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Prediction of Natural Frequencies of Thin Metal Plates

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Abstract - **In the present investigation, free vibration analysis of thin isotropic materials of different material plates under various boundary conditions is found using finite element method. In addition experiments are conducted on thin metallic plates to validate FEM with experimental modal analysis also. The finite element models (FEM) which use the elasticity theory for the determination of stiffness matrices are modeled in ANSYS software to evaluate first five natural frequencies of the laminate. The variation of natural frequencies with respect to various isotropic materials like brass, copper, stainless-steel and aluminium is presented.**

Keywords - Free vibration, metallic plates, natural frequencies, finite element method & experimental modal analysis.

I. INTRODUCTION

Among all the material types, the metals are the superior ones. These include iron, aluminum, copper etc. The mixture of metals called alloys. These alloys are formed by mixing two or more metals. Metals are more heavy and high temperature resistance when compared with plastics, composites and ceramics. They can be used for applications with higher service temperature requirements, due to their higher temperature resistance than plastics. The following paragraph provides a brief review of various research contributions on free vibration analysis of metallic structures.

Ajay S. Patil (2014) studied the performance of the developed finite element formulation is assessed for free vibration response of thin isotropic rectangular plate with various boundary conditions and different aspect ratios, earlier it is used only for static analysis of plate and no attempt is made to use it for free vibration response. The comparison of natural frequencies of thick and thin rectangular laminates with various boundary conditions is studied by (Chao C.C. and Yeong-chyuan chern, 2000) using 3-D elasticity theory. Cerdem Imrak and Ismail Gerdemeli (2007) discussed an exact solution of the governing equation of an isotropic rectangular plate with four clamped edges. Ehab N. Abbas, Mohammad Qasim Abdullah and Hatem R. Wasmi (2015) studied the static and dynamic analysis of thin isotropic and orthotropic CCCC plates using classical thin plate theory and finite element analysis. Ezeh J. C., Ibearugbulem O.M. and Onyechere C. I. (2013) reported an ordinary Finite Difference method, in free vibration (FB) analysis of thin rectangular flat plate using the proper boundary conditions of SSSS, CCCC and CSCS respectively. Kanak Kalita and Abir Dutta (2013) studied different mode frequencies for free vibration of isotropic plates using the ANSYS computer package. The finite element analysis of thick isotropic rectangular plates is presented by (Kulkarni S.D. and Khandagale N.G., 2011) based on Reddy's third order theory. Qian L.F., Batra R.C. and Chen L.M. (2003) analyzed three-dimensional infinitesimal elastodynamic deformations of a homogeneous rectangular plate subjected to different edge conditions using a meshless local Petrov-Galerkin method. Neffati M. Werfalli and Abobaker A. Karoud (2012) studied free vibration of thin isotropic rectangular plates with various edge conditions using a Galerkin-based finite element method. Yoshihiro Narita (1979) investigated the free, transverse vibration of thin isotropic plates of various shapes and boundary conditions.

The present investigation intends to apply the finite element techniques for the free vibration analysis of thin isotropic materials. The fundamental natural frequencies are studied by varying the different types of materials.

II. PROBLEM STATEMENT

Geometric and Finite element modeling

The metallic plates are made of brass, copper, stainless-steel and aluminum with sides of the plate are taken equal to 1inch and thickness 0.5mm. The element used for the present analysis is SHELL93 of ANSYS, the element has eight nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y and z-axes.

Boundary conditions

The sides of the plate considered for the analysis are one end clamped and both ends clamped.

Material properties

The following are the material properties of the metallic plates:

1) Brass: E = 112 x 10^9 N/m^2, υ =0.33, ρ=8500 kg/m^3
2) Copper: E = 117 x 10^9 N/m^2, υ =0.33, ρ=8940 kg/m^3
3) Stainless-steel: E = 200 x 10^9 N/m^2, υ =0.33, ρ=8027 kg/m^3
4) Aluminum: E = 70 x 10^9 N/m^2, υ =0.34, ρ=2710 kg/m^3

Finite element analysis

The finite element method (FEM),its practical application often known as finite element analysis (FEA) is a method for dividing up a very complicated problem into small elements that can be solved in relation to each other. Today, finite elements are used to analyse problems of vibration analysis, heat transfer, fluid flow, lubrication, electric and magnetic fields and many others. The finite element analysis uses the following equations.

