Control of motorcycles by variable geometry rear suspension

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Introduction

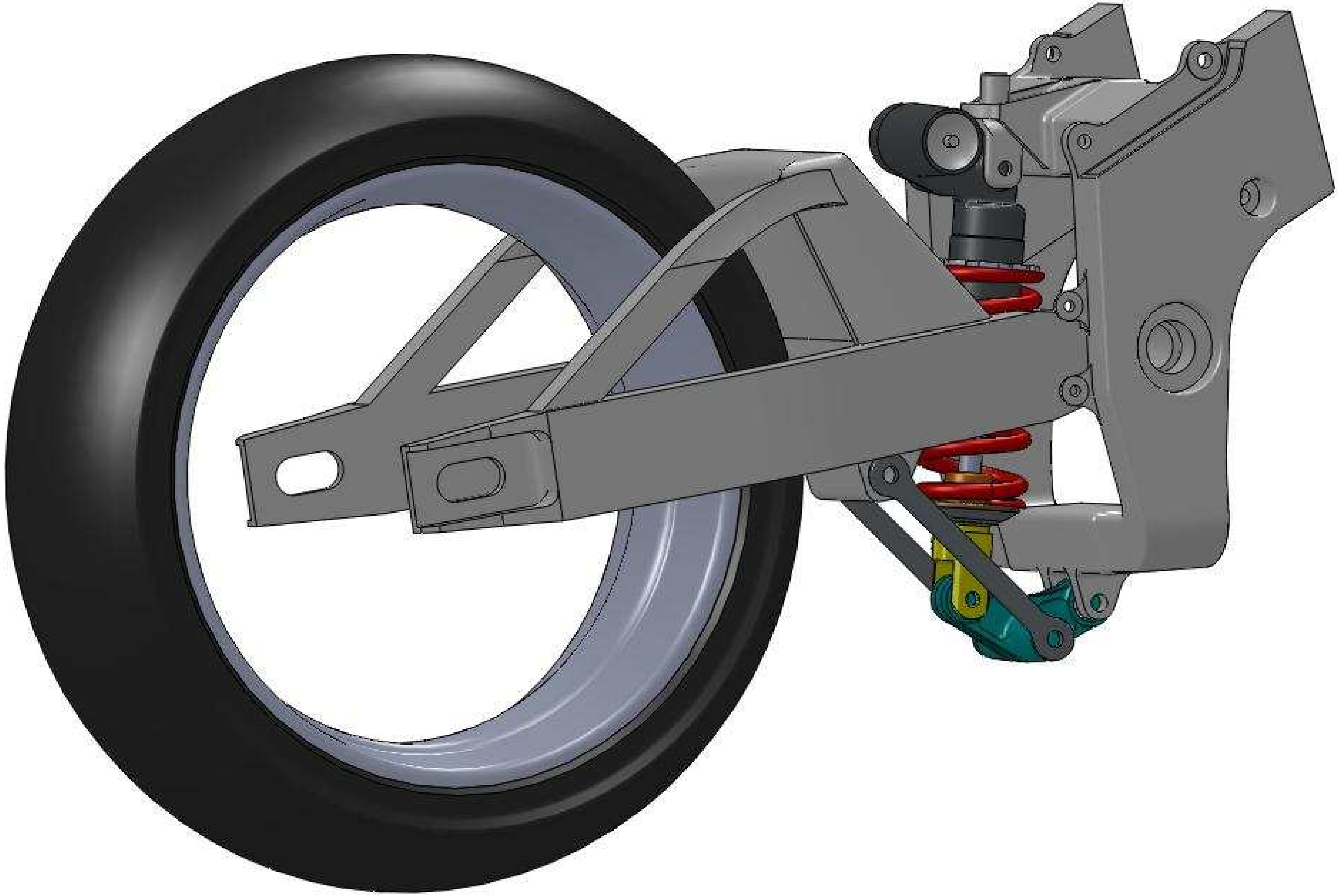
- Motorcycles can become unstable
- Wobble, 6 – 9 Hz – mainly steering
- Weave, 2 – 4 Hz – yawing, rolling, steering
- In cornering, lateral modes coupled to in-plane modes
- Motorcycle prone to resonant road forcing
- Rear suspension participation in weave oscillations
- Active control via rear suspension

