Design and Construction of A Vibration Testing System

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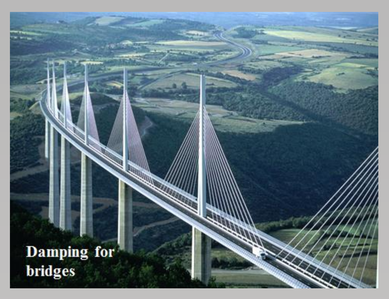
Structures affected by vibrations

Wind turbine blades, high-speed rail, aircraft rudders, helicopter rotors, satellites, automobiles, bridges, highways, high-rise buildings, helmets, etc

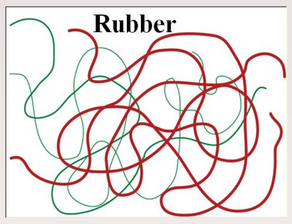


Structural Vibration Problems

1.Vibrations are undesirable for the performance, durability, operation, quality of most structures.
2.In earthquake, buildings with better damping property will have better performance.
3. Cement-based materials are dominant among construction materials.
4. Cement is inherently poor in vibration damping.
5. Damping can be improved by adding appropriate ingredients to the cement mix.

Vibration Damping Mechanisms

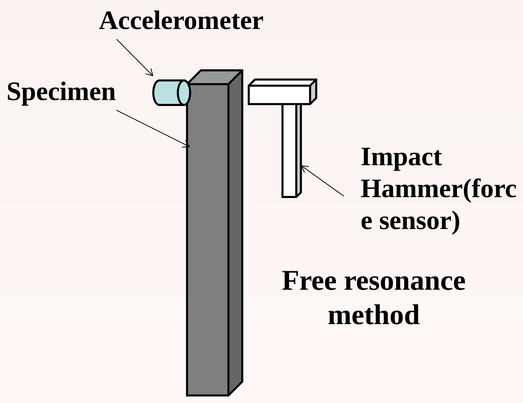
• Bulk viscous deformation: vibration causing inelastic deformation due to movements such as molecular movement in the bulk of a viscoelastic material.



• Interfacial slippage: vibration causing sliding at interfaces in a material

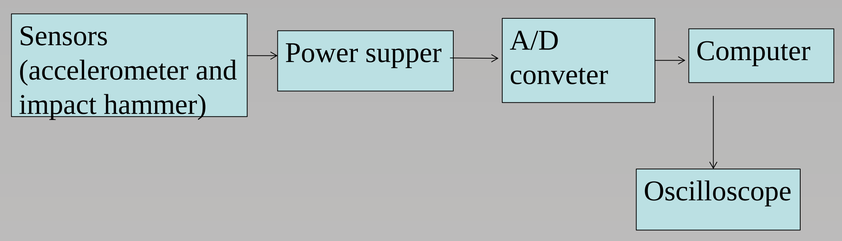
Vibration Testing Methods

1. Forced resonance method (with loading at a fixed frequency and measurement of the phase lag between the input stress wave and output strain wave)
2. Free resonance method (with a controlled impulse provided by a hammer near the end of a specimen bar and measurement of the acceleration of the specimen)



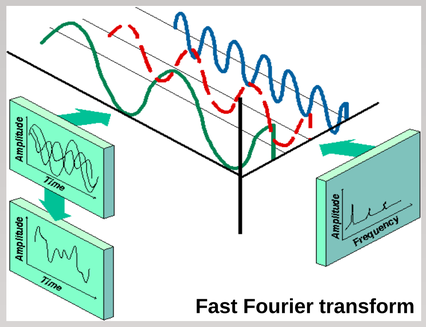
Free resonance method

Components in the vibration testing system



Concepts in free-resonance data analysis

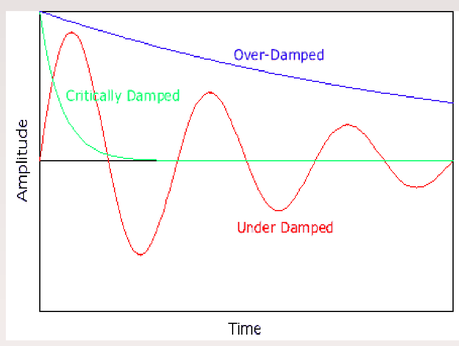
•Fast Fourier Transform (FFT): The algebra of FFT can transform data from time domain to frequency domain.
•Power spectrum density function (PSD): It is always used for dealing with signals. By using PSD, the noise from the original data can be minimized and thus more accurate data can be used for simulation.
•Frequency response: This is a measurement of how structure responds to vibration in frequency domain.