The equations of equilibrium of a discretised elastic structure undergoing small deformations can be expressed as

$$[M]\{\ddot{u}\} + [c]\{\dot{u}\} + [k]\{u\} = \{F(t)\}$$

(1)

For free undamped vibration, the equation reduces to

$$[M]\{\ddot{u}\} + [k]\{u\} = \{0\}$$

(2)

If modal co-ordinates are employed the equation becomes

$$[[K]\text{-}\omega^2\,[M]\,\{\varphi\}] = \{0\}$$

(3)

There are various methods of finding the natural frequencies ω_i and modal vectors $\{\varphi\}_i$ once the system mass [M] and stiffness matrices [K] are formulated. Here a twenty noded element has been chosen to discretise the plate.

The element stiffness matrix can be expressed as

$$[K]_e = \int_{-1}^{+1}\int_{-1}^{+1} [B]^T[D][B]|J|\,d\xi\,d\eta$$

(4)

Similarly the consistent element mass matrix is generated using

$$[M]_e = \int_{-1}^{+1}\int_{-1}^{+1} [N]^T[P][N]|J|\,d\xi\,d\eta$$

(5)

Effect of rotary inertia is neglected.

Finite Element Results

The following are the obtained analytical (ANSYS) values for thin metallic plates [Figures 1 -8]. The various isotropic materials used are brass, copper, stainless-steel and aluminium with one side clamping and two sides clamping.

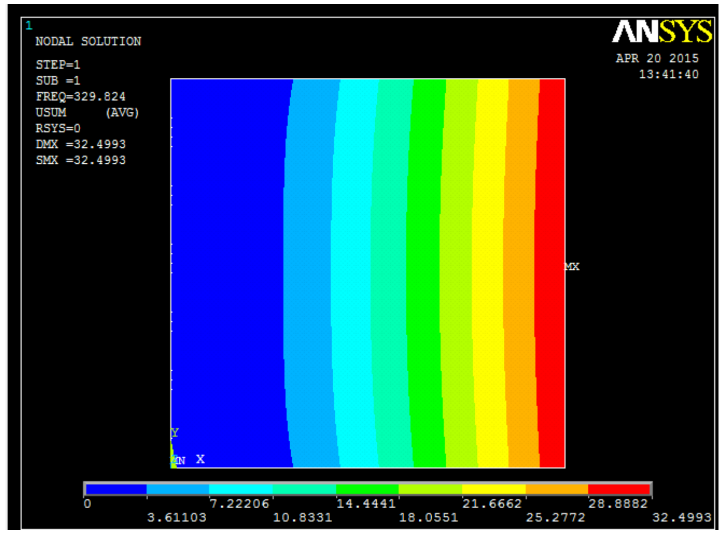

Fig.1: First mode shape of one end clamped brass plate (329.824Hz)

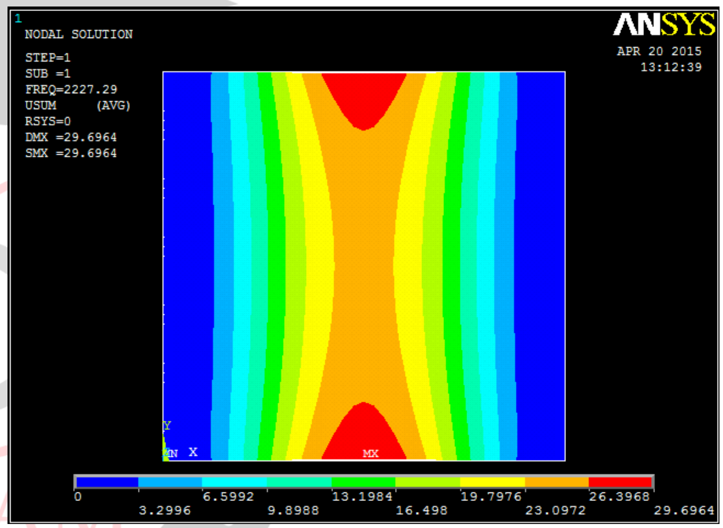

Fig.2: First mode shape of both ends clamped brass plate (2227.29Hz)

