMAIN RESULT

Example of time histories of the measured response is shown in Fig.6 and must display time decay behaviour. For random excitation, it was found the first mode occurs at the frequency of 1912.387Hz and damping range 2.753. A comparison of this result with the FDD and FEA frequencies were tabulated in Table 4 and shows that there is good agreement these techniques especially for first bending mode. The time domain technique is not able to predict the higher bending frequencies as only two sensors were used. This limitation can be overcome by using larger number of accelerometers for simultaneously acquiring the time signal.

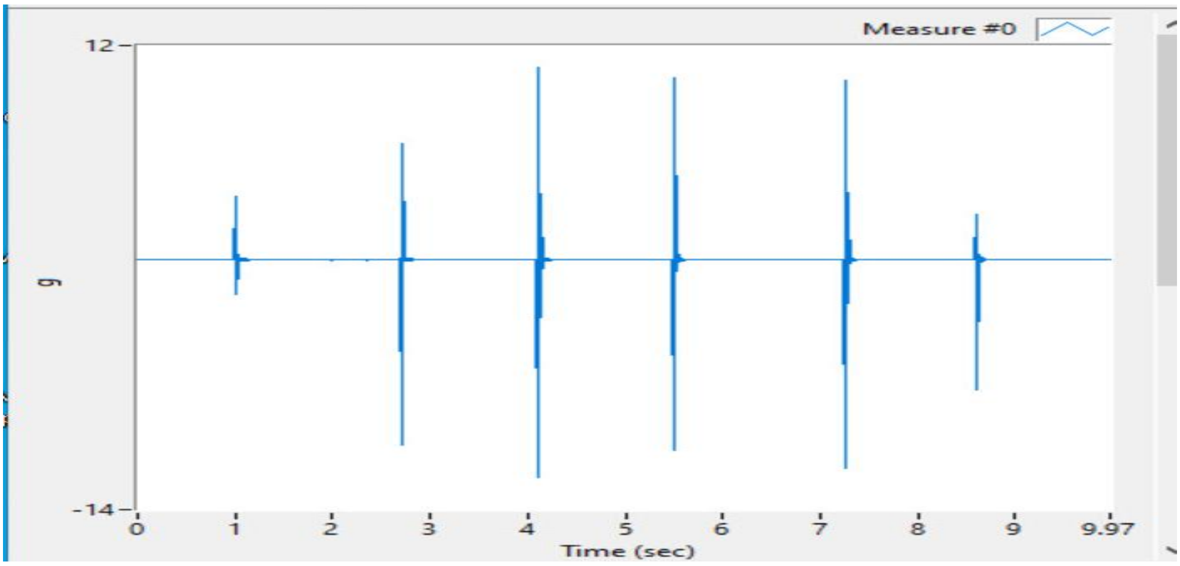


Fig 6: Time domain for random tapping

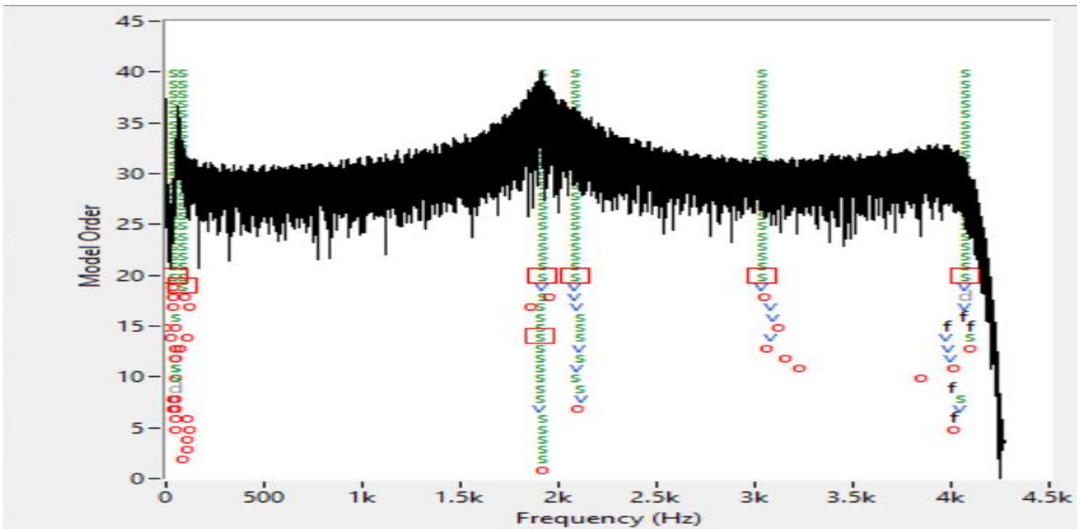


Fig 7: Time domain curve fit for random tapping

Table 4: Comparison between FDD, time domain and FE results

Mode index	Natural frequency(Hz) from FDD	Natural frequency(Hz) from FDD	Shape	FE result (Hz) from table 2
1	1952.566	1912.387	1st bending	1960.6
2	5142.176	__	2nd bending	5119.3
3	9315.370	__	3rd bending	9373.9

V. CONCLUSION

The present study had successfully applied a real time modal testing technique for plate using unmeasured random excitation to extract modal properties like damping, shape and frequency. The measured response data was extracted using Frequency Domain and Time Domain OMA. There will be a low frequency rigid body mode less than 100Hz which will be ignored. The accelerometers were placed only on the centre line of the beam and excitation was given only in the direction of accelerometer axes. This will only result in the excitation of bending modes. Other modes like torsional are neglected in this study. In Time Domain OMA, SSI (Stochastic Subspace Identification) technique is used to simultaneously extract multiple mode and having slight errors in estimating the higher modes. Moreover, it requires more accelerometers to connect the structure for simultaneously acquiring the time wave form. The time domain technique is not able to predict the higher bending frequencies as only two sensors were used in the present study. This limitation can be overcome by using larger number of accelerometers for simultaneously acquiring the time signal. Frequency domain technique using least squares complex frequency domain (LSCF) method proved to be better for higher modes and it supported roving techniques which will help to capture the response by using only two accelerometers.

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