COMPARISON OF NATURAL FREQUENCIES OF AISI 1018 MILD STEEL CANTILEVER BEAM THROUGH ANALYTICAL, MODAL TEST, NUMERICAL METHOD (FEM), AND PROGRAMMING SOFTWARE MATLAB

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***Abstract*—Natural frequency can be defined as the frequency at which a system tends to vibrate after giving it an initial excitation. All the engineering structures are subjected to some static and dynamic loads with a certain frequency of vibration during their service. Resonance occurs in structures, when the frequency of vibration is equal to the natural frequency of the structures. Calculation of natural frequencies is made for fault diagnosis of structures. In the present work, comparison of natural frequencies of AISI 1018 mild steel cantilever beam through an analytical, modal test, numerical method (FEM), and programming software MATLAB are performed. It was found that there is a good agreement between the results and a maximum error is observed at first mode between the analytical and modal test results by 7.51%.**

Index terms: Analytical, Cantilever beam, modal test, Mild steel, Numerical method.

I.INTRODUCTION

In real life applications, beams are used in building constructions, aircraft structures, machinery, etc. A cantilever beam is a structural member, whose one end is fixed while another end is free to move in a vertical direction. All the engineering structures are subjected to some static and dynamic loads with a certain frequency of vibration during their service. Resonance occurs in structures when the frequency of vibration is equal to the natural frequency of the structures. Resonance in the structures leads to catastrophic failure. So, vibration testing becomes a standard method in many industries for fault diagnosis.

In this paper, natural frequencies of a cantilever beam are calculated by the analytical, modal test, numerical method ANSYS and programming software MATLAB. Experimental modal analysis is performed on the cantilever beam with the help of FFT (Fast Fourier Transformer) analyzer. Finally, results obtained from these methods are compared. It was observed that the results found by analytical, modal test, numerical method ANSYS and programming software MATLAB are approximately the same.

Chandan et al. [1] calculated natural frequency of different modes of a cantilever beam analytically and experimentally. Both analytical and experimental results are compared for two materials (Aluminum and Mild Steel). It is found that the result found by analytically and experimentally is approximately the same. Nikil [2] performed a vibrational analysis on a portable crane to avoid failure of the crane due to resonance. This paper focuses on the vibration analysis of the beam of portable crane due to the motion of the load at its free end. As resonance occurs when the frequency of vibration of a beam mass assembly is equal to the natural frequency, he derived some mathematical equations to avoid the resonance. Pankaj et al. [3] studied the vibration behavior of beam type structures by an analytical approach and experiment using FFT analyzer. Results are compared from analytical and experimental methods. Joseph et al. [4] performed modal analysis on a cantilever beam through ANSYS 16.0 and MATLAB 2008 and the first three natural frequencies in both methods are almost the same. Deepak et al. [5] performed a comparative analysis of natural frequency for cantilever beam through analytical and software approach. Natural frequencies of aluminum, copper and mild steel are calculated analytically and these results are compared with ANSYS results. There is a good agreement of the theoretical calculated natural frequency with the experimental one. Sonawane et al. [6] analyzed a cantilever beam of a rectangular plate using ANSYS and results obtained from FEA software ANSYS and experimental modal analysis are compared. Zannon et al. [7] studied the vibrations of a thin film cantilever beam and derived frequency equations of vibration. [8] Wu et al. derived an analytical equation for calculating natural frequencies of a cantilever beam with a point mass. Barada et al. [9] performed an experimental modal analysis to detect the crack presence in a beam. First two natural frequencies of the cracked beam have been obtained experimentally and used for detection of crack location and size. Vader et al. [10] evaluated changes in natural frequencies of cantilever composite beam made of Glass Epoxy. The effect of location and depth of crack on the natural frequency of beam with transverse open crack is explored. The numerical results were found in good agreement with the experimental results.

II. ANALYTICAL METHOD

A cantilever beam is a structural member, whose one end is fixed while another end is free to move in a vertical direction. Consider a cantilever beam of length 'L' subjected to some transverse vibrations. The natural frequency of a cantilever beam is given by Euler's – Bernoulli's equation.