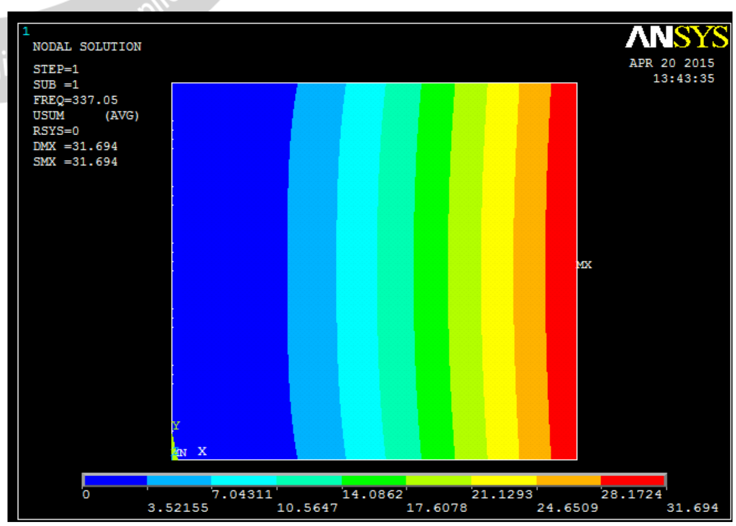

Fig.3: First mode shape of one end clamped copper plate (337.05Hz)

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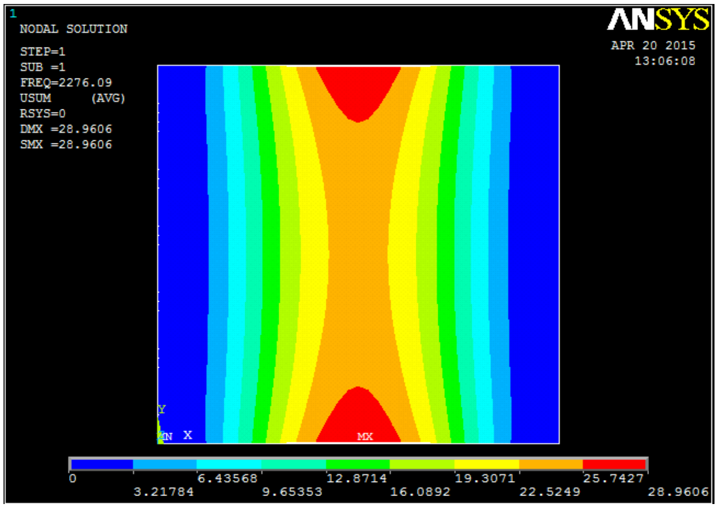

Fig.4: First mode shape of both ends clamped copper plate (2276.09Hz)

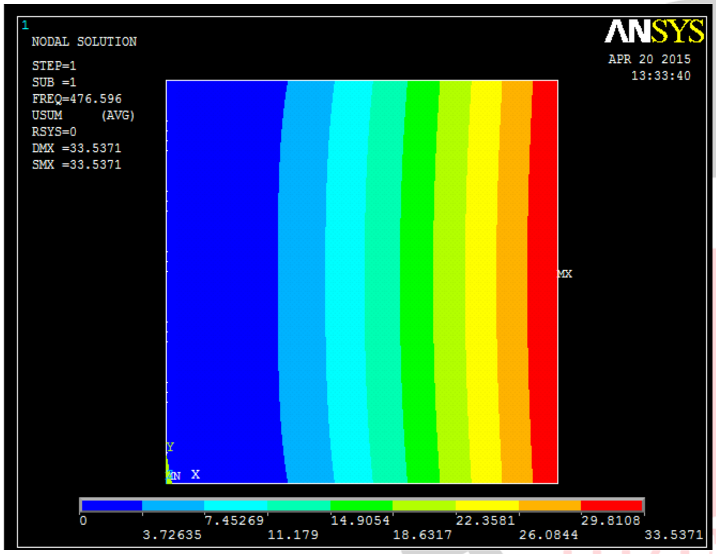

Fig.5: First mode shape of one end clamped stainless-steel plate (476.596Hz)

