The Power of Resonance and RAM Driver Systems

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What is Resonance?

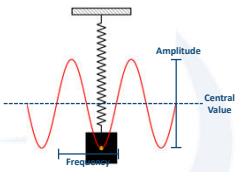
Book Definition:

*"Increased amplitude that occurs when the **frequency of an applied force** is equal or close to a natural frequency of the system on which it acts."*

The Tacoma Narrows Bridge: November 1940

Background – Oscillations and Frequency

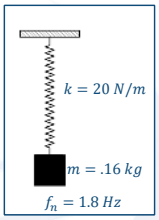
- An Oscillation is a Back-and-Forth Movement about some Central Value
- Frequency is the Speed at which the Oscillation Occurs
  - Defined in Hz (Number of Cycles per Second)
- Amplitude is the distance traveled during half of an oscillation
  - We will measure peak-to-peak amplitude



Background - Natural Frequency

- All Physical Structures have a Natural Frequency!
- This is the Frequency at which the Structure will Tend to Vibrate when Subjected to Certain External Forces
- Depends on the Relationship Between Stiffness and Mass:
  - f_n natural Frequency
  - k : spring stiffness
  - m : mass

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$



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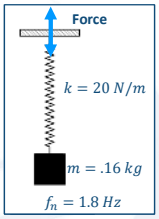
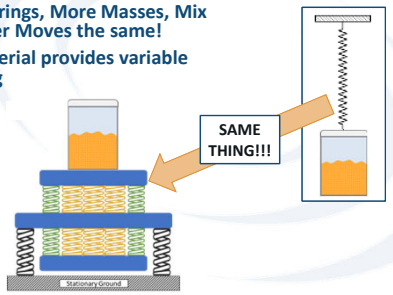


Providing an Oscillating Force at the Natural Frequency Creates Resonance

Simple Spring-Mass to RAM

- RAM Mixer is a More Complicated Spring-Mass System
- More Springs, More Masses, Mix Container Moves the same!
- Mix Material provides variable Damping



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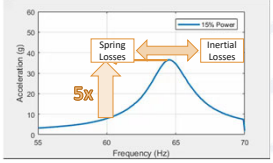
Why Resonant Acoustic Mixing?

- Resonance is not Needed for Mixing
- Energetic Collisions and Acoustic Waves are Needed for Mixing
- High Amplitude Vibrations Create Energetic Collisions and Acoustic Waves
- Resonance Efficiently Produces *"Increased Amplitude Vibrations"*



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Controlling Resonance in RAM

- RAM Mixers use two distinct Drive Systems
  - Linear Voice Coil Motor
  - Rotational Servo Motors
- Control System Accomplishes Two Goals
  - Adjust frequency to maintain resonant condition
  - Adjust power to maintain a set acceleration (g)

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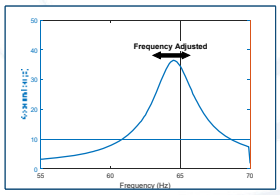
Embedded Controller Overview

Embedded Controller Accomplishes Two Goals

1. Maintain operation at the resonant condition
   - Frequency Control is Transparent to the User



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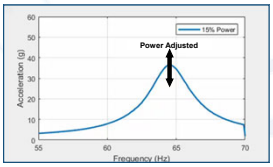
Embedded Controller Overview

Embedded Controller Accomplishes Two Goals

2. Adjust power to maintain a set acceleration

- Acceleration is the primary metric for Acoustic Mixing
- RAM Mixer Adjusts Driver Power to Obtain Acceleration Setpoint
- Operation is Analogous to Automobile Cruise Control



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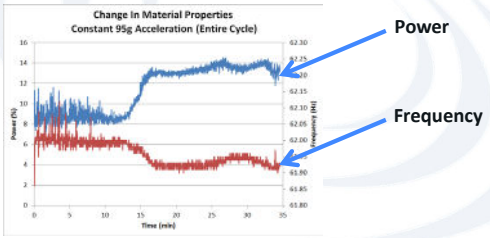
Acceleration Control

- Material Properties can Change During a Mix Cycle
- Changing Material Properties Require Frequency and Power Adjustments



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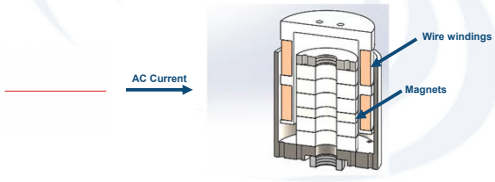
Linear Motor - Drive System

- Linear Voice Coil Motor Provides Input Force
- Operation Similar to a Speaker
- Alternating Current Generates Magnetic Field that Couples with a Magnet and Generates Force



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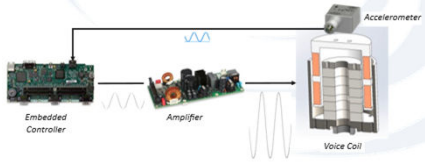
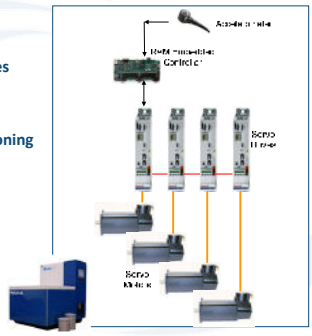
Linear Motor - Control System

- Embedded Controller
  - Acceleration tracking
  - Drive signals to amplifier
  - Reads accelerometer
  - Communicates with User Interface
- Amplifier Supplies Alternating Current to Voice Coil
- Voice Coil Provides Driving Force to Resonator



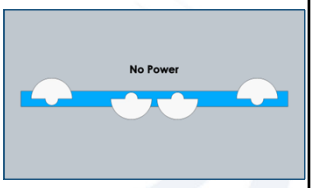
Rotational Motor - Control System

- Embedded Controller
  - Acceleration tracking
  - Reference signals to drives
  - Reads accelerometer
- Servo Drives
  - Control speed and positioning of motors
  - Generic input/output



Rotational Motor - Drive System

- Four Eccentric Masses Create Variable Vertical Force
- A Motor Pair is Necessary to Cancels Sideways Forces
- Two Pairs are Necessary for Variable Input Force
- Vertical Force Applied at Resonance
  - All Four Motor Velocity Changes with the Natural Frequency



Summary

- Mass and Spring Stiffness Establish RAMs Natural Frequency and Amplitude
- Resonance makes the Highly Energetic Conditions Needed for Acoustic Mixing Possible
- The Control System Keeps the Mixer at the Acceleration Setpoint and at Resonance, even with Changing Mix Material Properties
- Advanced Drive Systems are Used to Provide the Input Force for all RAM Mixers

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Thank you for your time and attention.

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