Predicting Dynamic Behavior of Cantilever Beams using FEA and validating through EMA

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***Abstract* - In this paper, dynamic behavior of cantilever beam type of structure is predicted in FEA software. Modal and harmonic are performed in FEA to derive natural frequencies, mode shapes and Frequency Response Function (FRF) respectively. Experiment Modal Analysis (EMA) is conducted on cantilever of different cross sectional areas using OROS Fast Fourier Transform (FFT) Analyzer. NVGate software is used for capturing & processing experimental data. This data are interpreted and meaningful information is extracted by using MATLAB. Experimental results are compared to those of FEA software for validation.**

Keywords - Experimental Modal Analysis (EMA); Finite Element Analysis (FEA;,Frequency Response Function (FRF) ; Modal analysis; Harmonic Analysis

I. INTRODUCTION

The primary reasons for recent developments in the field of vibration are:

- The speeds of operation of machinery have doubled over the past 50 years and consequently, the vibration loads generated due to rotational excitations and unbalances would have quadrupled if proper actions of design and control were not taken.
- Mass, energy and efficiency considerations have resulted in lightweight, optimal designs of machinery and structures consisting of thin members with high strength. Associated structural flexibility has made the rigid-structure assumption unsatisfactory and given rise to the need for sophisticated procedures of analysis and design that govern distributed parameter flexible structures [1].

The objective of this paper is to find out natural frequencies of mechanical structures so that operating frequencies cannot meet and resonance conditions can be avoided. FEA software is used for prediction of dynamic behavior. EMA validates prediction carried out by FEA.

II. THEORITICAL CONSIDERATIONS

Finite element methods (FEM) are most frequently used as mathematical simulations to study mechanical structures (such as crane), machining Process (with wide range of parameters: tool geometry, materials, cutting conditions) and to derive a computational models predicting deformations. In many cases, the FEM simulations have also been validated by comparison with results of experimental investigations [2]. Using FEM, structural models with very high levels of complexity and accuracy can be derived [3].

For machine and work-piece instability analysis, FE modeling in turning machine showed mode frequency in closeness to that of modal testing. Amount of error in chuck center with and without tailstock were 13% and 6% respectively [4]. While FE modeling in scaled model (1/10) of crane, maximum error in natural frequencies was 23.89%. By modifying FE model, this maximum percentage of difference could be reduced to 7.02% [5].

Experiment on material like PVC rather than steel or aluminum structure is preferable to easily measure damping characteristics with plate type structure offering response measurements perpendicular to it for bending and torsion vibration[6].Modal analysis can be used to detect damage by ambient (traffic) condition for large and heavy structures(civil structures such as bridge, dams) [7].

The grounded condition is more difficult to simulate in laboratory. Theoretically, a grounded condition means that all the six degree of freedom at the boundary is fixed. This cannot be achieved in reality. The best accuracy would arise if the mounting were rigid. In EMA, the arrangement is often to ‘fix’ the structure to a much more rigid and heavier object such as a concrete floor. Also sensitivity of sensor also plays important role in accuracy in EMA [8].

Modal analysis is the process of determining the inherent dynamic characteristics of a system in forms of natural frequencies, damping factors and mode shapes, and using them to formulate a mathematical model for its dynamic behavior.

The formulated mathematical model is referred to as the modal model of the system and the information for the characteristics is known as its modal data. Experimental modal analysis, basically, is a procedure of “experimental modeling.” Its primary purpose is to develop a dynamic model for a mechanical system using experimental data.

EMA produces a modal model that consists of natural frequencies, modal damping ratios and mode shape vectors as the primary result [8].In particular, EMA is useful in design, diagnosis and control of mechanical systems, primarily with regard to vibration.

A. *Finite Element Analysis (FEA)*

In FEA, modal analysis is performed to derive natural frequencies. Undamped FRF is captured using Harmonic analysis. Cantilever beam is modeled and meshed in FEA software having one end fixed with all dofs (Degree of Freedoms) are zero.

A. *Experimental Modal Analysis (EMA)*

Cantilever type structures with varying materials (M.S., Aluminum) are considered as specimen for experiment. The FRF measurements are performed on these structures. The cantilever is fixed on a vice, which is fixed to an approximate rigid experiment table. The impact hammer is applied at the location point of forty-eight centimeter. This impact hammer is used to excite the structure in a frequency range from zero to 800 Hz. The response is measured with an accelerometer that is placed at location point of fifty-seven centimeter. OROS-36 16 Channels FFT analyzer was setup to measure the input (channel 1) and output (channel 2), and to calculate the FRF. Different windows are used for FRF, trigger signal (response verses time) and for average spectrum. After obtaining the FRF data, it is saved in storage device (USB drive) and the data format is changed to ASCII format that is divided in frequency, real, and imaginary columns 1, 2, and 3, respectively. The sampling frequency is equal to 2.56 multiplied by the highest spectral frequency line. Bandwidth of 800 Hz with 0.5 Hz resolution is set.