Motorcycle model – prior model

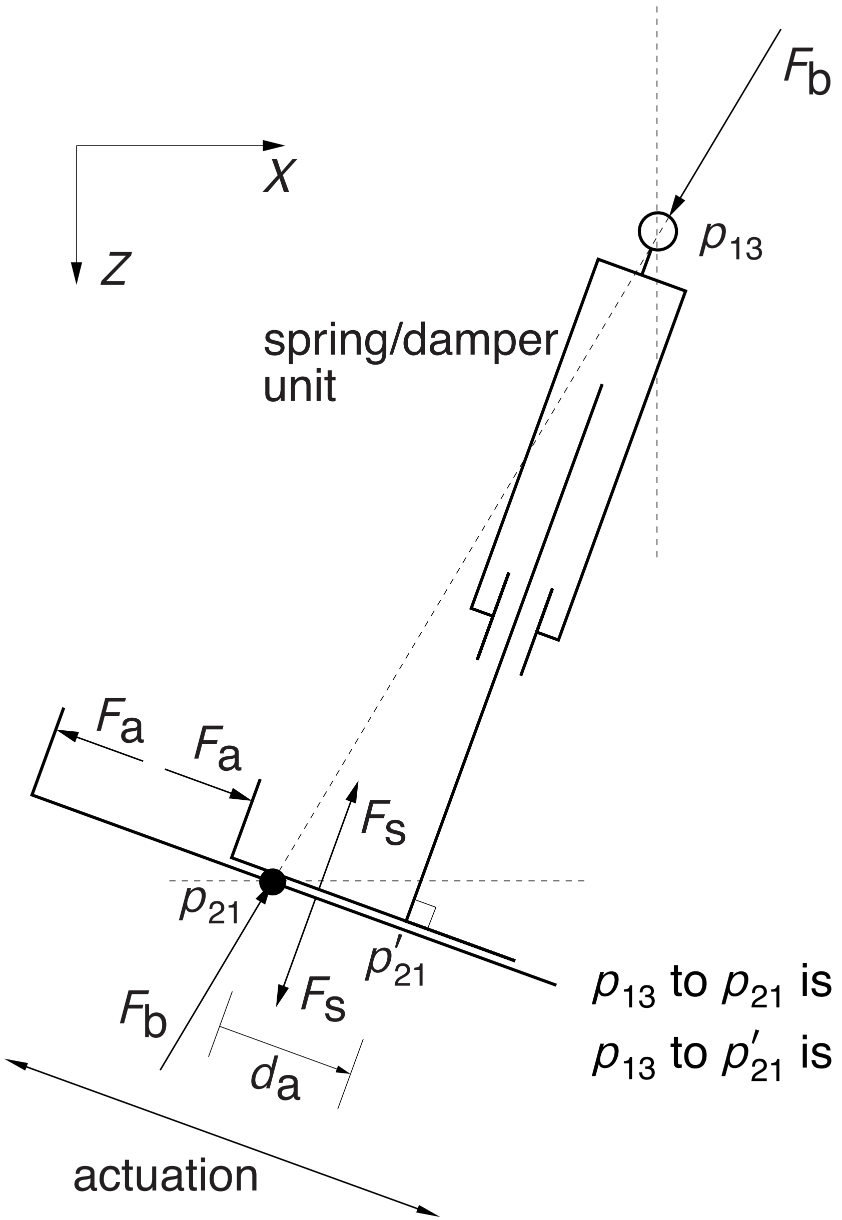
- Suzuki GSX-R1000 parameter set
- Main frame – 6 DOF
- Swinging arm, rider upper body, front frame, spinning wheels
- Rear monoshock suspension, telescopic front forks
- Aerodynamic forces, moments
- ‘Wide’ / flexible tyres, ‘magic formulae’, relaxation
- Autosim, nonlinear simulation C++, linearisation Matlab

