Vibration isolation

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DIRECT VIBRATION ISOLATION

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Washing machines

https://www.youtube.com/watch?v=SRbFxgezAX0

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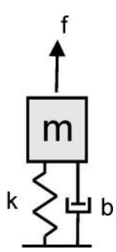
Direct vibration isolation : principle



$$m\ddot{x} + b\dot{x} + kx = f \qquad x(t) = Xe^{i\omega t} \qquad f(t) = Fe^{i\omega t}$$

$$\rightarrow (k - \omega^2 m + i\omega b)X = F$$

$$|F| = \sqrt{(k-\omega^2 m)^2 + (\omega b)^2}|X|$$

Force transmitted to the ground:

$$F_T = (k + i\omega b)X$$

$$|F_T| = \sqrt{k^2 + (\omega b)^2}|X|$$

Isolation factor:

$$\frac{|F_T|}{|F|} = \frac{\sqrt{k^2 + \omega^2 b^2}}{\sqrt{(k-\omega^2 m)^2 + \omega^2 b^2}}$$

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Direct vibration isolation : principle

$$\frac{|F_T|}{|F|} = \frac{\sqrt{k^2 + \omega^2 b^2}}{\sqrt{(k - \omega^2 m)^2 + \omega^2 b^2}} \qquad \begin{aligned} \xi &= b/(2\sqrt{km}) \\ \omega_n &= \sqrt{k/m} \end{aligned}$$

$$\frac{|F_T|}{|F|} = \frac{\sqrt{1 + (2\xi\frac{\omega}{\omega_n})^2}}{\sqrt{(1 - (\frac{\omega}{\omega_n})^2)^2 + (2\xi\frac{\omega}{\omega_n})^2}}$$

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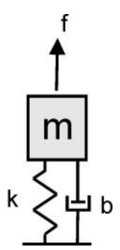
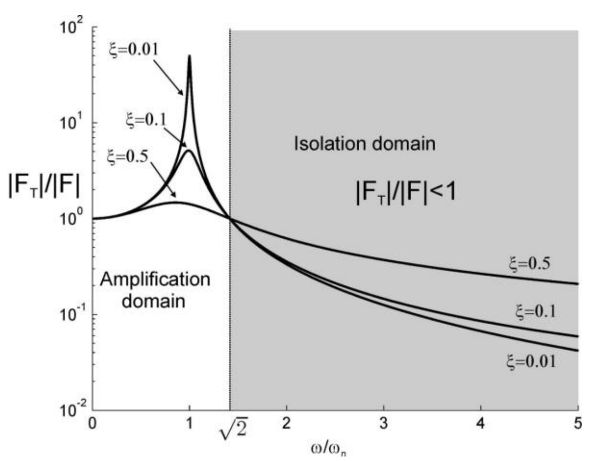
Direct vibration isolation : principle





- Choose k such that the isolation domain corresponds to the frequency content of the excitation signal f(t)
- This results usually in the use of soft springs

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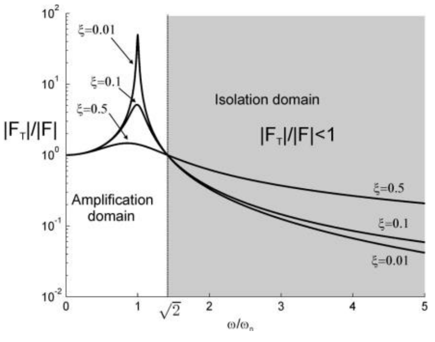
Direct vibration isolation : principle



High damping
- Reduced isolation ☹
- Low amplification around resonance ☺

Low damping
- High amplification around resonance ☹
- Good isolation at high frequencies ☺

→ Ideal solution : frequency dependent damping (high at low frequencies, low at high frequencies)
Example: rubber, elastomers ...

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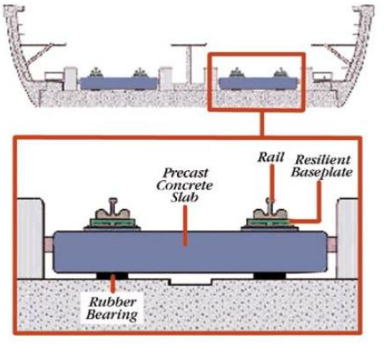
Direct vibration isolation : Railway

