Ride

Excitation sources

- Road profile

Variations in the road surface such as bumps, potholes, and rough patches.

Directly introduces vertical displacement to the tires ans suspension.

Higher frequency bumps can cause vibrations felt in the cabin.

Large obstacles or uneven terrain can lead to suspension compression and body motion

Suspension design aims to isolate the cabin from road disturbances

Use of dampers and springs tuned to absorb road irregularities

- Tires/wheels

Irregularities in tire shape, uneven tire wear, or imbalance in the wheel assembly

Generates cyclic vertical forces as the tire rotates

Causes vibrations felt at higher speeds, often percieved as wheel wobble or shaking.

Proper tire balancing

Use of uniform tire materials and precision manufacturing

- Driveshaft

Rotational imbalances or misalignment in the driveshaft or transmission components

Introduces periodic vibrations linked to the driveshaft rotation speed

Can lead to noticeable oscillations in the cabin, especially under acceleration or deceleration

Precision balancing of rotating components

Proper alignment of driveshaft and transmission parts,

- Engine

Vibrations created by reciprocating motion of pistons, rotating crankshafts, and other engine components

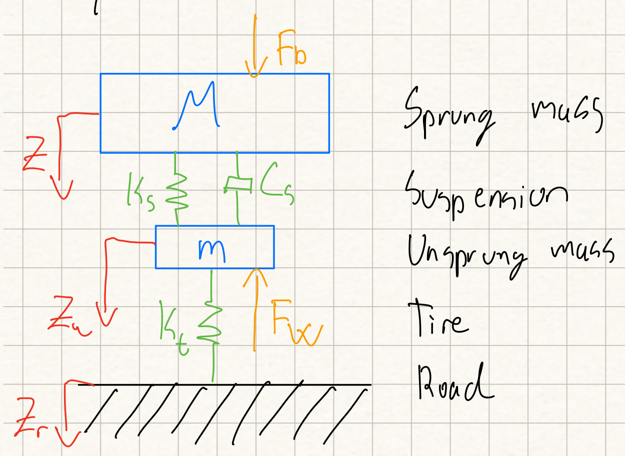
Introduces high-freq vibrations into the chassis

Engine mounts designed to isolate engine vibrations

Balancing shafts and harmonic dampers in engines

Quarter-car model

Dynamic model



Ride rate: effective stiffness

$$RR = \frac{k_s k_t}{k_s + k_t}$$

Undamped frequency

$$\omega_n = \sqrt{\frac{RR}{M}}$$

Damped frequency

$$\omega_d = \omega_n \sqrt{1 - \zeta_s^2}$$

ζ: damping ratio: 0.2 – 0.4

$$M\ddot{z} + C_s\dot{z} + K_s z = C_s\dot{z}_u + K_s z_u + F_b$$

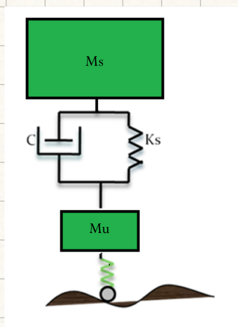
$$m\ddot{z}_u + C_s\dot{z}_u + (K_t + K_s) z_u = C_s\dot{z} + K_s z + K_t z_r + F_w$$

Analytical frequencies

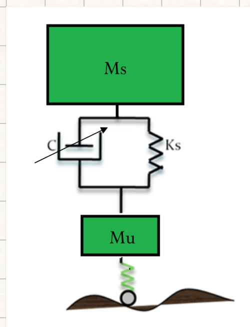
If $K_t \gg K_s \rightarrow K_s + K_t \approx K_t - K_s \approx K_t \rightarrow \omega_1 = \sqrt{\frac{K_s}{m_s}},\ \omega_2 = \sqrt{\frac{K_t}{m_u}}$