Weave mode

Monoshock rear suspension



Variable geometry rear suspension model



p_{13} to p_{21} is l_0;
p_{13} to p'_{21} is l

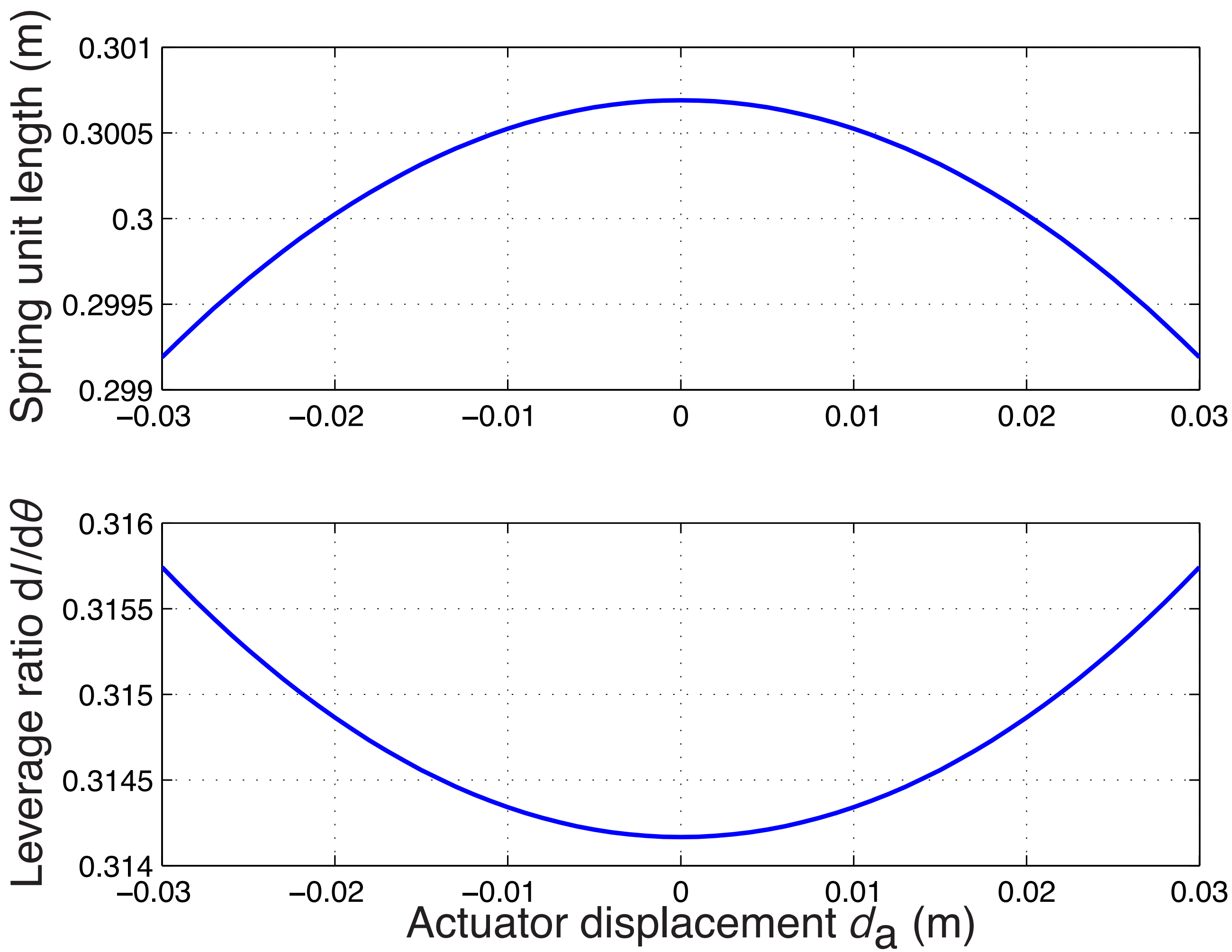
$$l = \sqrt{{l_0}^2 - {d_a}^2}$$

$$\frac{\partial l}{\partial \theta} = \frac{l_0}{l}\frac{\partial l_0}{\partial \theta}$$

$$\frac{\partial l}{\partial d_a} = -\frac{d_a}{l}$$

Variable geometry rear suspension

