Comparative Study on Damping Ratio of Different Materials

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Abstract - The concept of vibrations has an eminent role in the field of Mechanical operations. The operation of a machine may introduce additional vibrations which is undesirable in many domains, primarily engineered systems and methods are being developed in order to prevent transfer of vibration to the concerned engineering system. This is achieved with the help of vibration isolators (Dampers). The vibrational aspect of analysis has a detrimental effect in order to understand the response of system. There are various software packages available in the market to track down the frequency response of the specimen for analysis purpose. The article includes the comparison of the dynamic properties of Steel, Aluminum, Granite and Mineral Casting. The main aim of this comparison is to study the natural frequencies and mode shapes and showcase that the Mineral Casting has a better damping than the latter specimens under observation. This would help to figure out the scope of Mineral Casting for machine tool application. Experimentation is carried out using FFT analyzer and the specimens were mounted in Free-Free Configuration. In short, the experiment is a case of Damped Free Vibration and the results are validated based on general equations of free vibration, etc.

***Key Words*:** Composite, Damped Free Vibration, Damping, FFT Analyzer, Frequency Response, Mineral Casting, Vibration Isolators.

1. INTRODUCTION

Every material/ Specimen has its own specific natural frequency. When the externally applied frequency matches the natural frequency of the material then resonance occurs. The resonance is undesirable as it leads to a violent behavior to the applied frequency and cause irreplaceable damage / system failure. Hence knowing the natural frequency of the specimen is of keen interest in order to avoid the consequences of resonance. Vibration at lower level can be either eliminated using isolators or are neglected if the intensity is much lower than the natural frequency. Damping comes into picture at resonance because when resonance is about to take place, we can avoid it by either altering the applied frequency or we can use dampers to damp the vibration so as to reduce the vibrational effect. S. Ema et al [1] have studied the effect of impact damper which can be used as an attachment while performing drilling/ boring with long sized tools. There are two types of investigations done in the experiment. One in which the direction of damper is in parallel direction to Gravity and in other one it is perpendicular to gravity. They have concluded that the damper can be used with the tool effectively during machining. Prabhu Raja Venugopal et al [2] have keenly observed the effects of vibration on machined component. They have developed a base to replace cast iron bed with it and have performed experimentation and validation using modal analysis. This has led to improvement in static stiffness and they have concluded that deformation up to much great extent has been reduced in comparison with cast iron bed. Hence, they have put forth the alternative to Cast iron bed and have made up the effort to improve the structural rigidity with the ease of manufacturing.

2. METHODOLOGY

A. Objective & Scope

In this project we have formulated the natural frequencies for different specimen and have predicted the damping value using frequency response software. The specimen used has a dimension of 50x50x300 mm and we have assumed it to be a beam. Hence, we have used Euler-Bernoulli equation. The comparison of the damping value was done in order to find out the scope for application of mineral casting according to the values of damping and its resonant frequency as per current dimension of the specimen.

a) Mathematical Considerations [3]

The Euler-Bernoulli equation for free vibration case can be written as follows.

$$\frac{\partial^2}{\partial x^2}\left(EI\frac{\partial^2 w}{\partial x^2}\right) + (\rho A)\frac{\partial^2 w}{\partial t^2} = 0$$

The solution for the equation of above differential equation is given as below

$$W(x) = C_1.\cos(\beta_n x) + C_2.\sin(\beta_n x) + C_3.\cosh(\beta_n x) + C_4.\sinh(\beta_n x)$$

When we solve the equation for the constants, the natural frequency of beam can be computed using the listed formula. The same equation is also mentioned in ASTM E756 for fixed-free configuration. [4]

$$\omega = (\beta_n l)^2 . \sqrt{\frac{EI}{\rho A l^4}}$$

For our experimentation, we have mounted the specimen in Free-Free Configuration and hence according to the boundary conditions the solution can be given by following equation from where we can get the values of the term $(\beta_n l)$

$$\cos(\beta_n l) \cdot \cosh(\beta_n l) = 1$$

The values of the term $(\beta_n l)$ at various modes are listed in the **Table-1**.