TABLE I. GEOMETRY (IN MM) & MATERIAL PARAMETERS FOR EXPERIMENT (CANTILEVER)

Width	Thickness	Length	Material
50 ×25	2 mm	600	Al Box
50	6 mm	600	M.S. Plate 1
25	6 mm	600	M.S. Plate 2 Al Plate


Fig. 1 Aluminum box


Fig. 2 Aluminum plate


Fig. 3 M.S. plate 1


Fig. 4 M.S. plate 2

III. RESULTS AND DISCUSSION

Table 2 to 5 show comparison and percentage in error of experimental modal frequencies with those of FEA. Figures 10, 12, 14 and 16 shows FRF plot for FEA while figures 11, 13, 15 and 17 shows FRF plot for EMA (OROS FFT analyzer) FRF data. Mode shapes for first cantilever beam are plotted in figure 6, 7, 8, 9 and 10 for aluminum box type only.

3.1 Aluminum box

TABLE II. COMPARISON OF MODAL FREQUENCIES

Mode	EMA (Hz)	FEA (Hz)	Percent of error (%)
1	85	99.34	14.14
2	445	341.94	23.16
3	487	588.39	20.82
4	626	699.15	11.69

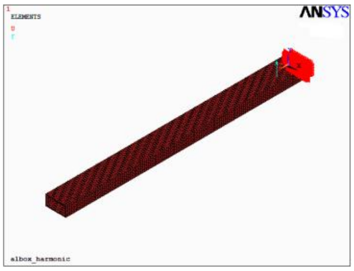

Fig.5 FEA model

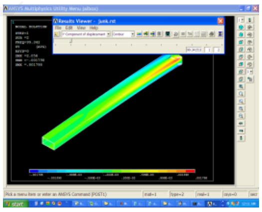
Fig.6 First Mode shape

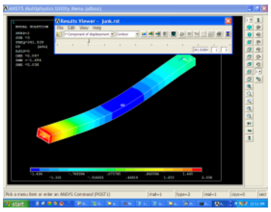
Fig.7 Second Mode shape

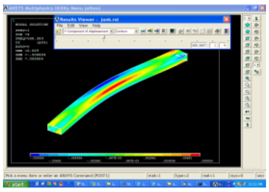
Fig.8 Third Mode shape

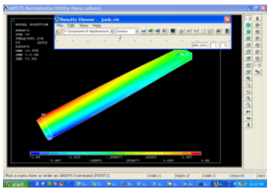
Fig.9 Fourth Mode shape

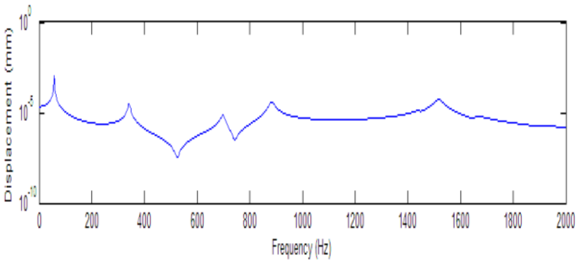

Fig.10 FRF (FEA) plot semilogy (displacement vs. frequency (Hz))

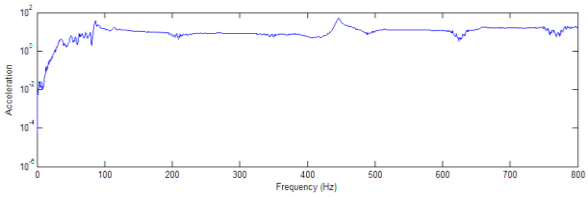

Fig.11 EMA FRF plot semi-logy (Acceleration Vs. frequency (Hz))

3.2 Aluminum plate

TABLE III. COMPARISON OF MODAL FREQUENCIES

Mode	EMA (Hz)	FEA (Hz)	Percent of error (%)
1	12	11	8.33
2	222	235	5.86
3	457	435	4.81
4	652	667	2.30
5	719	702	2.36
6	726	737	1.52

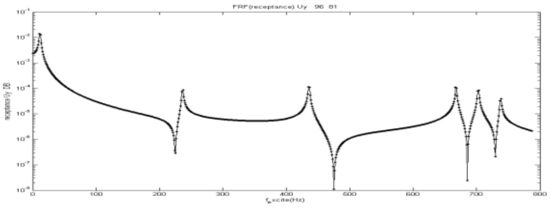

Fig.12 FRF (FEA) plot semilogy (displacement vs. frequency (Hz))

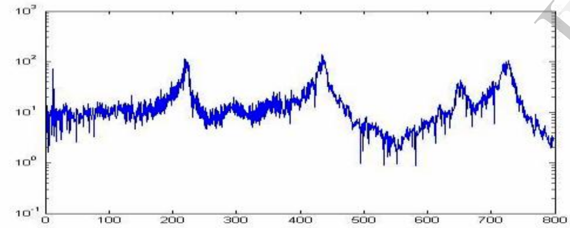

Fig.13 Experiment FRF plot semilogy (Acceleration Vs. frequency (Hz))