Suspension types

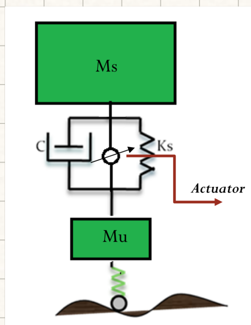
Passive



Semi-active



Active



Semi-active suspension

- Electromagnetic coils located in the piston to generate a localized magnetic field around the piston's passages
- The hydraulic fluid inside the dampers contains tiny iron particles, distributed randomly before electric current is applied to the piston coils
- Applying current to the coils create a magnetic field, which arranges the

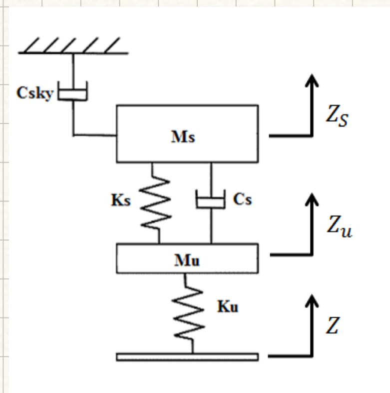
particles into lines, making the fluid more resistant to flow

Active suspension

Control the suspension with actuators

Skyhook control for semi-active suspension

Imagine vehicle body is suspended not from the wheels, but from an imaginary fixed point in the sky. This point doesn't move, so the suspension would only work to dampen the body oscillations, independent of road disturbances.



Since this connection to the sky is impossible, the semi-active damper is used to mimic this behavior as closely as possible.

The damping force applied by the semi-active damper is adjusted based on the vertical velocity of the vehicle body relative to the wheel.

$$C_s = \begin{cases} C_{max}, & \dot{Z}_s(\dot{Z}_s - \dot{Z}_u) \geq 0 \\ C_{min}, & \dot{Z}_s(\dot{Z}_s - \dot{Z}_u) < 0 \end{cases}$$

Lets say: body moving upwards: $\dot{z}_s < 0$, $\dot{z}_s > 0$

When do we want high damping?

$$\dot{z}_s(\dot{z}_s - \dot{z}_u) \geq 0 \Rightarrow \dot{z}_s^2 - \dot{z}_s \dot{z}_u \geq 0$$

≥ 0

>0

$$\Rightarrow \dot{z}_s^2 \geq \dot{z}_s \dot{z}_u$$

$$\Rightarrow \dot{z}_s \geq \dot{z}_u$$

When unsprung mass is also moving upwards with the same or higher speed (negative direction), we want high damping

What about low damping?

$$\dot{z}_s(\dot{z}_s - \dot{z}_u) < 0 \Rightarrow \dot{z}_s^2 - \dot{z}_s \dot{z}_u < 0$$

$$\Rightarrow \dot{z}_s^2 < \dot{z}_s \dot{z}_u$$

$$\Rightarrow \dot{z}_s < \dot{z}_u$$

When unsprung mass is moving either downwards or upwards but with lower speed than the spring mass, we want low damping.

Downward motion: $\dot{z}_s > 0$

When do we want high damping?

$$\dot{z}_s(\dot{z}_s - \dot{z}_u) \geq 0 \Rightarrow \dot{z}_s^2 - \dot{z}_s \dot{z}_u \geq 0$$

$$\Rightarrow \dot{z}_s^2 \geq \dot{z}_s \dot{z}_u$$

$$\Rightarrow \dot{z}_s \geq \dot{z}_u$$

When unsprung mass is moving upwards or downwards but with slower speed, we want high damping

What about low damping?

$$\dot{z}_s(\dot{z}_s - \dot{z}_u) < 0 \Rightarrow \dot{z}_s^2 - \dot{z}_s \dot{z}_u < 0$$

$$\Rightarrow \dot{z}_s^2 < \dot{z}_s \dot{z}_u$$

$$\Rightarrow \dot{z}_s < \dot{z}_u \qquad (\dot{z}_s > 0)$$

When unsprung mass is moving downwards but at a higher speed than the sprung mass.