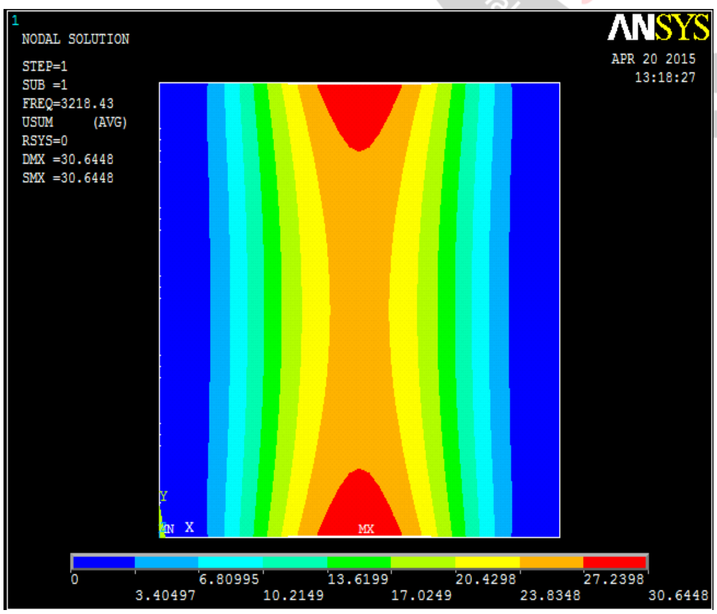

Fig.6: First mode shape of both ends clamped stainless-steel plate (3218.43Hz)

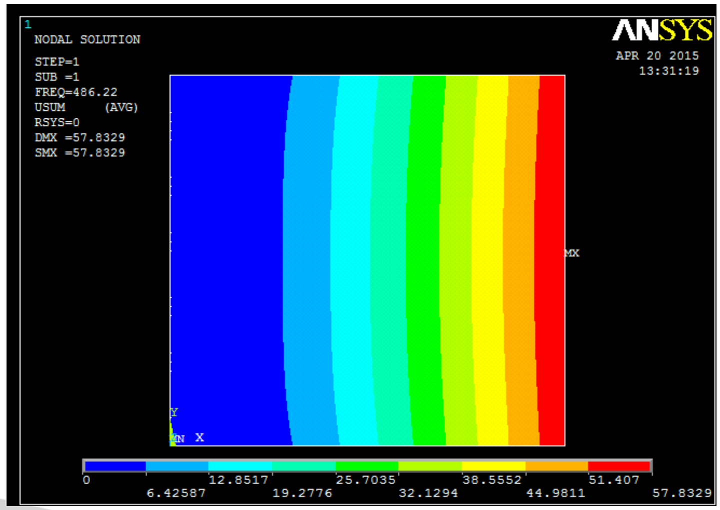

Fig.7: First mode shape of one end clamped aluminum plate (486.22Hz)

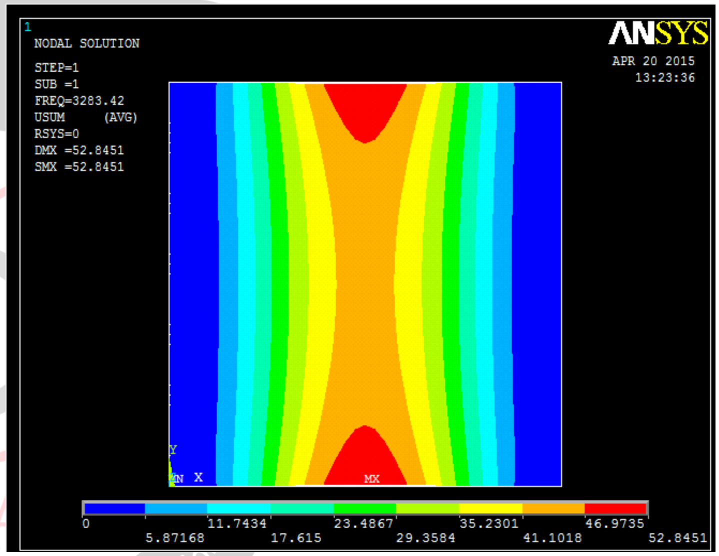

Fig.8: First mode shape of both ends clamped aluminum plate (3283.42Hz)

III. EXPERIMENTAL INVESTIGATION

Experimental set up

In experimental set up, supporting block is initially fixed on a rotating machine edge frame using nut and bolt arrangement. At the end of supporting block, the metal plate is edge clamped between the supporting block and bottom block in 1/10 surface area. Figure9 show the configuration of one end clamped metal plate.