Spring/damper unit length and leverage ratio



Equivalent moment

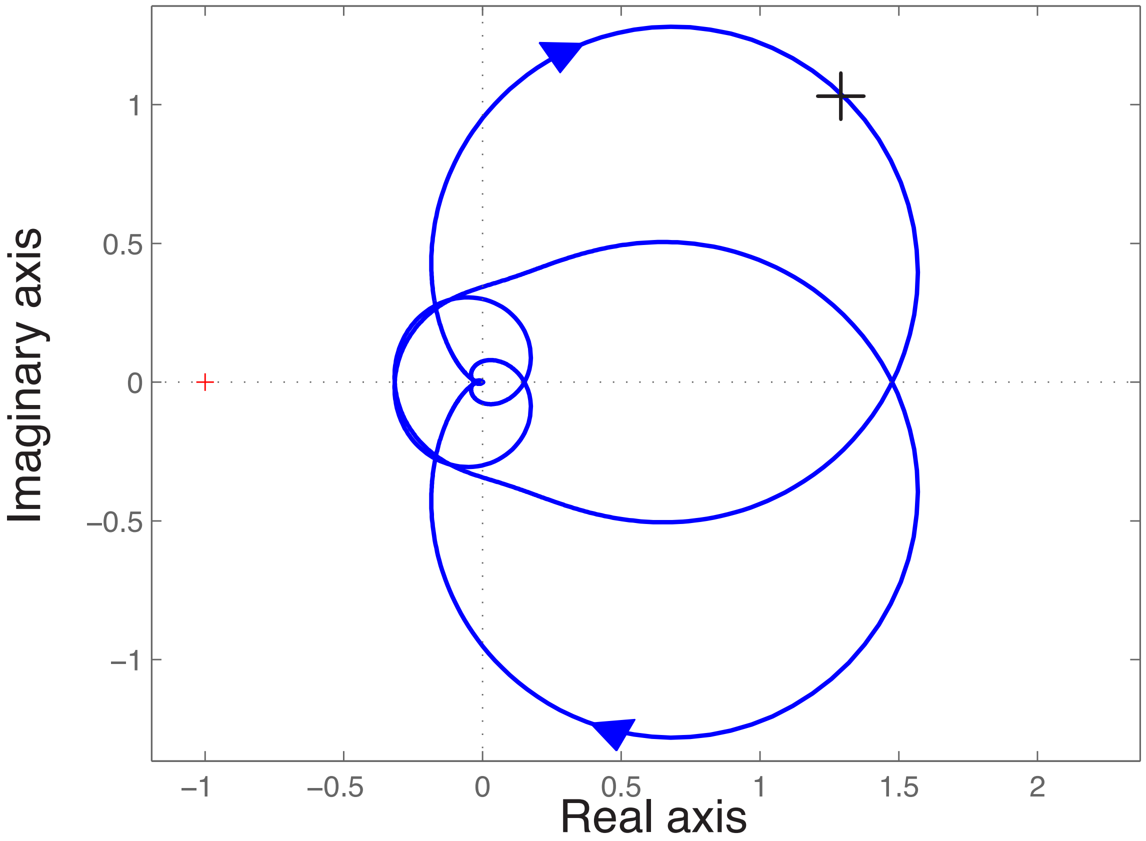
The moment M corresponding to a spring/damper force $F_{\text{s}} = f(l, \dot{l})$, by virtual work, is

$$M = F_{\text{b}} \frac{\partial l_0}{\partial \theta} = f\left(l, \dot{l}\right) \frac{l_0}{l} \frac{\partial l_0}{\partial \theta} = f\left(l, \dot{l}\right) \frac{\partial l}{\partial \theta}$$

