Simulation of Heat generation from Vibration in COMSOL Multiphysics

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Abstract: The vibrations are an essential part of our day to day engineering environment, which happens in automobiles, avionics, machines, electric motors, structures, electronic equipments etc. When a system is vibrating under higher frequencies leads to higher displacement, noise and heat generation. Thus it is essential to study these effects of vibrations to improve the stability of parts in machines. In this paper, heat generation and temperature distribution is studied for longitudinally vibrating beam under its resonant conditions. Every material has its unique internal damping characteristic against vibrations. This causes heat generation in a material. The first resonance frequency of beam is found by Eigen frequency analysis for the longitudinal vibration and performed frequency response analysis to get the conditions for an expected displacement of vibration. Then the frequency response analysis is coupled with the general heat transfer module to study the heat generation and temperature distribution of a beam.

Keywords: Loss factor, longitudinal vibration, heat generation**,** displacement, hysteric damping.

1. Introduction

When a body is vibrating under its resonant conditions, a loss of energy happens due to its internal damping characteristic of the material of the body. Internal loss is defined here by Hysteresis damping. When a material is loaded and unloaded, the stress and strain due to this loading and unloading follows a different path as like shown in the figure 1. This is because of the loss in property of any material, which can be expressed as complex modulus (storage modulus+ i loss modulus). Thus loss factor (η_s) is the ratio of loss modulus to storage modulus. The amount of energy lost by the vibration of that body by internal damping is dissipating as heat. Sometimes this leads to system shutdown as in the case of resonators, piezoelectric actuators etc. This may cause system malfunctioning or system damage in terms of structural collapse. Thus studying this nature of material of a body is a prime focusing factor while designing a vibrating system. Due to over self heating nature which may change the material properties also thus makes the design doesn't suite for that requirement.

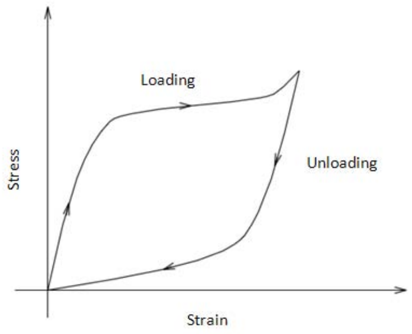

Figure 1.Hysteric damping curve

COMSOL Multiphysics is used for this analysis because of having advantage in solving more physics simultaneously.

2. Modeling in COMSOL Multiphysics

A Freely vibrating longitudinal rectangular beam is made of titanium which is shown in the figure 2 is considered for this analysis.

3 Model Navigator

Two modules are used for this analysis. Eigen frequency (smsld) and frequency response analysis (smsld) from structural mechanics module for vibration and coupled with general heat transfer module (htgh) for thermal analysis.

3.1 Eigen frequency and frequency response analysis

The Eigen frequency analysis finds the natural frequency and their corresponding modes of vibration (Our analysis is restricted to longitudinal vibration) .The first resonance frequency for longitudinal vibration is found from this analysis. The frequency response analysis is done to find the response nature of the structure under harmonic excitation which can be used to find the condition to get the expected level of vibration.

3.2General Heat Transfer Module

A general heat transfer module is coupled with the frequency response analysis to find the temperature distribution of the system under transient condition. The heat flux is defined as per reference [1].

$$\text{Qdamp\_smsld} = 1/2 * \omega * \eta_s * \text{Real}[\varepsilon .\ \text{Conj}(\ D\ \varepsilon)]$$

The term Qdamp_smsld represents the internal work of the nonelastic forces over a period is the energy transfer between the mechanical and thermal domains due to the nonlinear nature of thermo-elastic coupling, ω represents the angular excitation frequency and ε and D represents the strain tensor and elasticity matrix.

4. Boundary settings

The beam is allowed to vibrate freely for Eigen frequency analysis and a harmonic excitation force is given at one end of the rod to find the response of the structure. Constant convective heat transfer coefficient is defined to represent the convective heat transfer at the boundary.

5. Subdomain settings

The titanium material is selected from COMSOL basic material properties library for both structural vibration and heat transfer analysis. The structural loss factor (η_s) is defined for frequency response analysis to represent the system under internal damping condition. The energy lost to heat domain by internal damping nature of the system is given as input for heat flux in the heat transfer module. This is represented as Qdamp_smsld in COMSOL.

6. Meshing solving and post processing.

Default mesh settings were used. The model is solved under transient conditions .SPOOLES solver is used for this analysis. The measured values of displacement, temperature distribution and heat generation are plotted using domain plot parameters. The Eigen frequency analysis results for first and second resonance are shown in the deformed shape with sub domain results. The heat generation and temperature distribution plot results are shown of normal sub-domain results.

7. Results and discussion:

A rectangular beam of length 100mm and width 10mm and depth 5mm is considered for this analysis. Material properties for titanium are selected from the COMSOL material library for both structural and heat transfer analysis.

The first resonance frequency for longitudinal vibration happens at 23034 HZ as shown in the figure 3.Similarly the second resonance happens at 46013 HZ with two nodes as in the figure 4.

This frequency depends on the shape, size, material properties and also the conditions which the system is vibrating.

