Vibration & System ID

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Lecture Outline

• Why
• How
  – Model
  – SMD Model
  – Vibration Sensors
  – Accelerometers
  – Tap Test
  – PSD
Rocket Vibration

- [http://www.youtube.com/watch?v=rASHRBo9Rg&feature=player_embedded](http://www.youtube.com/watch?v=rASHRBo9Rg&feature=player_embedded)

- HEAT1X-Tycho Brahe inaugural flight / Pilot's POV – 9Hz oscillation
Saturn Rocket Vibration

“Pain was directly associated with motion of the eyeballs and testicles, as well as from internal heating that resulted from sloshing of the brain and viscera. The vibration frequency was also in the range of normal brain waves, adding confusion to decision making, hand and arm movement, and even speech.” –Jim Fenwick on Pogo oscillations

http://www.pwrengineering.com/articles/pogo.htm
Space Shuttle Main Engine Turbopumps

“The high-pressure pumps rotated at speeds reaching 36,000 rpm on the fuel side and 24,000 rpm on the oxidizer side. At these speeds, minor faults were exacerbated and could rapidly propagate to catastrophic engine failure.”

“...the vibration spectral data contained potential failure indicators in the form of discrete rotordynamic spectral signatures. These signatures were prime indicators of turbomachinery health...”

"Wings in Orbit" edited by Wayne Hale and Helen Lane
“While the lower stages of the North Korean rocket continued to function for several minutes, resonance at the top of the launch vehicle resulted in ‘catastrophic disassembly of the third stage at Max Q,’ said Charles Vick, senior technical and space policy analyst at GlobalSecurity.org. ‘The vibrations just tore it apart.’”


Model

• Continuum Model
  – Analytical <http://iitg.vlab.co.in/?sub=62&brch=175&sim=1080&cnt=1>
  – Finite Element (SolidWorks Simulation)

• SMD Model
  – Stiffness
  – Equivalent mass
  – Damping
Finite Element Model

• SolidWorks Simulation
Mode 1 – 229.09 Hz
Mode 2 – 1297.9 Hz
Mode 3 1417.6 Hz
Mode 4 – 1679.3 Hz
Mode 5 – 3917.6 Hz
Mode 6 – 5149.6 Hz
Mode 7 – 6538.1 Hz
Mode 8 – 7545.1 Hz
Mode 9 – 8377.9 Hz
Mode 10 – 8933.4 Hz
Mode 11 – 12199 Hz
Mode 12 – 13198 Hz
Mode 13 – 14941 Hz
Mode 14 – 17714 Hz
Mode 15 – 18072 Hz
SMD Model

- Around a resonance you can model as

\[
m_e \ddot{y} = f - ky - cy
\]

\[
m \ddot{y} + c \dot{y} + ky = f
\]

\[
\ddot{y} + \frac{c}{m_e} \dot{y} + \frac{k}{m_e} y = \frac{f}{m_e}
\]

\[
\ddot{y} + 2\zeta \omega_n \dot{y} + \omega_n^2 y = \frac{f}{m_e}
\]

\[
\omega_n = \sqrt{\frac{k}{m_e}} \quad \zeta = \frac{c}{2\sqrt{m_e k}}
\]
• Position

\[
\frac{Y}{F} = \frac{1}{m_e} \left( \frac{1}{\omega_n} \right)^2 \frac{1}{1 - \left( \frac{\omega}{\omega_n} \right)^2 + 2\zeta \frac{\omega}{\omega_n} j}
\]

• Velocity

\[
\frac{V}{F} = \frac{j\omega}{m_e} \left( \frac{1}{\omega_n} \right)^2 \frac{1}{1 - \left( \frac{\omega}{\omega_n} \right)^2 + 2\zeta \frac{\omega}{\omega_n} j}
\]
\[ \frac{A}{F} = \frac{-\frac{1}{m_e} \left( \frac{\omega}{\omega_n} \right)^2}{1 - \left( \frac{\omega}{\omega_n} \right)^2 + 2\zeta \frac{\omega}{\omega_n} j} \]
From your data

• From the peak \( \omega_r = \omega_n \sqrt{1 - \zeta^2} \)
• From the \( \frac{1}{2} \) power bandwidth \( \Delta \omega = \omega_{hp} - \omega_{-hp} \)

\[
Q = \frac{\omega_r}{\Delta \omega}
\]

\[
\zeta = \frac{1}{2Q}
\]

• You can also use log decrement.
How Do We Measure?

- Expensive Accelerometers
Measure (cont.)

- Expensive Impulse Hammers

MODEL 5800B2, DYNAPULSE™ IMPULSE HAMMER

Model# 5800B2

**FEATURES:**
- 100 mV/lsf sensitivity
- 50 lbf range
- 1,000 lbf maximum force
- BNC connector
- 100 gram head weight
- IEPE

**APPLICATIONS:**
- Machinery parts
- MIMO test
- Modal and structural analysis
- Root cause failure analysis
- General purpose use on car frames, bearing housings, brake rotors, I-beams, plates and other small-to-medium sized structures and machinery
Measure (cont.)

- Moderately Priced Strain Gauges
Measure (cont.)

- **Low Priced Dynamic Strain Gauges**

**Piezo Sensor - FDT Series**

- Applications: Contact microphone, Dynamic strain gages, Speakers, Switches
- Industries:
- Replaces:
- Datasheet: [FDT_Series](#)

**Piezo Sensor - DT Series**

- Applications: Contact microphone, Dynamic strain gages, Speakers, Switches
- Industries:
- Replaces:
- Datasheet: [DT_Series](#)
Mode 1 – 0 Hz
Mode 2 – 7.0439E-4 Hz
Mode 3 – 1.7816E−3 Hz
Mode 4 – 11.752 Hz
Mode 5 – 11.802 Hz
Mode 6 – 62.133 Hz
Mode 7 – 62.287 Hz
Mode 8 – 111.02 Hz
Mode 9 – 111.06 Hz
Mode 10 – 114.37 Hz
Mode 11 – 154.73 Hz
Mode 12 – 155.32 Hz
Mode 13 – 257.09 Hz
Mode 14 – 266.75 Hz
Mode 15 – 273.79 Hz