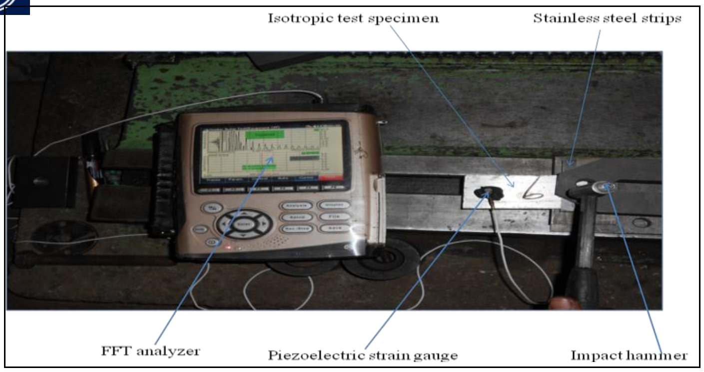

Fig.9: Configuration of the one end clamped metal plate

Testing procedure

Modal testing has been conducted to determine the frequency response. A piezoelectric strain gauge that senses the vibration signal is placed on the metal plate and impact hammer is used to excite the structure. Finally the output measurements are recorded by the FFT analyzer through the accelerometer.

Experimental results

The following are the obtained experimental values for thin metallic plates [Figures10-17].

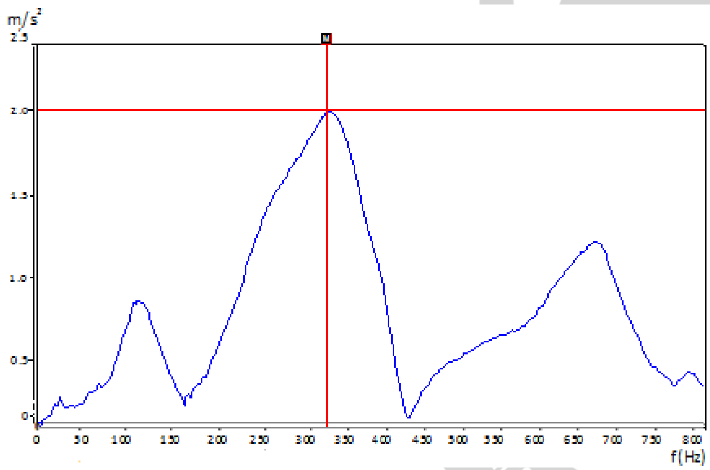

Fig.10: First mode shape of one end clamped brass plate (332.48Hz)

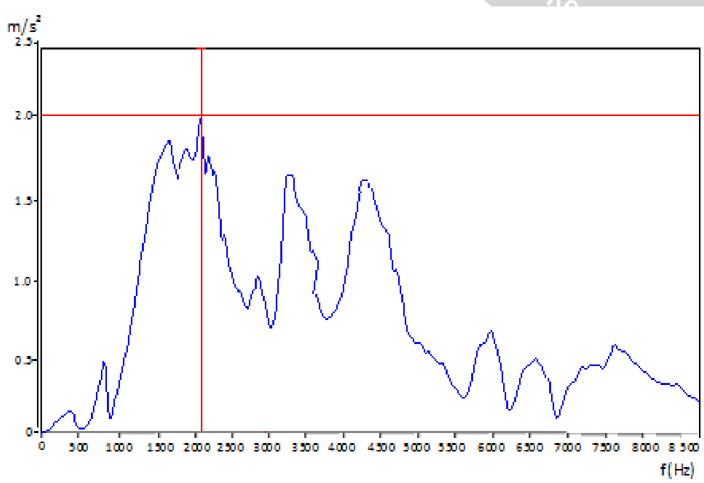

Fig.11: First mode shape of both ends clamped brass plate (2272.47Hz)

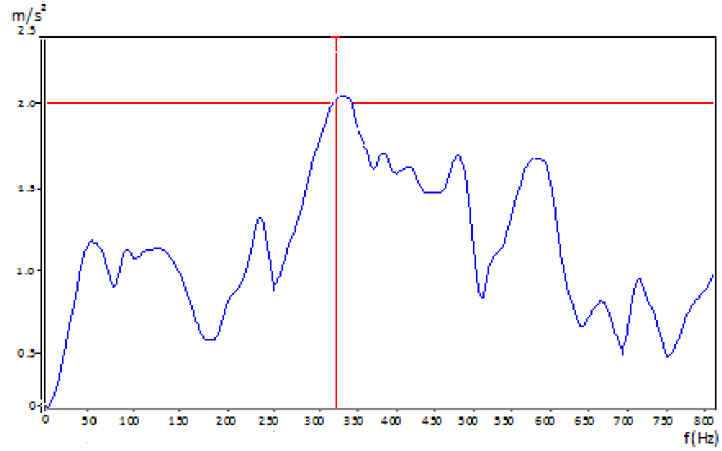

Fig.12: First mode shape of one end clamped copper plate (341.24Hz)