Natural frequency in rad/s is given by, $\omega_n = \alpha_n^2 \sqrt{\frac{EI}{\rho A L^4}}$

Natural frequency in Hz is given by, $f_n = (\omega_n / 2\pi)$

Where, E = Modulus of elasticity, N/m^2

I = Moment of inertia, m^4

ρ= Density of material, Kg/m^3

A= Area of the cross section, m^2

L= length of the cantilever beam, m

α_n = Constant depends upon boundary conditions of the beam.

$\alpha_n = n\pi$, n=1, 2, 3, 4……,∞

Schematic view of cantilever beam is shown in figure 1.

Fig.2.1 A cantilever beam

For the rectangular AISI 1018 Mild steel beam,

$E = 205 * 10^9$ N/m^2

ρ= 7870 Kg/m^3

A= 0.04988 m* 0.00295 m

L= 0.3 m

$I = \frac{b d^3}{12} = 106.9425 * 10^{-12}$ m^4

First, three natural frequencies are given by, $f_n = (\omega_n / 2\pi)$

Table 2.1 Analytical results

Mode number	Natural frequency, Hz
1	19.188
2	120.261
3	339.347

III. NUMERICAL METHOD

A finite element modal analysis has been performed by the ANSYS APDL 15.0 software. ANSYS is finite element software used to solve the wide variety of engineering problems. The three natural frequencies of an AISI 1018 mild steel cantilever beam are calculated by the following procedure.

Open ANSYS APDL software and select the element type for cantilever beam (beam 188-2 nodes). Go to the preprocessor, specify the material properties young's modulus, density and poison's ratio in material models and create a modal of the cantilever beam . Apply meshing and boundary conditions for a beam. Now go to loads and set analysis type as modal and specify the number of modes to expand (i.e number of natural frequencies required) and a number of modes to extract. Solve the modal and read the results in the post processor.

