Output Only Modal Analysis of Engineering Structures

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***Abstract*— This paper deals with the experimentation of traditional modal analysis which is also known as experimental modal analysis (EMA) and an operational modal analysis (OMA) was performed on a cantilever beam. For EMA, an impact hammer and an accelerometer was used to give an excitation force and to measure the response respectively. Then a data acquisition device was used to transfer the response to the computer and finally the modal parameters were extracted using ME scope software. But in the case of OMA a random excitation was given on the test setup and the response was taken using two accelerometers and the modal properties of the structure was extracted using ME scope software. Finally the experimental results of EMA were compared with the experimental results of OMA and MATLAB results of EMA as well as OMA.**

Keywords*— *Experimental modal analysis, Operational modal analysis, Modal parameters.

I. Introduction

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. It is the field of measuring and analysis of the dynamic response of structures and fluids during excitation. Classically this was done using single input multiple outputs (SIMO) approach that is only one excitation point and then the response is measured at many other points. But in recent years multiple input multiple output (MIMO) have become more practical. Modal analysis has been widely used in vibration trouble shooting, structural dynamics modification, optimal dynamic design, vibration control as well as vibration based health monitoring in aerospace, mechanical and civil engineering.

In this study, initially the vibrational characteristics of an experimental setup were investigated using experimental modal analysis (EMA) and operational modal analysis (OMA). For experimental setup a cantilever beam made up of stainless steel is used which is connected to an accelerometer. The impact hammer is used to create an impulse on the beam and the acceleration response is measured by using the accelerometer on the beam. The data acquisition device is used for transferring the acceleration data from accelerometer to the computer. At the end of the experiment, we have the acceleration response of the beam and the excitation data were obtained using ME scope software. We will use this data to identify the system and construct a mathematical model of the beam.

Unlike EMA, experimentation of OMA used two accelerometers and a white noise excitation was given on to the cantilever beam and the data acquisition device was used to transfer the data. Dynamic characteristics of the system were extracted using ME scope software. Finally a transient analysis in MATLAB was performed to correlate the experimental results.

II. EXPERIMENTAL MODAL ANALYSIS

A. EXPERIMENTAL MODAL ANALYSIS USING TEST SETUP

For experimentation of EMA a cantilever beam made of stainless steel is taken as shown in Figure 4.1. In addition to that an accelerometer, an impact hammer and a signal analyzer (which was used to transform the time domain input signals to frequency domain signals) were used.

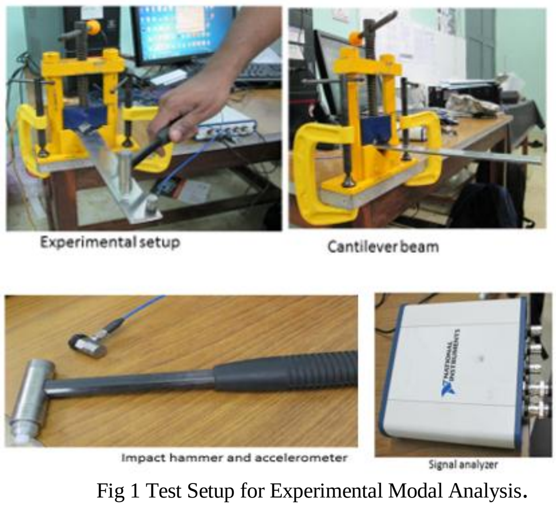

Fig 1 Test Setup for Experimental Modal Analysis.

The cantilever beam used is divided into four elements and have three nodes on each element. The accelerometer is fixed at node 1 is used to measure the response and the impact hammer gives the excitation force which is roving from one node to another. The response spectrum finally obtained is transformed from time domain to frequency domain using FFT. Then the FRF is curve fitted using ME scope software and the modal parameters are extracted using equation 1.

$$[H(s)]_{s=j\omega} = \sum_{k=1}^{m} \frac{[A_k]}{(j\omega - P_k)} + \frac{[A_k{}^*]}{(j\omega - P_k{}^*)} \qquad (1.1)$$

In the above equation [A] are the residues which are obtained from the curve fitting process, we also get the poles (p_k) or the frequency and damping from the denominator of the equation. These residues are related to the mode shapes. The matrix [A] is given as

$$[A(s)]_k = q_k \{u_k\}\{u_k\}^T \qquad (1.2)$$

That is residues are therefore nothing more than the mode shape multiplied by a scalar which is the value of the mode shape at the reference location, u and the scaling constant, q.