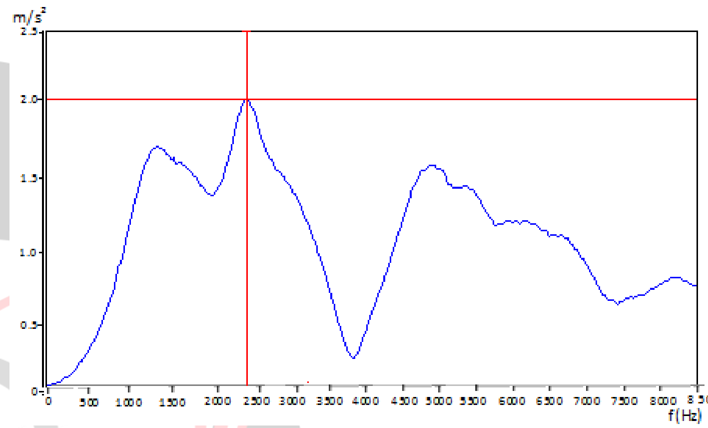

Fig.13: First mode shape of both ends clamped copper plate (2305.07Hz)

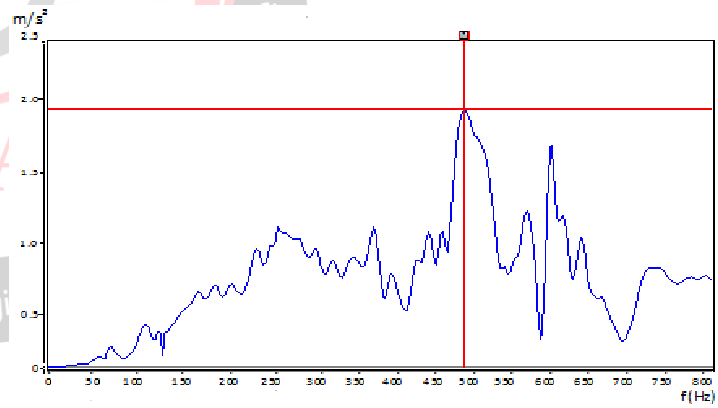

Fig.14: First mode shape of one end clamped stainless-steel plate (472.64Hz)

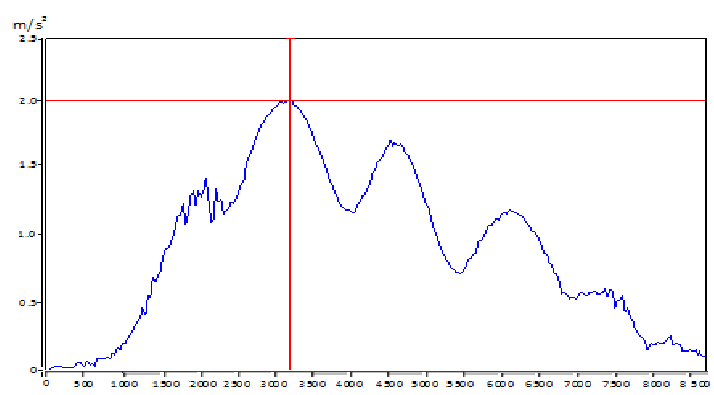

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Fig.15: First mode shape of both ends clamped stainless-steel plate (3174.66Hz)