Equivalent moment $M(\theta, d_{\text{a}}, \dot{\theta}, \dot{d}_{\text{a}})$ about the swing arm pivot is

$$M = f\left(l, \frac{\partial l}{\partial \theta}\dot{\theta} + \frac{\partial l}{\partial d_{\text{a}}}\dot{d}_{\text{a}}\right) \frac{\partial l}{\partial \theta},$$

Control design – Nyquist diagram



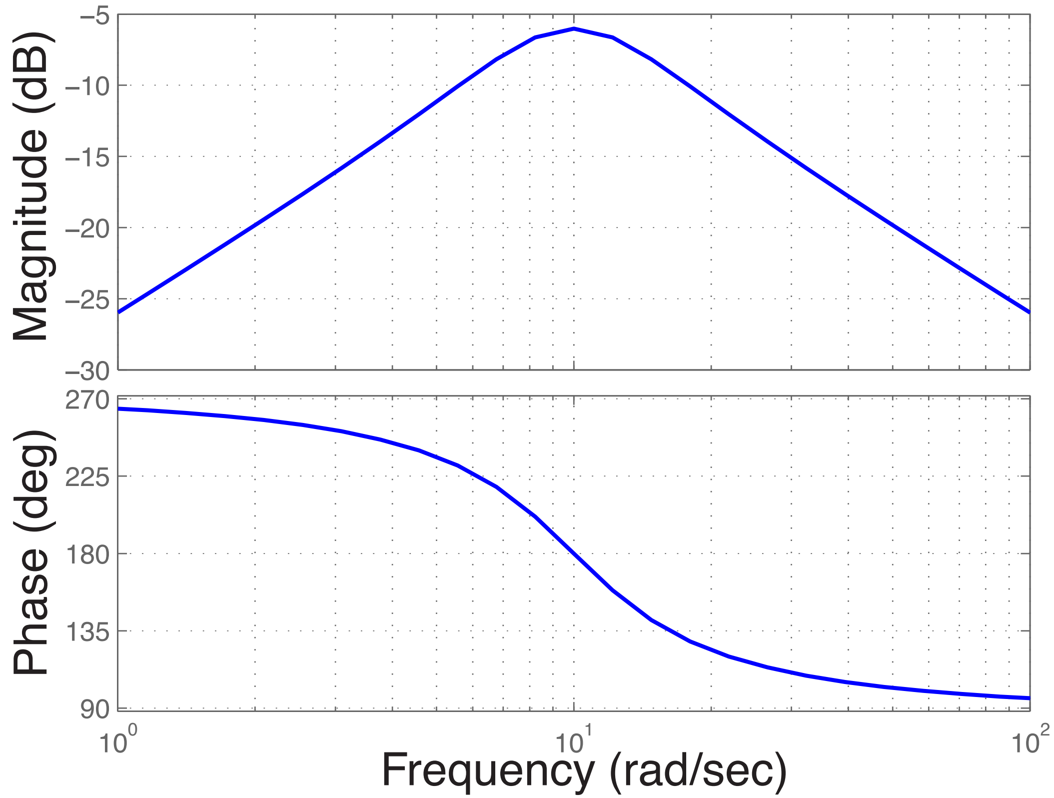
- $d_a \rightarrow \dot{\psi}$
- 75 m/s speed
- 15 deg roll
- weave 27.5 rad/s
- wobble 47.9 rad/s