Curve fitting technique is probably the most difficult part of the whole experimental and operational modal analysis. It is also referred to as modal parameter extraction by smoothing out the FRF. That is we are trying to find out the modal parameters like damping ratios, mode shapes and most importantly the natural frequencies from the measured data.

B. CANTILEVER BEAM SPECIFICATIONS

Length, L= 23.8e-2m
Width, w = 40e-3m
Thickness, t = 4e-3m
Material = Stainless steel
Density, ρ = 7800 kg/m^3
Elastic modulus = 210 GPa
Poisson's ratio = 0.3

C. ME SCOPE ANALYSIS SETTINGS

Sensitivity of accelerometer=100mv/g [g-acceleration due to gravity]
Sensitivity of impact hammer= 10mv/lbf
No: of averages used= 20
Input= force
Output= acceleration
Total no: points in beam = 12
Reference input point number = 1
No: of samples= 8192
Time resolution (sec) = 0.0004
Ending time (sec) = 1.64
No: of samples = 4096
Frequency resolution (Hz) = 0.61
Trigger lines= 0.1% of the channel voltage
Pretrigger delay samples= 6
Double hit lines= 10% of channel voltage

After entering all the settings in ME scope software the curve fitted image is obtained as illustrated in Fig 2.

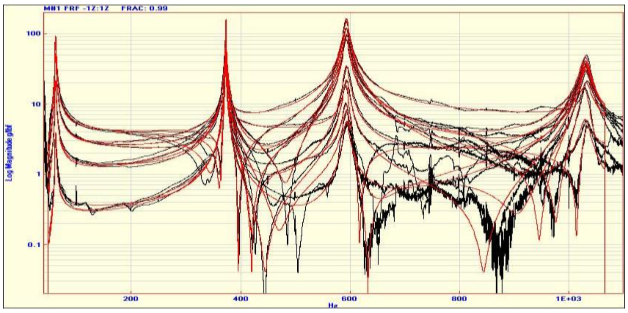

Fig 2 Final Curve fitted Image of Entire FRF (EMA) using ME scope Software.

Table 1 Results Obtained Using ME' Scope Software after Curve fitting for EMA

Mode	Frequency	Damping(Hz)	Damping %
1	62.4	0.898	1.44
2	374	0.741	0.198
3	594	4.67	0.787
4	1.03E+03	7.82	0.759

D. MODE SHAPES OBTAINED AT DIFFERENT FREQUENCIES

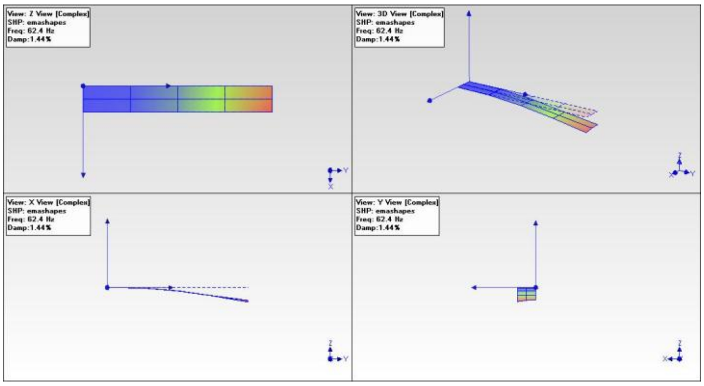

Fig 3 Mode Shape (bending) Obtained After Curve fitting at 62.4 Hz.

