RAM Mix Coupling

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Coupling In Practice

Talc
Material free flowing with chaotic motion relative to vessel

Solids Loaded Paste
Material quiescent relative to vessel

0 — *Coupling Coefficient* — 1

Calculating Coupling Coefficient

Coupling Coefficient C_c is empirically determined based on Natural Frequency equation

$$f \propto \sqrt{\frac{K}{m}}$$

$$C_C = \left(f_{empty} - f_{mix}\right)\frac{C1}{M_{mix}}$$

f_{empty}: Frequency of an empty vessel
f_{mix}: Frequency with mix material
$C1$: Machine specific constant
M_{mix}: Mass of mix material added

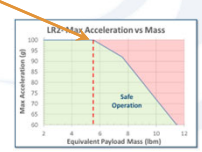
Machine Constants

	lbm/Hz	gm/Hz
LabRAM I	0.95	431
LabRAM II	1.3	590
OmniRAM	11.7	5.3 kg
RAM5	34	15.4 kg

Application #1: Equivalent Mass

- **How much material can I mix?**
  - Each Mixer has a maximum equivalent mass payload capacity
  - Many users assume this is the TOTAL mass!

Model	Maximum 100g Equivalent Mass
LabRAM I	4.2 lbm
LabRAM II	5.5 lbm
OmniRAM	80 lbm
RAM 5	375 lbm
RAM 55	3100 lbm



Application #1: Equivalent Mass

- **Easy to calculate but we find classes of materials exhibit normal ranges***
  - Typical Pastes: 0.4 – 0.6
  - Typical Powders: 0.1 – 0.4
- **Coupling used when Calculating Total Equivalent Mass**
  - Used when determining Total Equivalent Mass which is the mass affecting the resonator

* Approximations may vary

$$M_{Eqv} = M_{Tooling} + M_{Live} \times C_c$$

Application #1: Equivalent Mass

- **How much material can I put on my mixer?**
  - Example: Calculating maximum amount of material that can be mixed by a LabRAM II with a 5" Vessel Holder

$$M_{Live\ MAX} = \frac{M_{MachineLimit} - M_{Tooling}}{C_c}$$

$5.5lb$

- Conservative: 3.1 lbm
- Typical Paste*: 5.2 lbm
- Typical Powder*: 7.8 lbm

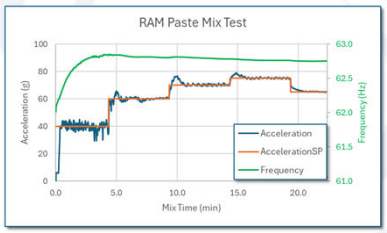
Typical Powder could have 150% Free Capacity

$2.4lb$

5" Vessel Holder 8oz Jar

Application #2: Starting Frequency

- Coupling means the resonant frequency will change even if mix mass remains constant



EXTREME

Coupling

Note: This probably doesn't apply to you.

What is Extreme Coupling

- Standard coupling model only permits coupling coefficients in the 0 – 1 range but this model conflicts with observations
- Extreme coupling can occur when mix material acts like a lumped mass on the vessel creating a 4-mass system
  - Cohesive Powders, Milling Media, & Decoupled Paste

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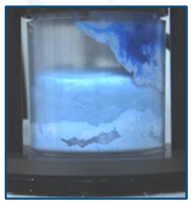
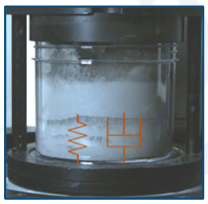

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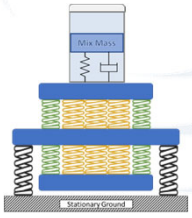
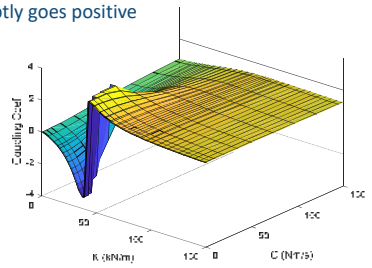
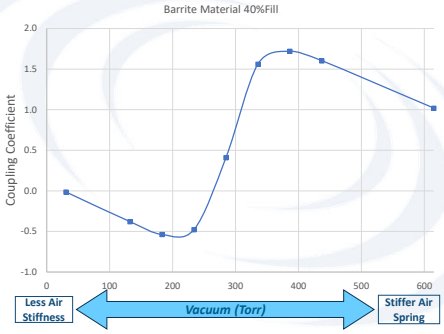


Modeling RAM as a 4-Mass System

- Extreme Coupling is a function of both stiffness and damping of the mix material
- As stiffness increases, the coupling goes negative then abruptly goes positive

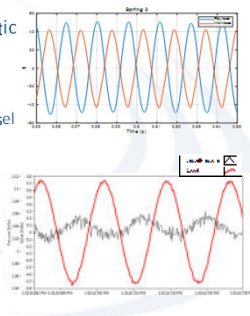


Early Evidence of a 4-Mass System



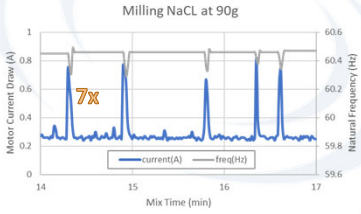
Phase Angle Influences Extreme Coupling

- Phase angle of the coupled mass determines if you're adding kinetic or potential energy to the resonator
  - Coupling Coefficient < 0
    Mix Material Out of Phase with Vessel
  - Coupling Coefficient > 1
    Mix Material In Phase with Vessel
    Material force can exceed $\rho g h$



Impact of Extreme Coupling

- Extreme coupling can interfere with resonant frequency tracking and produce power surges



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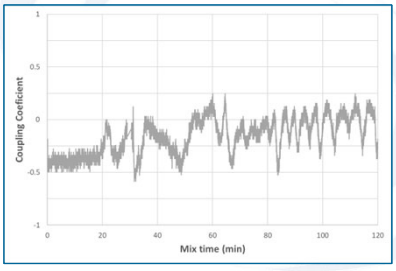
- Interferes with the max acceleration de-rate which puts onus on user not to exceed payload of the resonator
  - Possible but has not been observed
- Extreme coupling can be a stable mixing regime

Stable Mixing with Extreme Coupling

Resodyn developed the mixing plan for a RAM5 client's cohesive powder which experienced extreme coupling



Summary

- Coupling Coefficient is a convenient metric for the behavior of mix material relative to the vessel
- Primary uses for coupling coefficient
  1. Predicting maximum mix mass at an acceleration
  2. Consideration for the starting frequency
- Extra care required in the unlikely case of extreme coupling
- Use Resodyn as a resource for unusual mix problems!

Thank you for your time and attention.