Control design – frequency response

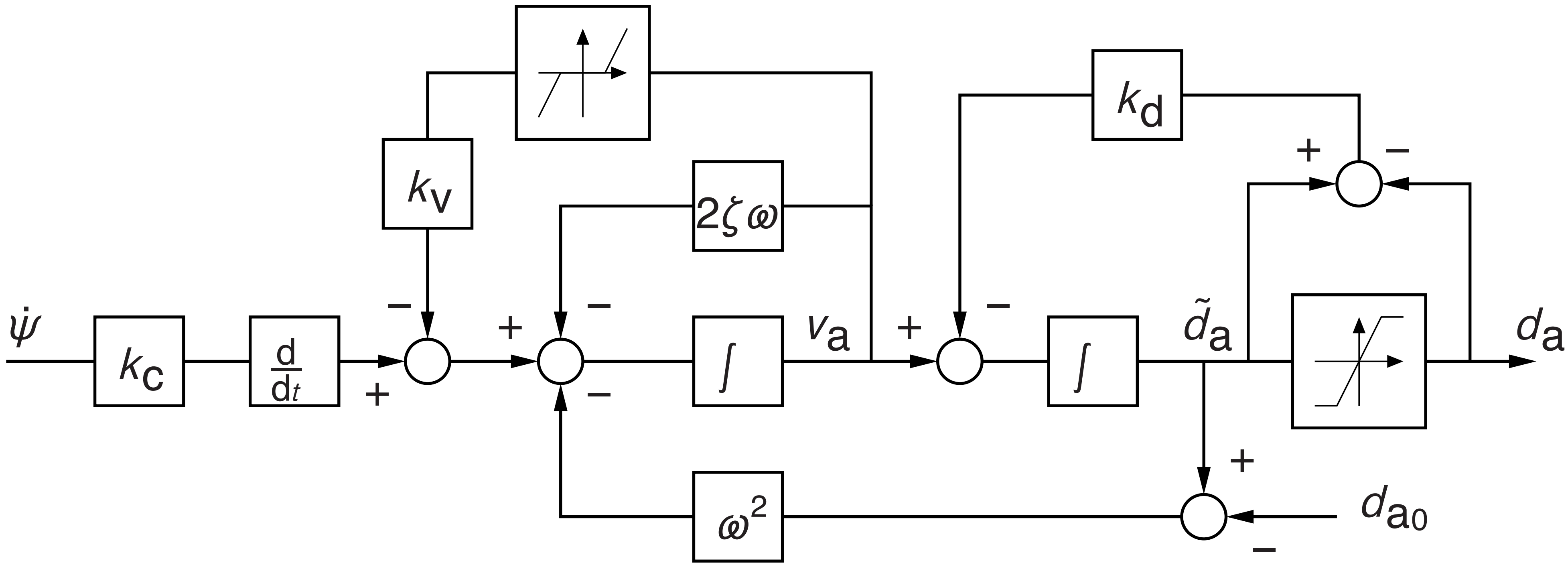
$$d_a = K(s)\, s\psi$$

$$K(s) = \frac{k_c s}{s^2 + 2\zeta\omega s + \omega^2}$$

$$k_c = -5,\ \zeta = 0.5,\ \omega = 10$$



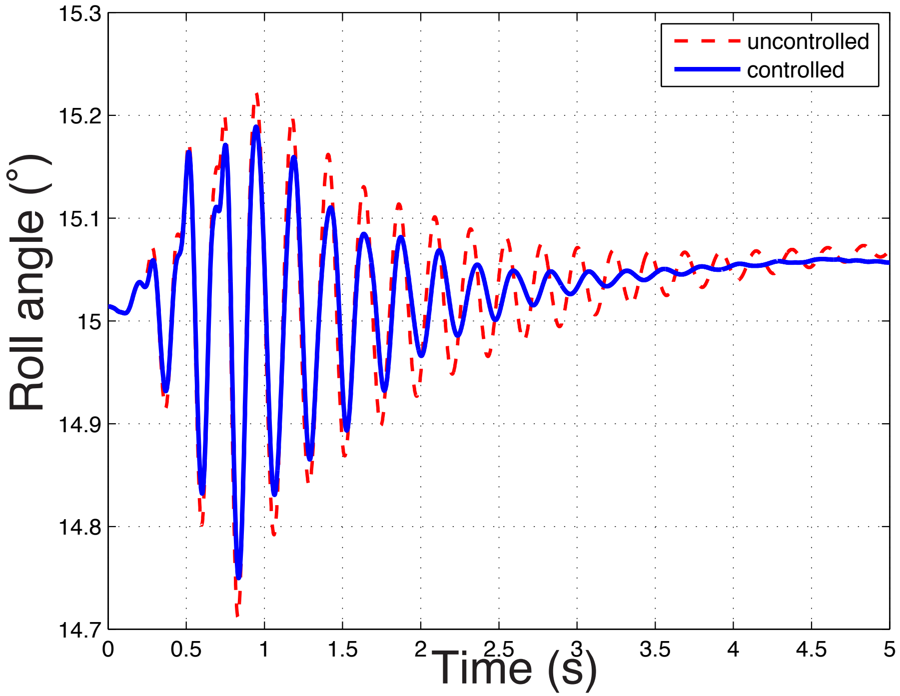