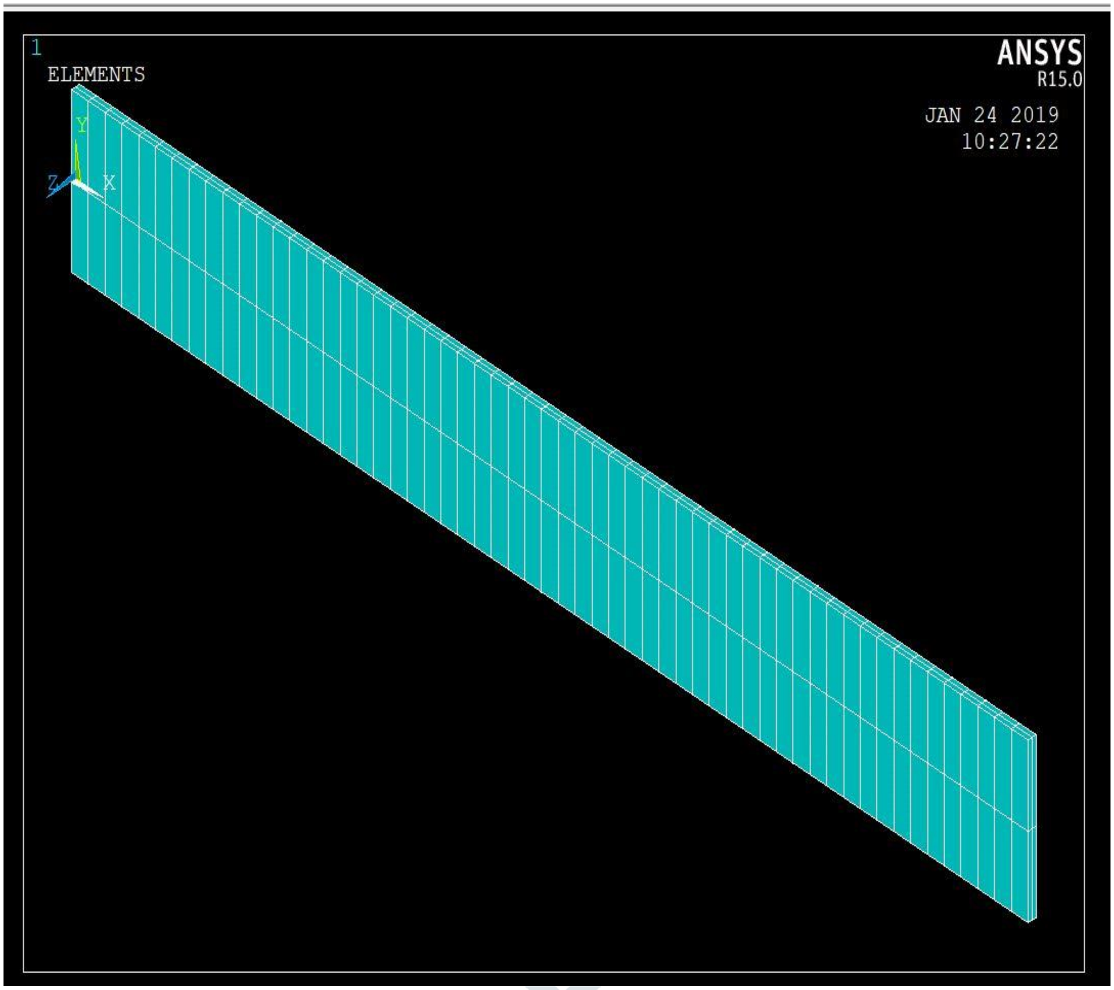

Figure.3.1 Meshing of the cantilever beam.

Results obtained from ANSYS 15.0 are shown in figure (3).