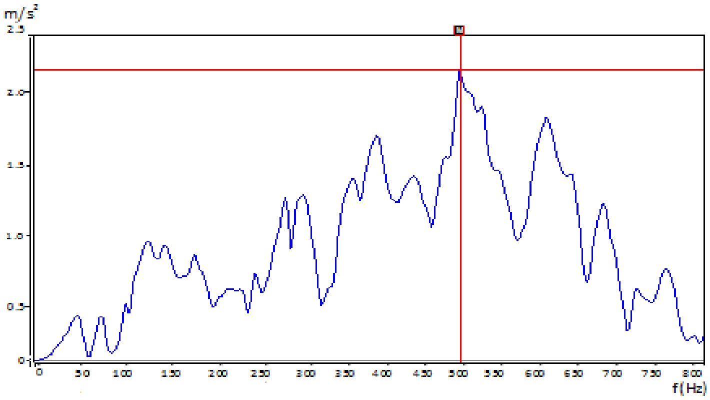

Fig.16: First mode shape of one end clamped aluminum plate (497.54Hz)

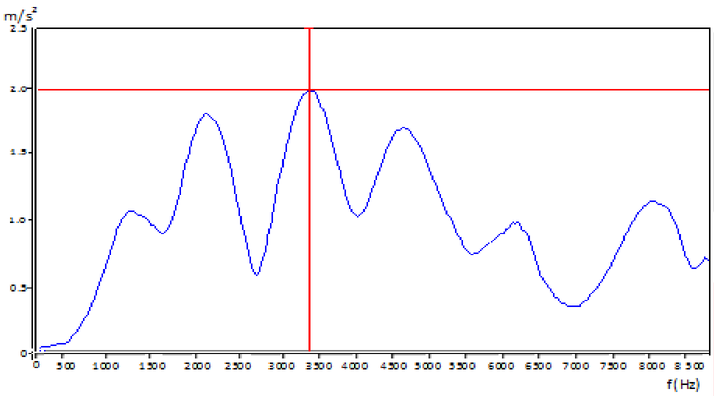

Fig.17: First mode shape of both ends clamped aluminum plate (3414.62Hz)

The above experimental graphs are plotted between force and frequency illustrating the force with which the specimen is hammered and the frequency recorded on FFT analyzer.

The percentage deviation in frequency is given

$$e = \frac{|\text{Analytical value} - \text{Experimental value}|}{\text{Analytical value}} \times 100$$

For the above analytical and experimental values, the percentage deviation is observed in Table1.

Table1: Experimental and analytical (FEM) values percentage deviation of one end clamped and both ends clamped metallic plates

Metallic plates	percentage deviation of experiment with FEM (one end edge clamped)	percentage deviation of experiment with FEM (both ends edge clamped)
Brass	0.8%	2.02%
Copper	1.2%	1.27%
Stainless steel	0.083%	1.359%
Aluminum	2.3%	3.99%

In Table1, for one end clamping cases, the arrangement between the experimental and FEM results is very good for all metal plates. Similarly, for both end clamping cases, the arrangement between the experimental and FEM results is very good for all metal plates except aluminum having nearly 4%discrepancy.

In both ends edge clamping configuration, the percentage deviation is high when compared to the one end edge clamping, because shorter length and boundary conditions results in natural frequencies that is higher than those for the other configuration. It may not be a considerable reason for the increase in the percentage difference between the experimental and FEM predictions are due to the ecological conditions.

IV. CONCLUSIONS

The free vibration analysis of thin metallic plates of isotropic materials under various boundary conditions is solved using finite element method. The experiment modal analysis validation is also carried out, the finite element results are in close agreement with all analytical and experimental results of isotropic materials. It is observed that as the number of free edges decreases i.e. from CFFF to CCFF, the natural frequencies increases for all the cases of metallic plates. The present analysis is useful for the design of skew plates for dynamic response.

NOMENCLATURE

E - Modulus of elasticity
υ - Poisson's ratio
ρ - Density
G - Shear modulus
a/h - Thickness ratio
CFFF - 3edges simply supported and 1 edge clamped
CCFF - 2edges simply supported and 2 edgeS clamped
ξ – Local coordinate in x direction
η - Local coordinate in y direction
ζ - Local coordinate in z direction
p – Polynomial order number
q – Order of all shape functions in ζ direction
ϕ – Basis function
[B] – Strain displacement matrix
[D], [C] - Material constant matrix
$[K]^e$ Elemental stiffness matrix
/J/ - Jacobin matrix
[T] – Transformation matrix
[M] – Mass matrix
σ - Stress
F – Force
δε – Strain energy

δu_e -Variation in strain energy

$\delta\omega$ - Variation in work done

δu - Virtual displacement

ω - Natural frequency

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