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Table-1: Common boundary condition

End Condition of Beam	Value of ($\beta_n l$)
Free-free	($\beta_1 l$) = 4.730041 ($\beta_2 l$) = 7.853205 ($\beta_3 l$) = 10.995608

B. Apparatus

To conduct the experiment, we have used a frequency response package for the hardware included Accelerometer of sensitivity 100 mV/g, an Impact hammer, Data Acquisition system (Dewe43V), Rope, MS washer. **Fig - 1** shows the complete setup and experimental conditions under which experiment was conducted. The accelerometer has a magnetic base which can be directly mounted on ferrous material (in our case Steel) but to measure the response of a non-magnetic material like Aluminum (Al) and Mineral casting (MC) we have used a MS washer. The use of wrapping a magnetic substance over non-magnetic specimen is mentioned in ASTM E756 [4] to measure the response. Later the accelerometer is mounted on the washer being wrapped with cellotape over the specimen and experiment is conducted.

3. EXPERIMENTATION

A. Experimental Setup

The Experimental setup (Free-Free configuration) was confirmed after an intensive literature survey. The experiment was carried out on the specimens of Steel, Aluminum, Granite and Mineral casting Specimen number 28 (MC Sp 28). The Experimentation is carried out using DeweFRF software. As mentioned in [3], we had prepared the testing for cantilever configuration and we did so. Further we started with Free-Free configuration, the results of damping were found to be quite promising.

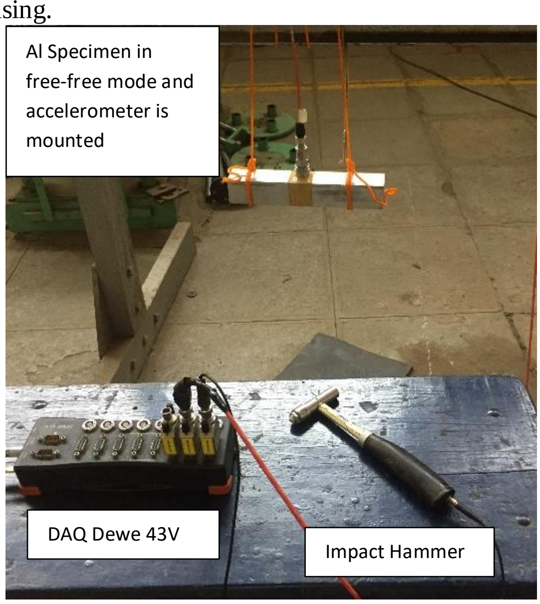

Fig - 1: Setup for experimentation

B. Procedure

- Mount the specimen with the help of rope to create the free-free condition.
- Mount the accelerometer on the specimen and connect the impact hammer and accelerometer to the DAQ (Dewe 43V).
- Start the frequency response package on the laptop and feed the channel setup data. Channel setup includes sensitivity of Accelerometer and impact hammer, Frequency resolution, number of hits etc.
- One has to set these values in order to begin the measurement. When the measurement starts, we can see the window at right corner of the screen notifying that system is ready to process the response.
- The intensity of hitting the impact hammer on the specimen should be gentle. Harsh hitting may lead to the channel overload error.
- After a specific number of hits the system calculates the response and the analyze window shows us the frequency curve.
- There are number of options available from Phase angle-Frequency, Amplitude-Frequency, Coherence-Frequency graphs, etc. [5]
- There are other analysis options such as modal circle fit, Coherence which help us to find the most precise value.
- The frequency where we get the maximum peak amplitude is treated to be natural frequency of the specimen.
- At the same point, the damping ratio is predicted, which is assumed to be the best as the system hardware and software is calibrated at the start of experimentation.
- The theoretical and Experimental natural frequencies were compared and the results were validated.