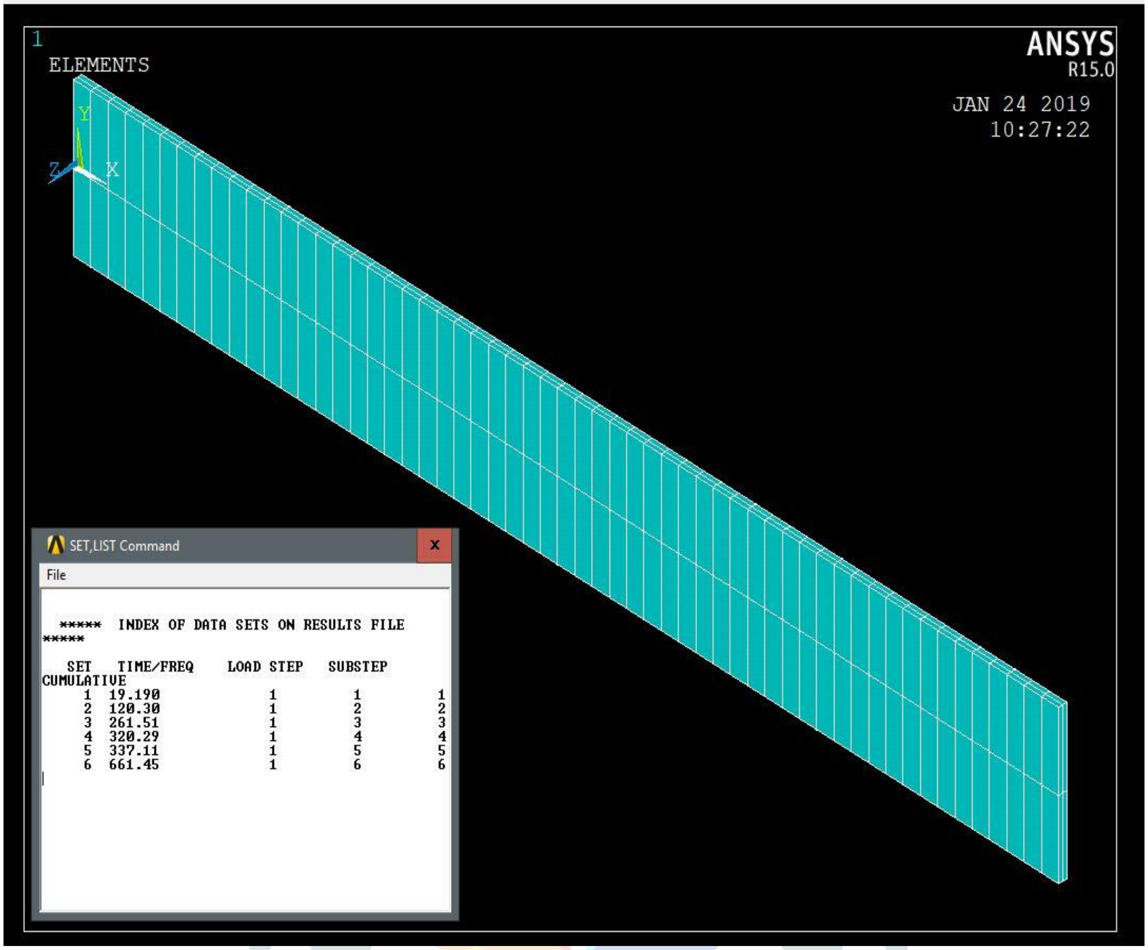

Fig.3.2 Frequency results from ANSYS APDL

IV. MODAL TEST

A modal test is conducted on a cantilever beam with the help of FFT analyzer (Fast Fourier Transformer). A Fast Fourier Transformer is used in industries for fault diagnosis and the experimental set up contains following components.

1. Data acquisition system (A 4-channel FFT analyzer).

2. Accelerometer (sensitivity -107 mv/g).

3. Impact hammer (sensitivity- 10 mv/lbf).

4. A computer with engineering data management software (EDM).

5. Connecting cables.

6. A power supply unit.

7. AISI 1018 mild steel cantilever beam.

4.1. Modal test procedure: Modal test has been done to verify the results obtained ANSYS and analytical method. One end of the cantilever beam with dimensions (356mm × 49.98mm × 2.95mm) is rigidly fixed with the help of bench vice or baby vice. Impact hammer is connected to a channel 1 and accelerometer is connected to a channel 2 of the FFT analyzer. The output channel is connected to the computer. An accelerometer is placed at the selected location and initial excitation is given by the impact hammer. The input power is supplied to the FFT analyzer and computer. Now open the EDM (Engineering Data Management) software in a computer to read the results.

Schematic view of modal test set up is shown below.