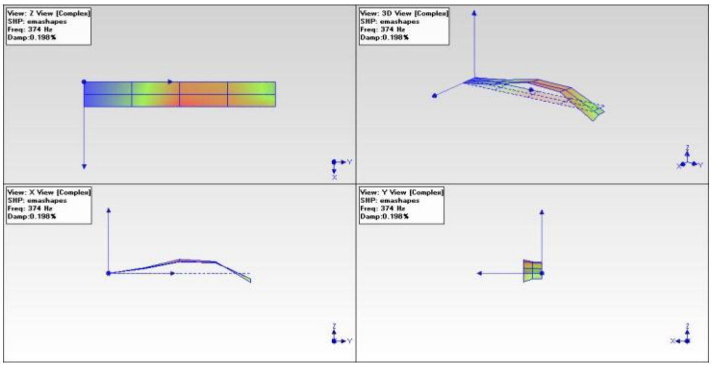

Fig 4 Mode Shape obtained at 62.4 Hz.

III. EXPERIMENTAL MODAL ANALYSIS USING MATLAB

The Runge-Kutta algorithm is used in MATLAB. It is several times faster than the solver in ANSYS. Code for transient analysis is prepared in MATLAB and is implemented. Rayleigh damping is assumed for computing the impulse response in MATLAB. The result obtained is compared with that of experimental results. The Runge-Kutta method is an extremely accurate scheme. However it requires the function $hf(x_n y_n)$ to be evaluated four times for each time step. In some cases, e.g. in elastoplastic or visco-plastic spring systems, the function evaluation itself can be quite expensive, and the Runge-Kutta method may turn out to be computationally costly. Nevertheless, the Runge-Kutta method is widely used for its accuracy and the fact that reliable codes are available that carry out adaptive time step adjustment, making the method even more accurate.

A. *RESULTS OBTAINED USING MATLAB*

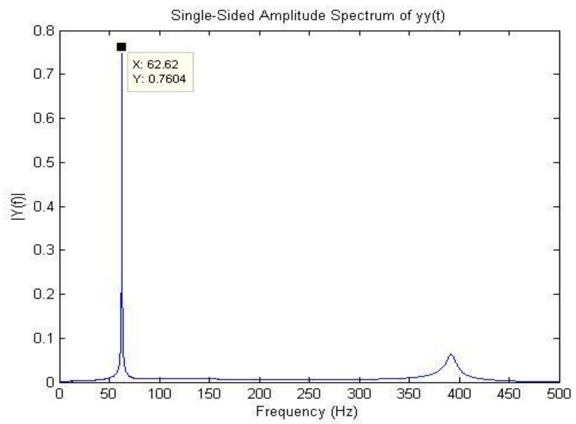

Fig 5 MATLAB Results.

Table 2 Frequencies Obtained Using Matlab

Mode	**Frequency**
1	62.62hz
2	392.6hz

IV. OPERATIONAL MODAL ANALYSIS

A. *OPERATIONAL MODAL ANALYSIS USING TEST SETUP*

Operational modal analysis has been using in many engineering fields like automobile industry, space crafts, tall buildings which are all subjected to random excitation like wind, sounds, water currents etc. As mentioned before in OMA input forces are unknown as in the cases of bridges, skyscrapers etc.

For experimental setup of OMA a cantilever beam with one accelerometer fixed at an active node and another accelerometer is roving from one node to another for measuring the vibration as shown in

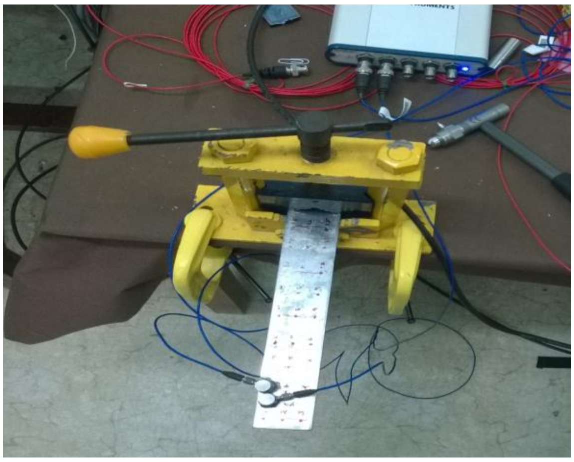

Fig 6 Test setup for OMA.