C. Calculations

For calculating the natural frequency, we have used the equation derived from Euler-Bernoulli. To find out the value we require the Elastic Modulus (E), Moment of Inertia (I), Linear density ($\rho_L = \rho.A$), Length of the specimen (l), etc.

$$\omega = (\beta_n l)^2 . \sqrt{\frac{EI}{\rho A l^4}}$$

For Steel,

E = 210 GPa
l = 0.3m
A= 0.0025 m^2
ρ = 7850 kg/m^3
$I = \frac{bd^3}{12}$ = (0.05 x 0.05^3) / 12

Now for mode 1, $\omega = (\beta_n l)^2 . \sqrt{\frac{EI}{\rho A l^4}}$

$= (4.730041)^2 . \sqrt{\frac{210E9 \times 0.05^4}{7850 \times 0.0025 \times 12 \times 0.3^4}}$

= 18558.44 rad/ sec

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Theoretical Frequency (f_{th}) = $\omega / 2\pi$
= 2955.16 Hz

For Aluminum,

E = 70 GPa
l = 0.3m
A= 0.0025 m^2
ρ = 2690 kg/m^3
$I = \frac{bd^3}{12}$ = (0.05 x 0.05^3) / 12

Now for mode 1, $\omega = (\beta_n l)^2 . \sqrt{\frac{EI}{\rho A l^4}}$

$= (4.730041)^2 . \sqrt{\frac{70E9 \times 0.05^4}{2690 \times 0.0025 \times 12 \times 0.3^4}}$

= 18303.73 rad/ sec

Theoretical Frequency (f_{th}) = $\omega / 2\pi$
= 2914.606 Hz

For Granite,

E = 90 GPa
l = 0.3m
A= 0.0025 m^2
ρ = 2700 kg/m^3
$I = \frac{bd^3}{12}$ = (0.05 x 0.05^3) / 12

Now for mode 1, $\omega = (\beta_n l)^2 . \sqrt{\frac{EI}{\rho A l^4}}$

$= (4.730041)^2 . \sqrt{\frac{90E9 \times 0.05^4}{2700 \times 0.0025 \times 12 \times 0.3^4}}$

= 20716.01 rad/ sec

Theoretical Frequency (f_{th}) = $\omega / 2\pi$
= 3298.727 Hz

For Mineral casting Specimen 28 (MC Sp. 28),

E = 45 GPa
l = 0.3m
A= 0.0025 m^2
ρ = 2450 kg/m^3
$I = \frac{bd^3}{12}$ = (0.05 x 0.05^3) / 12

Now for mode 1, $\omega = (\beta_n l)^2 . \sqrt{\frac{EI}{\rho A l^4}}$

$= (4.730041)^2 . \sqrt{\frac{45E9 \times 0.05^4}{2450 \times 0.0025 \times 12 \times 0.3^4}}$

= 15377.65 rad/ sec

Theoretical Frequency (f_{th}) = $\omega / 2\pi$
= 2448.67 Hz

The final calculated values of theoretical frequencies are tabulated in **Table- 2** along with the theoretical values fundamental frequency value are also obtained by Modal analysis and experiment. **Fig- 2** to **Fig- 5** shows the fundamental frequency mode for different specimens obtained by modal analysis.

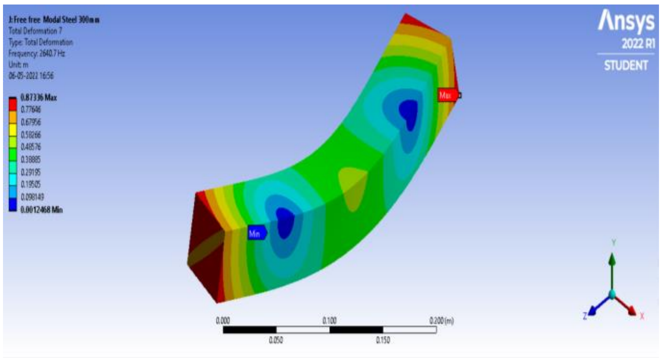

Fig- 2: Modal Analysis (Mode 1) for Steel Specimen.