TRELLEBORG
ENGINEERED SYSTEMS



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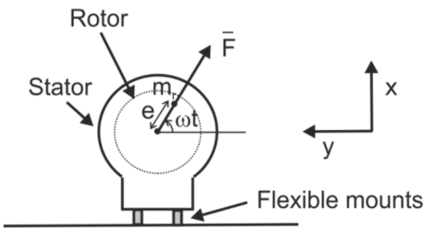
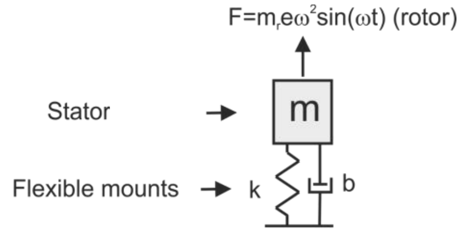
Direct vibration isolation for rotating machines





$$F = m_r e\omega^2 \sin(\omega t) \rightarrow |F| = \sqrt{(k-\omega^2 m)^2 + (\omega b)^2}\,|X| = m_r e\omega^2$$

$$\frac{|F_T|}{m_r e\omega^2} = \frac{\sqrt{k^2 + (\omega b)^2}}{\sqrt{(k-\omega^2 m)^2 + (\omega b)^2}}$$

$$\frac{|F_T|}{m_r e} = \omega^2 \frac{\sqrt{k^2 + (\omega b)^2}}{\sqrt{(k-\omega^2 m)^2 + (\omega b)^2}}$$

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Direct vibration isolation for rotating machines

$$\frac{|F_T|}{m_r e} = \omega^2 \frac{\sqrt{k^2 + (\omega b)^2}}{\sqrt{(k-\omega^2 m)^2 + (\omega b)^2}}$$

$$\downarrow \quad \xi = b/(2\sqrt{km}) \qquad \omega_n = \sqrt{k/m}$$

$$\frac{|F_T|}{m_r e\omega_n^2} = \left(\frac{\omega}{\omega_n}\right)^2 \frac{\sqrt{1 + (2\xi\frac{\omega}{\omega_n})^2}}{\sqrt{(1-\frac{\omega}{\omega_n})^2)^2 + (2\xi\frac{\omega}{\omega_n})^2}}$$

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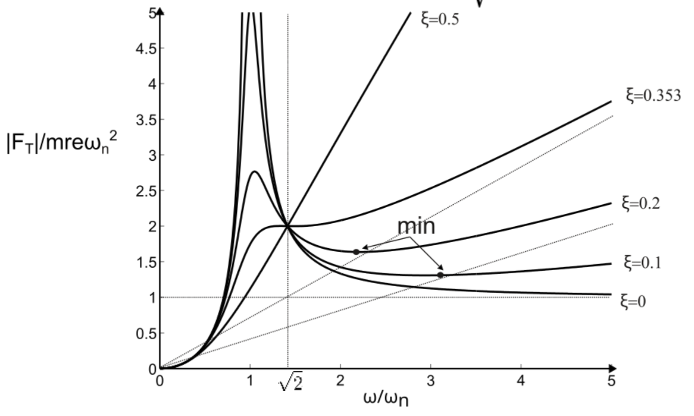
Direct vibration isolation for rotating machines

Asymptotic behavior

$$lim_{\frac{\omega}{\omega_n}\to\infty} \frac{|F_T|}{m_r e\omega_n^2} = \left(\frac{\omega}{\omega_n}\right)^2 \frac{\sqrt{1+(2\xi\frac{\omega}{\omega_n})^2}}{\sqrt{(1-\frac{\omega}{\omega_n})^2)^2+(2\xi\frac{\omega}{\omega_n})^2}} = 2\xi\frac{\omega}{\omega_n}$$



Existence of a minimum for $\xi < 0.353$ (soft isolation)

Reducing e reduces F_T

→ Rotor balancing

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Direct vibration isolation : Machines

[https://avtinc.net/avt/vibration-isolation.html]

[https://www.berleburger.com]

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Direct vibration isolation : Engine mounts

https://www.samarins.com

https://motorcounts.com

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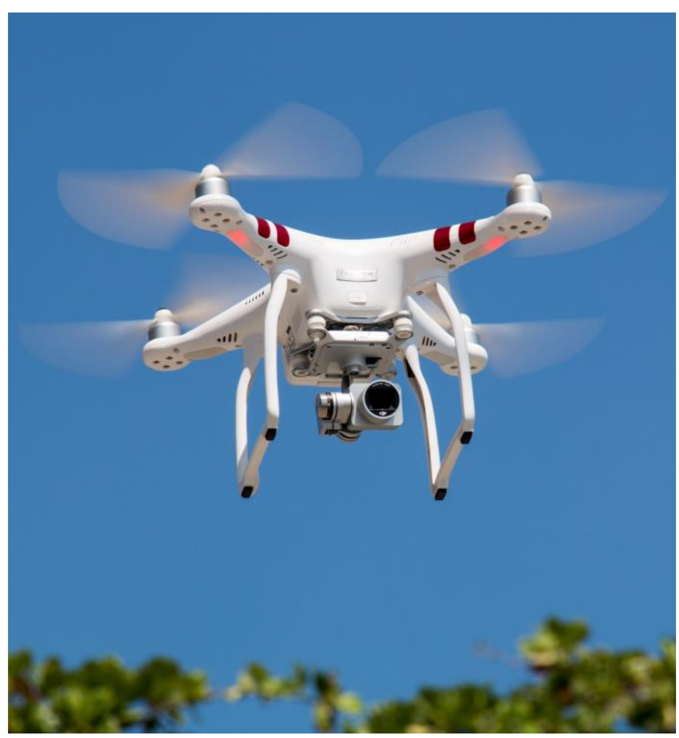
INVERSE VIBRATION ISOLATION