The excitation gave was a random hand tapping and the input time response is transformed into frequency response function using ME'scope software. Finally the FRF was curve fitted and the modal parameters like frequency, damping ratios and mode shapes were extracted. The final curve fitted image of cantilever beam is shown Fig 7.

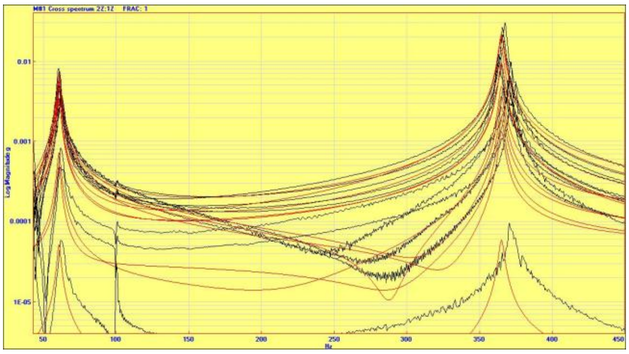

Fig 7 Curvefitted Image of Entire FRF

Table 3 Results Obtained from ME'scope Software

Mode	Frequency	Damping(Hz)	Damping %
1	60.5	1.13	1.86
2	365	1.65	0.452

B. *OPERATIONAL MODAL ANALYSIS USING MATLAB*

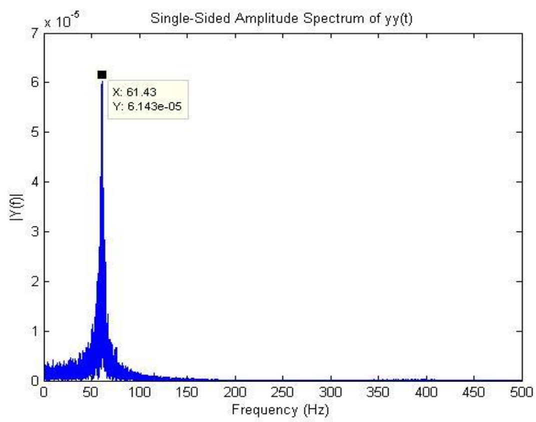

Fig 8 MATLAB Results for OMA

Table 4 Frequencies Obtained for OMA

Mode	Frequency
1	61.43Hz

V. RESULTS AND DISCUSSION

The results obtained from both experimental modal analysis and operational modal analyses are shown in tables 4 and 5 respectively.

Table 4 Frequency Obtained for Experimental Modal Analysis.

MESCOPE	MATLAB
62.4Hz	62.62Hz
374Hz	392.6Hz
593Hz	-
1040Hz	-

Table 5 Frequencies Obtained for OMA

MESCOPE	MATLAB
60.5Hz	61.43Hz
371Hz	-
567Hz	-

From the results it is clear that the frequency values obtained for numerical EMA and numerical OMA are almost similar. The values of frequency are only considered for comparison. Other values like mode shape, damping etc. are expected to follow similar patterns. It can also be said that the values obtained in ME'scope software is correct as the values are similar to that of MATLAB as well as ANSYS results.

The numerical EMA and numerical OMA are validated by experimental results of EMA and OMA and it can be seen that values obtained for numerical as well as experimental results of OMA are matching with EMA. From this it can be said that the OMA is a newly developed technique which have many advantages compared to EMA.

VI. CONCLUSIONS

Operational Modal Analysis is a new technique in modal parameter extraction. The applications and advantages of OMA are discussed briefly in this report. Modal analysis can be performed by two different methods Experimental Modal Analysis (EMA) and Operational Modal Analysis (OMA).

In this paper modal analysis were done experimentally and numerically. The aim was to prove that the results obtained from OMA is similar to that of EMA. For that, both EMA and OMA were done experimentally and numerically using MATLAB. The results suggest that the modal parameters extracted from EMA and OMA were similar. Thus it can be said that OMA is a new technique which is capable of replacing EMA.

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