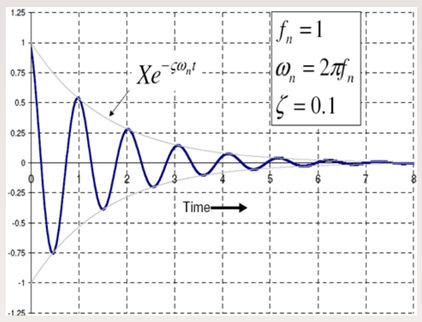


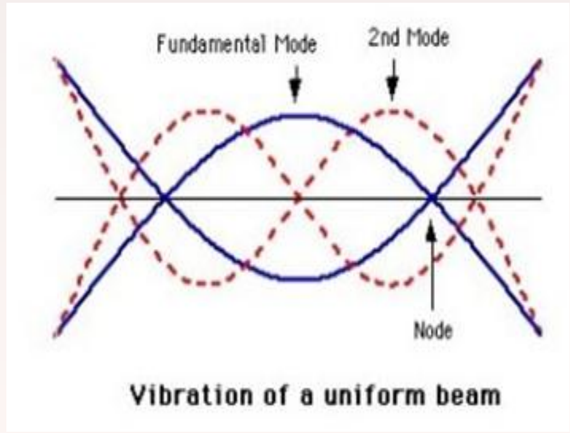
Fast Fourier transform

Description of Damping Performance

- **Damping ratio (ζ) is a parameter that describes how the vibration decays with respect to time.**
- **$\zeta = c/c_c$, where c is the damping coefficient of the system, and c_c is the critical damping (explained below).**



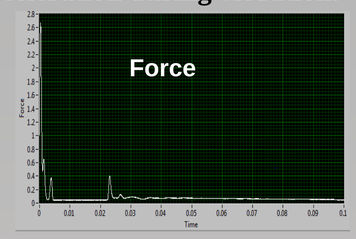


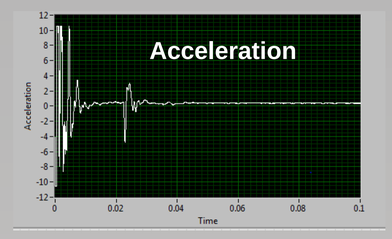


Vibration of a uniform beam

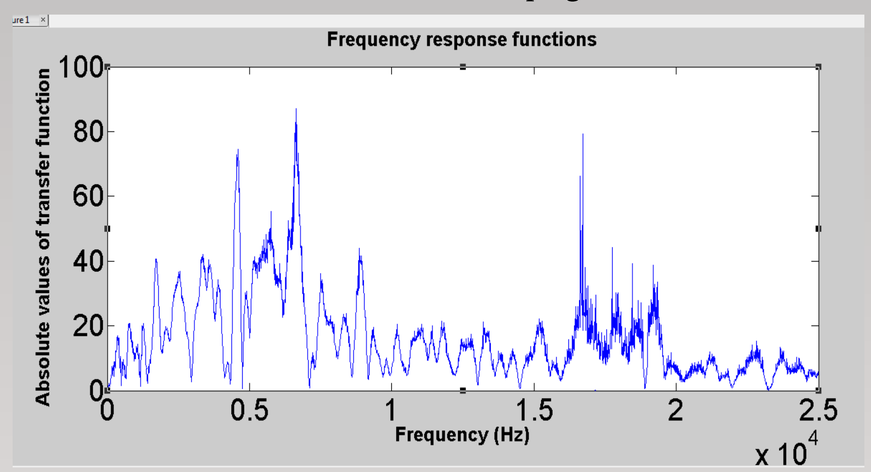
Method of data analysis

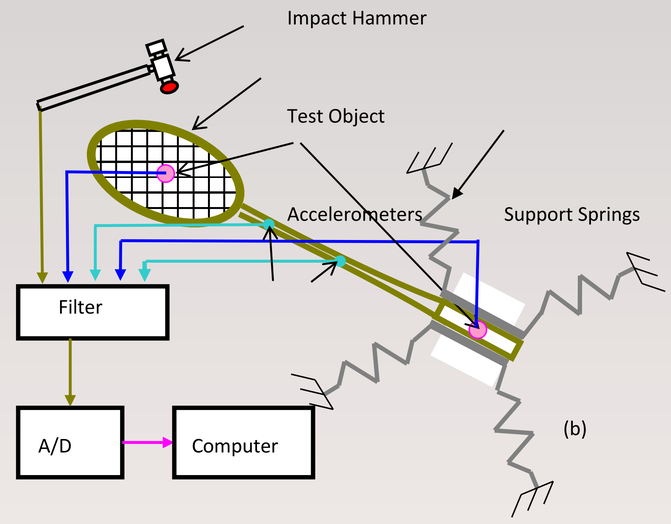
1.Measure the initial impulse force and the resulting acceleration during vibration.





2.Analyze the vibration frequencies, which correspond to different vibration modes.
3.Choose the dominant vibration mode for analysis.
4.Obtain the transfer function, which is the acceleration (output) divided by the force (input).
5. Use the transfer function to calculate the damping ratio, which describes the extent of damping.





Conclusions

- **A vibration testing system based on free resonance has been successfully designed and constructed.**
- **The method of data analysis based on modal analysis has been developed for this testing system.**
- **The system and analysis methods are being used for the study of engineering materials, particularly cement-based materials and ability.**

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Reference

Sivaraja Muthusamy, Shoukai Wang and D.D.L. Chung, "Unprecedented Vibration Damping with High Values of Loss Modulus and Loss Tangent, Exhibited by Cement-Matrix Graphite Network Composite," Carbon 48(5), 1457-1464 (2010).

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