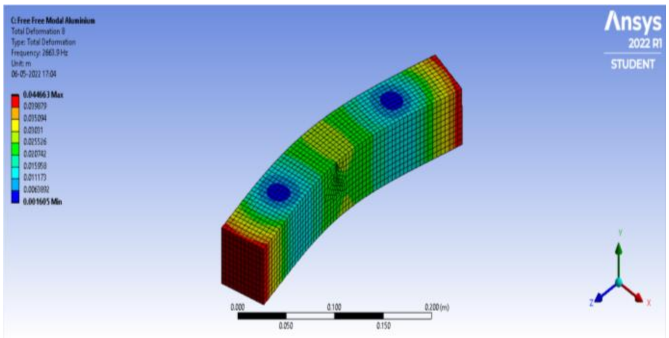

Fig-3: Modal Analysis (Mode 1) for Aluminum (Al) Specimen.

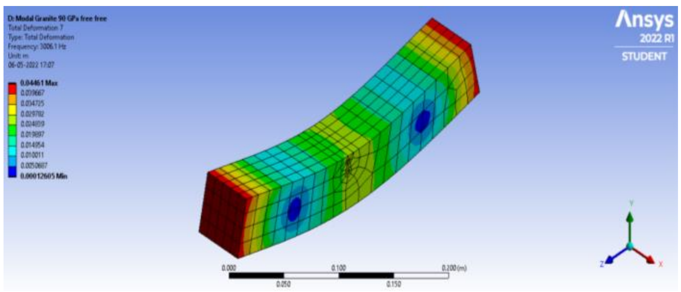

Fig-4: Modal Analysis (Mode 1) for Granite Specimen.

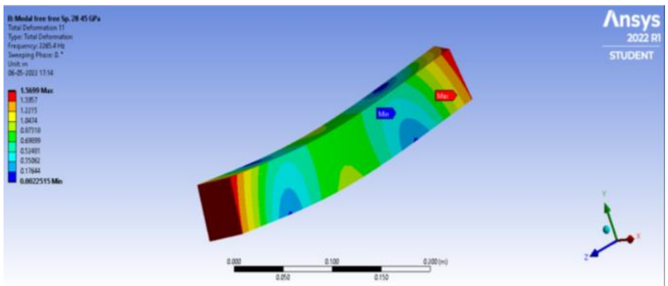

Fig-5: Modal Analysis (Mode 1) for MC Sp. 28

4. RESULTS & DISCUSSION

The value of frequency was calculated using the equation suggested in ASTM E756 [4] and was compared with the values obtained from ANSYS Workbench 2022 R1 and the experimental frequency was compared too. **Table-2** shows the comparison of theoretical, Modal and Experimental Frequencies for 1st mode of vibration (Fundamental Frequency).

Table-2: Comparison of Natural frequencies at 1st mode.

Material	ω (rad/s)	f_{th} (Hz)	Modal Frequency (Hz)	Exp. Frequency (Hz)
Steel	18558.44	2955.16	2640	2577
Aluminum	18303.73	2914.6	2663.9	2737
Granite	20716.01	3298.7	3006.1	3229.7
MC Sp. 28	15377.6	2448.7	2265.4	2365

The Experimental value of frequency as shown in **Table-2** has been obtained considering the Phase angle change, Maximum peak amplitude. Also, the results for damping ratio are tabulated in **Table-3** based on which the scope of application for Mineral casting is to be decided.

Table-3: Experimentally derived damping ratio

Material	Damping Ratio (%)
Steel	1.29
Aluminum	2.08
Granite	4.23
MC Sp. 28	6.54

From the values of **Table 3** we can confirm that the damping capacity of Mineral casting is approximately 1.5 times of Granite. Hence by varying the composition of mineral casting one can also make an effort to improve other properties of the composite and find out the suitable scope of application.

5. CONCLUSION

From the above we can conclude that though Granite is the best, naturally available option for damping material but the manufacturing processes included for finishing of Granite is time consuming. There is a need to look up for the better alternatives and we suggest that the composite (Mineral casting) is of strong potential as the result showcases that the damping ratio of Mineral casting > Granite > Aluminum > Steel.

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