3.3 M.S. plate 1

TABLE IV. COMPARISON OF MODAL FREQUENCIES

Mode	EMA (Hz)	FEA (Hz)	Percent of error (%)
1	12	14	16.67
2	78	69	11.54
3	224	200	10.71
4	298	278	6.71
5	439	416	5.24
6	504	496	1.59
7	602	589	2.16
8	661	649	1.82
9	729	690	5.35
10	740	728	1.62

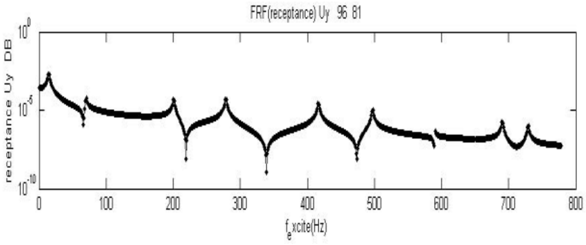

Fig.14 FRF (FEA) plot semi-logy

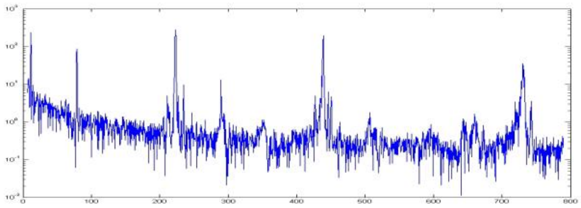

Fig.15 Experiment FRF plot semi-logy (Acceleration Vs. frequency (Hz))

3.4 M.S. plate 2

TABLE V. COMPARISON OF MODAL FREQUENCIES

Mode	EMA (Hz)	FEA (Hz)	Percent of error (%)
1	12	13	8.33
2	234	239	2.14
3	418	412	1.44
4	461	455	1.30
5	468	460	1.71
6	738	733	0.68
7	794	788	0.76

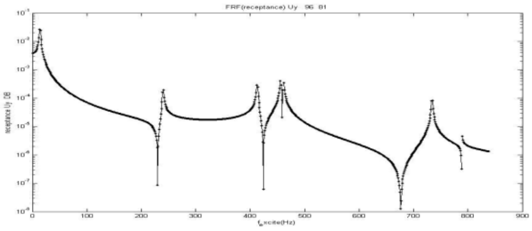

Fig.16 FRF (FEA) plot semilogy

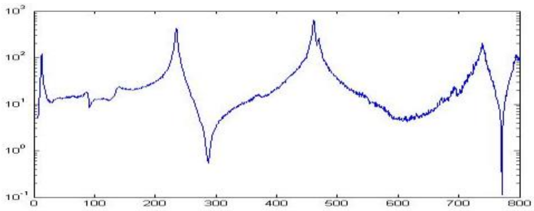

Fig.17 Experiment FRF plot semilogy (Acceleration Vs. frequency (Hz))

As discussed earlier, percentage of error can be reduced effectively by proper fixing all degree of freedom.

IV. CONCLUSION

With FEA, natural frequencies and mode shapes can be obtained. This is very important and helpful, particularly, for knowledge of resonance conditions. Structures can be designed in such a way that these resonant frequencies can be kept away from operating frequency to coincide. Thus resonance can be avoided and structures can be saved form damage. Here No-damping condition is considered. Damping estimates can be taken in FEA to exhibit similar results of real structures and simulations can be incorporated into product design phase. In EMA, an effective end condition creates accurate results.

REFERENCES

[1] Pikey D.F., Park G, “ Damping matrix identification and experimental verification ” , 2000

[2] Mackerle J, “Finite element analysis and simulation of machining: a bibliography (1976-1996) “, *Journal of materials processing technology, 1999, vol. 86, pp17-44..*

[3] Baker J. R., Rouch K. E., “Use of finite element structural models in analysis machine tool chatter”, *finite elements in analysis and design, 2002, vol 38, pp1029-1046*.

[4] Mahdavinejad R, “Finite element analysis of machine and work piece instability in turning“, *International Journal of Machine Tools & Manufacture 2005, vol.45, pp- 753–760*.

[5] Wu J J, “Finite element analysis and vibration testing of a three dimensional crane structure”, *measurement, 2006, vol39, pp740-749*.

[6] Zaghbani I, Songmene V,” Estimation of machine-tool dynamic parameters during machining operation through operational modal analysis”, *International Journal of Machine Tools & Manufacture, vol. 49, pp 947–957.*

[7] Cunha A, Caetano E, “Experimental Modal Analysis of Civil Engineering Structures“, Sound And Vibration, International Modal Analysis Conference, 2006, IOMAC,.

[8] Silva De, Clarence W, “Vibration: Fundamentals and Practice “Vibration Engineering”Boca Raton: CRC Press LLC, 2000, pp 1-15