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Inverse vibration isolation : drone camera

https://youtu.be/4sigvHN9R3s

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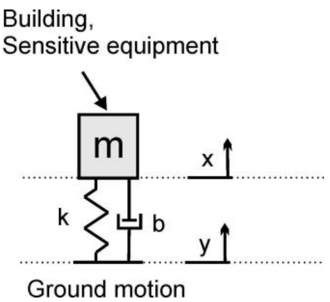
Inverse vibration isolation : principle



$$m\ddot{x} + k(x-y) + b(\dot{x}-\dot{y}) = 0$$

$$x(t) = Xe^{i\omega t}$$

$$y(t) = Ye^{i\omega t}$$

$$\left(k - \omega^2 m + i\omega b\right) X = (k + i\omega b)\, Y$$

Transmissibility : $\dfrac{|X|}{|Y|} = \dfrac{\sqrt{k^2+\omega^2 b^2}}{\sqrt{(k-\omega^2 m)^2 + \omega^2 b^2}}$

The transmissibility is equal to the isolation factor previously defined
The aim is to 'decouple' the motion of the building from the ground motion

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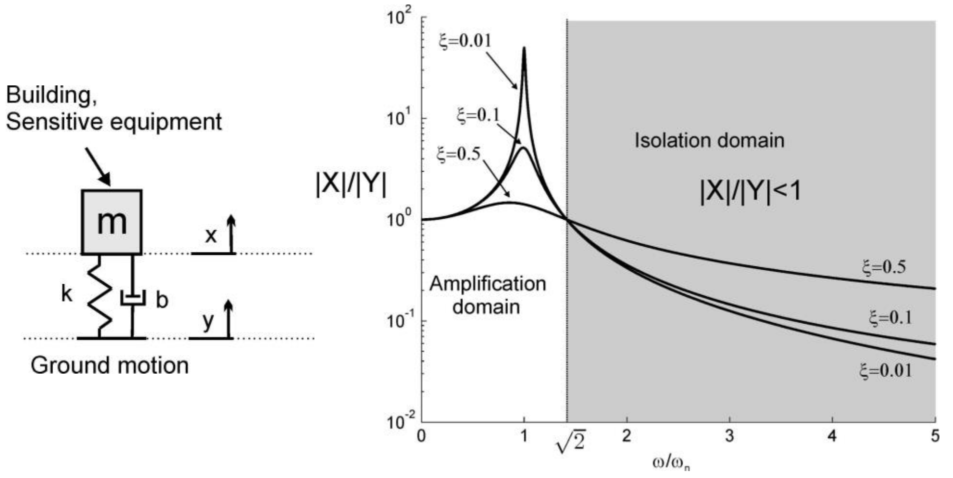
Inverse vibration isolation : principle



→ To isolate in the low frequency domain, we need k small, m high

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Inverse vibration isolation : examples

https://www.erzan.com

https://www.minusk.com

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Inverse vibration isolation : precision microscope

https://youtu.be/YPAOZXc33gE

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Inverse vibration isolation : art pieces

https://youtu.be/ntV6LQF1GxA

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Direct vibration isolation : car suspension

Comfortable ride : f=1 Hz to 1.5 Hz (up to 2 Hz)

[https://www.3bloom.com/]