Figure 2.Rectangular beam for simulation

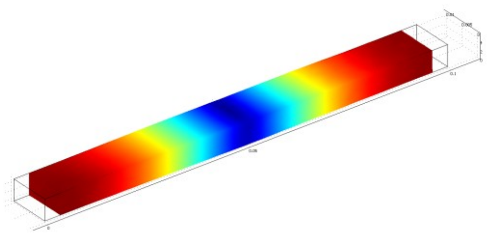

Figure 3.Total displacement plot for longitudinal vibration at first resonance frequency (Eigen frequency=23034 HZ)

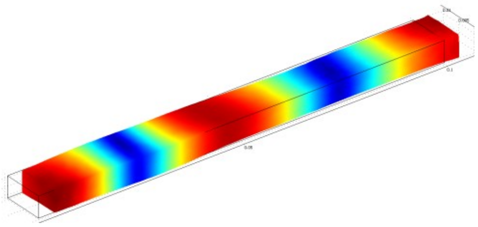

Figure 4.Total displacement plot for longitudinal vibration at second resonance frequency(Eigen frequency=46013HZ).

The distributed harmonic excitation of 50 KPa is applied at the end face B to study the response of the system shown in the figure 5. It is helped to find the condition for which the expected displacement or level of vibration of the system.

Figure 5.Distributed Harmonic force for Frequency Response analysis

This force can be varied to simulate the real nature of any structure under longitudinal vibration. The measured displacement at a point at end B is shown in the figure 6.where the maximum displacement is at the resonance condition. Similarly displacement for the second resonance can also be find from this analysis. The internal damping is defined as structural loss factor(η_s) which is assumed as 0.005 for this analysis.

The vibration energy loss due to the internal damping is defined as heat flux input to the heat transfer module which is defined as an inbuilt equation Qdamp_smsld in COMSOL with constant heat transfer coefficient of 10 W/m^2 K is assumed to all the surface of the beam. The heat generation and temperature distribution is shown in figure 7 and figure 8.This analysis is performed under transient conditions for 5 minutes.

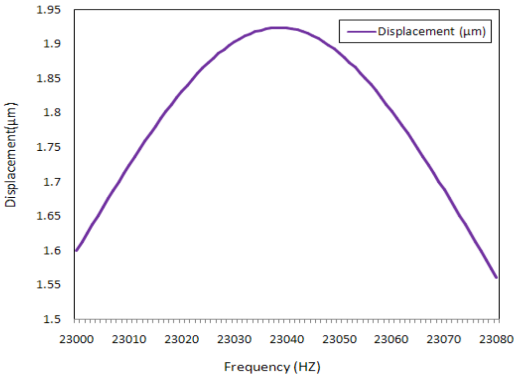

Figure 6.Displacement of the structure under harmonic excitation of 50kPa is measured at a point in end B

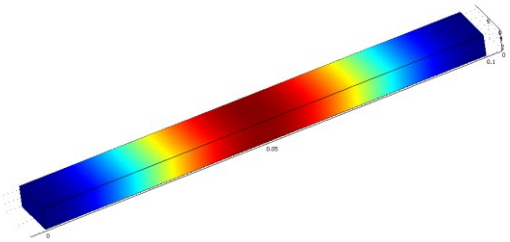

Figure 7.Heat generation due to internal damping

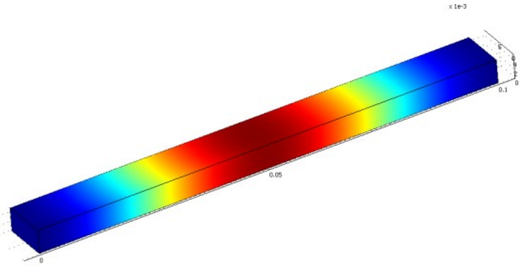

Figure 8.Temperature distribution contour of the beam

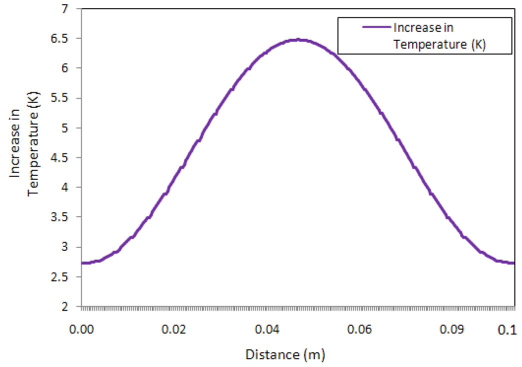

Figure 9.Temperature distribution measured at an edge of beam from A to B

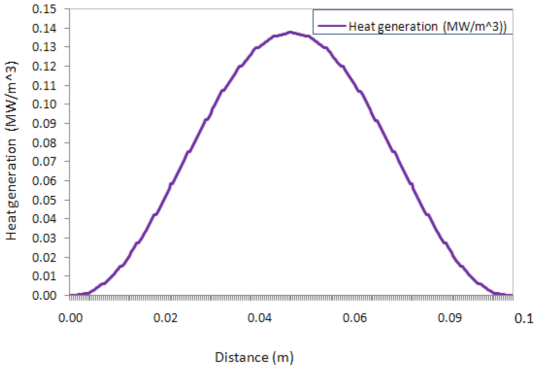

Figure 10.Heat generated measured at an edge of beam from A to B

8. Conclusions

The majority of heat generation by vibration is because of vibration energy loss due to internal damping of the system. The heat generation and temperature distribution shows a greater value at the node position when compared to the other portion of the beam. This is because of the beam is not allowed to move freely under resonant conditions at the node location. Thus it creates more stress intern responsible for creating more heat generation at the node location when compared with the other portion of the beam. The convection heat transfer can be defined with the correlations instead of using constant values to simulate the physics accurately. This correlation differs according to the shapes and size of the systems to analyze.

9. References

1. COMSOL Multiphysics 3.5a user manual
2. D.D. Ebenezer ,D. Thomas ,S.M. Sivakumar, *Non-uniform heat generation in rods with hysteretic damping*, page numbers 892-902. Elsevier, Journal of Sound and Vibration (2007).
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