Fig.4.1 Modal test setup

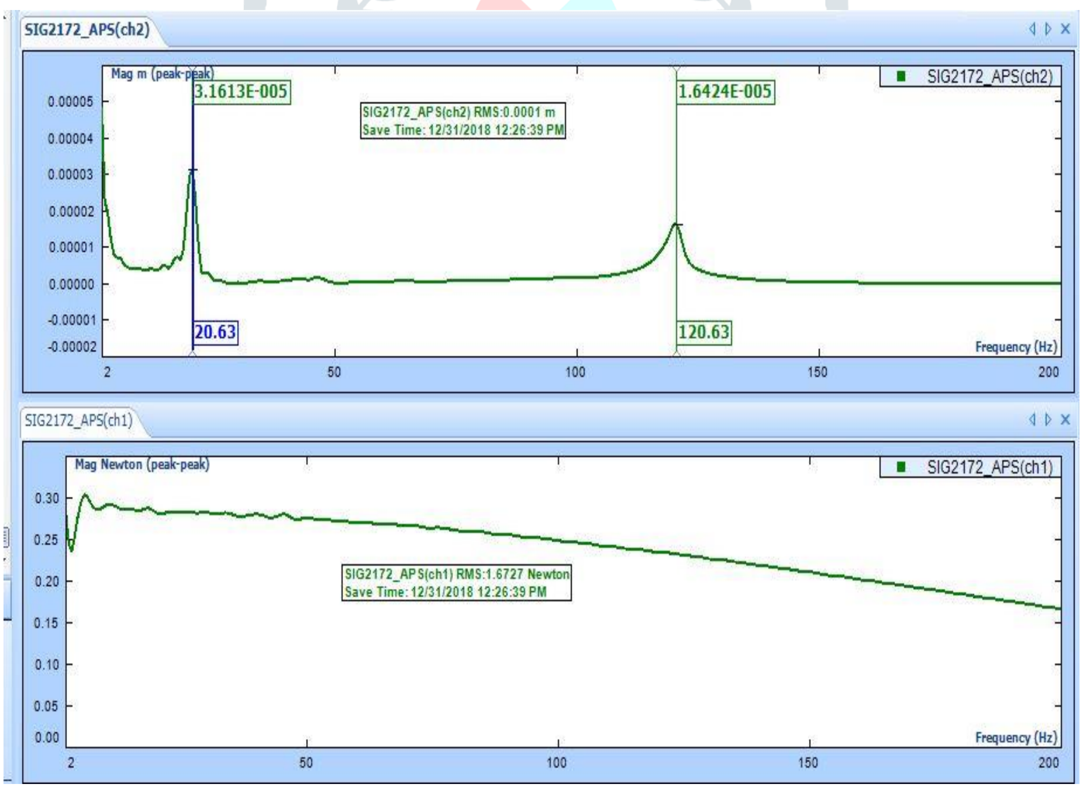

Fig.4.2 Natural frequency results from modal test

V. MAT LAB CODE FOR FINDING NATURAL FREQUENCY OF A CANTILEVER BEAM

Following mat lab code is used to obtain first three natural frequencies of a cantilever beam.

```
% programming in MATLAB R2015b to obtain the first three natural frequencies and mode    shapes of a cantilever beam
%
% Input data
%
% Cross-section of the beam
% Length of the beam
% Area of cross section
% Young’s modulus of the material
% Poisson’s ratio
%
% Out put
%
% Natural frequencies
% Mode shapes
%
clc;
display('specify the cross section of the cantilever beam')
disp('If rectangle, enter 1')
disp('If circle, enter 2')
disp('If square, enter 3')
% Input data
acs=input(' specify your choice :   ');
if isempty(acs) || acs ==1
% For rectangle section
    w=input('Enter width of the rectangle section in [m]: ');
    t=input('Enter thickness of the rectangle section in [m]:');
    L=input('Enter length of the cantilever beam in [m]: ');
 % Moment of inertia of a rectangular cross section (Ixx)
 Ixx=(1/12)*(w*t^3);
  % Area of a rectangle section of a beam (A)
A=(w*t);
    disp('Material properties of the cantilever beam')
     E=input('Enter Young’s modulus in [N/m^2]:  ');
     ro=input('Enter material density in [kg/m^3]:  ');
    end

if acs ==2
% For circular section
    R=input('Enter Radius of the X-section: ');
    L=input('Enter Length: ');
    % Moment of inertia of a circular cross section (Ixx)
 Ixx=(1/4)*(pi*R^4);
   % Area of a circular section of a beam (A)
   A=(pi*R^2);
    disp('Material properties of the beam')
    E=input('Enter Young''s modulus in [Pa]:  ');
    ro=input('Enter material density in [kg/m^3]:  ');
    end
if acs==3
 % For square section
   w=input('Enter Width of the X-section in [m]: ');
    L=input('Enter Length in [m]: ');
```

```
 % Moment of inertia of a square cross section (Ixx)
 Ixx=(1/12)*(w^4);
 % Area of a square section of a beam (A)

 A=(w^2);
   disp('Material properties of the beam');
   E=input('Enter Young''s modulus in [Pa]:  ');
   ro=input('Enter material density in [kg/m^3]:  ');
   end
% For natural frequencies and mode shapes
modes=zeros(3,1);
modeshapes=zeros(3,50);
beta = [1.875 4.694 7.856];
for i=1:3,
modes(i) = beta(i)^2 * sqrt((E* Ixx )/(ro*A*L^4));
modes(i) = modes(i)/(2*pi);
betaL = beta(i);
a1 = sin(betaL) - sinh(betaL);
a2 = cos(betaL) + cosh(betaL);
x=0;
increment = L/50;
for j =1:50,
y = a1*(sin(x) - sinh(x));
ymax =y + a2*(cos(x) - cosh(x));
x=x+(beta(i)/L)*increment;
modeshapes(i,j) = y;
end;
end;
beamspan=(1:50)*(1/50)*L;
% For the first mode shape
figure(1);
plot(beamspan, modeshapes(1,:)/ymax);
grid on;
ylabel('modeshape amplitude');
xlabel('beam span');
title('Mode shape of the first natural frequency of a cantilever beam');
legend([ ' first natural frequency =', num2str(modes(1))]);
% For the second mode shape
figure(2);
ymax =max(abs(modeshapes(2,:)));
plot(beamspan, modeshapes(2,:)/ymax);
grid on;
ylabel('modeshape amplitude');
xlabel('beam span');
title('Mode shape of the second mode of a cantilever beam');
legend([ 'second natural frequency =', num2str(modes(2))]);
% for the third mode shape
figure(3);
ymax =max(abs(modeshapes(3,:)));
plot(beamspan, modeshapes(3,:)/ymax);
grid on;
ylabel('modeshape amplitude');
xlabel('beam span');
title('Mode shape of the third mode of a cantilever beam');
legend([ 'third natural frequency =', num2str(modes(3))]);
% To display results
```

```
for i=1:3,
   mode=i
disp(sprintf ('%s natural frequency is: %d\n', mode,modes(i)));
end;
% End of the program
```