0.5-1.5 Hz - Passenger cars
1.5-2.0Hz - Rally Cars
1.5-5Hz - Racecars

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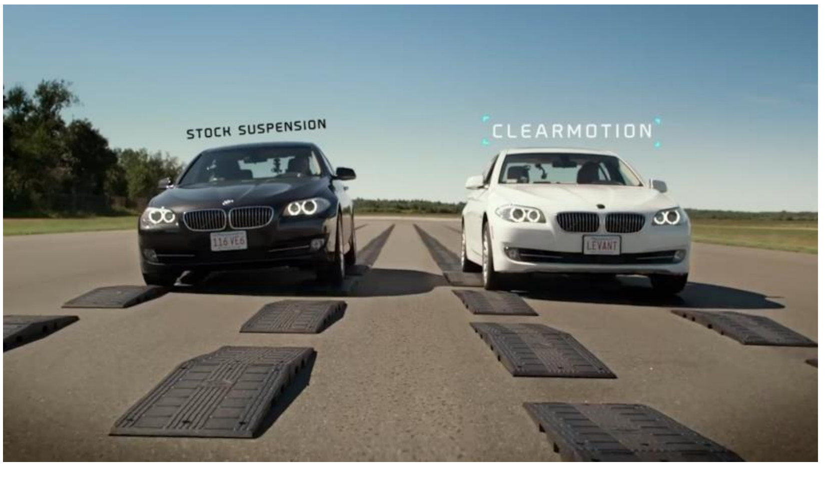
Direct vibration isolation : active car suspension



https://www.youtube.com/watch?v=00K5WBPOueE

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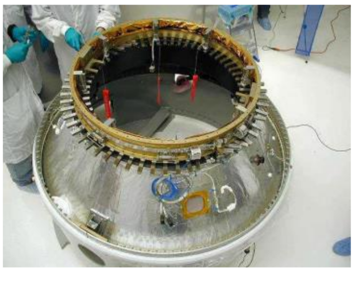
Direct vibration isolation : Payload comfort in launchers

https://www.youtube.com/watch?v=00S0euumSFI

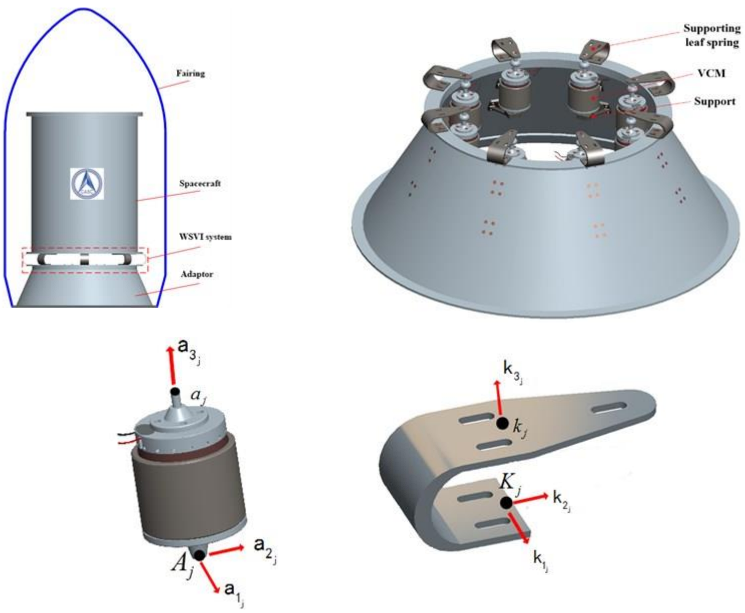
Direct vibration isolation : Payload comfort in launchers

SoftRide from MOOG



https://www.csaengineering.com/

Active vibration isolation for payload comfort



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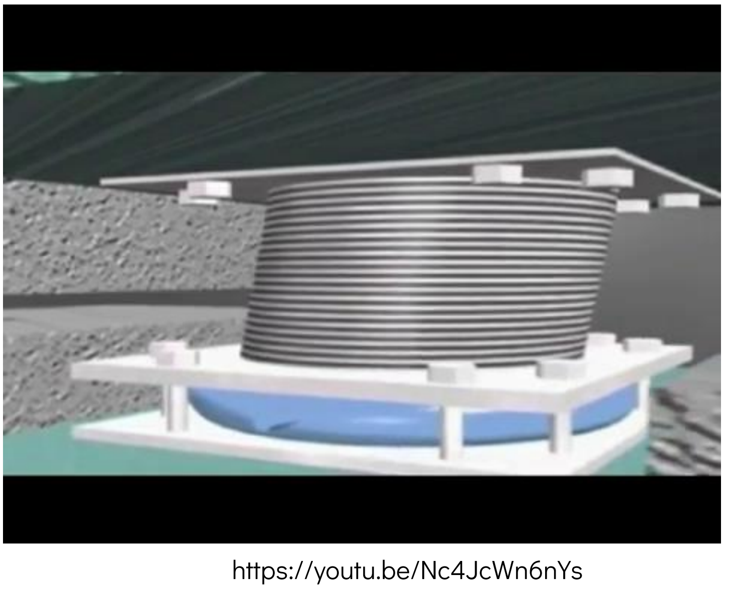
Inverse vibration isolation : buildings



https://youtu.be/Nc4JcWn6nYs

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