VI. RESULTS

The first three natural frequencies of AISI 1018 mild steel cantilever beam were calculated by analytical method, modal test, numerical method (FEM), and programming software MATLAB. A comparison of numerical, modal test and MATLAB was made with analytical calculations and results obtained from these methods are tabulated below.

Table 6.1 First three natural frequencies for a cantilever beam

Mode	Analytical (Hz)	Numerical (APDL - ANSYS 15.0) (Hz)	MATLAB (Hz)	Modal Test (Hz)
1	19.188	19.190	19.188	20.63
2	120.261	120.30	120.261	120.63
3	339.347	337.11	336.203	347.27

Variation of the natural frequencies between analytical and modal test are tabulated below.

Table 6.2 Percentage of error between modal test results from and analytical results.

Mode	Modal test(Hz)	Analytical(Hz)	Error (%)
1	20.63	19.188	7.51
2	120.63	120.261	0.30
3	357.27	339.347	5.28

Table 6.3 Percentage of error between modal test results and numerical results.

Mode	Modal test(Hz)	Numerical (APDL -ANSYS 15.0) (Hz)	Error (%)
1	20.63	19.190	6.98
2	120.63	120.30	0.27
3	357.27	337.11	5.64

From the above tables (3) and (4) it was observed that the maximum error was found at first mode. A graph was made between mode number and natural frequencies of Analytical, Numerical method and Modal test as shown below.

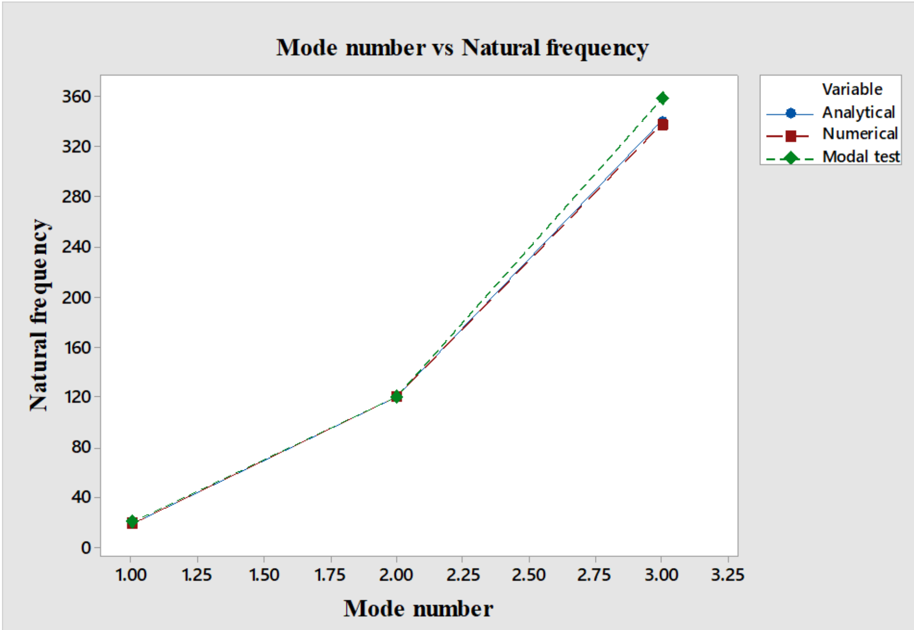

Fig.6.1 Comparison graph for first three natural frequencies

VII. CONCLUSIONS

From the table (3), it was observed that the results found by analytical method, numerical method ANSYS and programming software MATLAB are approximately the same. The maximum error is found between analytical and modal test results at first mode by 7.51%. These methods are used in industries for fault diagnosis and also for safe design of mechanical components.

VIII. REFERENCES

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