Displacement controller with nonlinear saturation

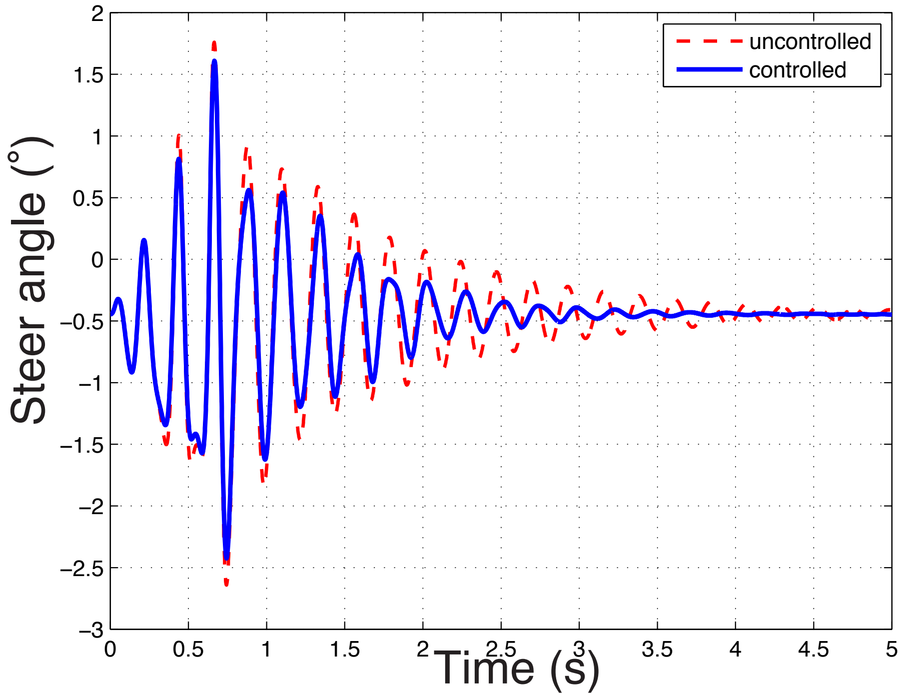


$k_d = 10000$, $k_v = 3000$, $d_{a0} = 0.015$ m, $d_{amin} = -25$ mm,

$d_{amax} = 25$ mm, $v_{amin} = -1.15$ m/s, $v_{amax} = 1.15$ m/s.

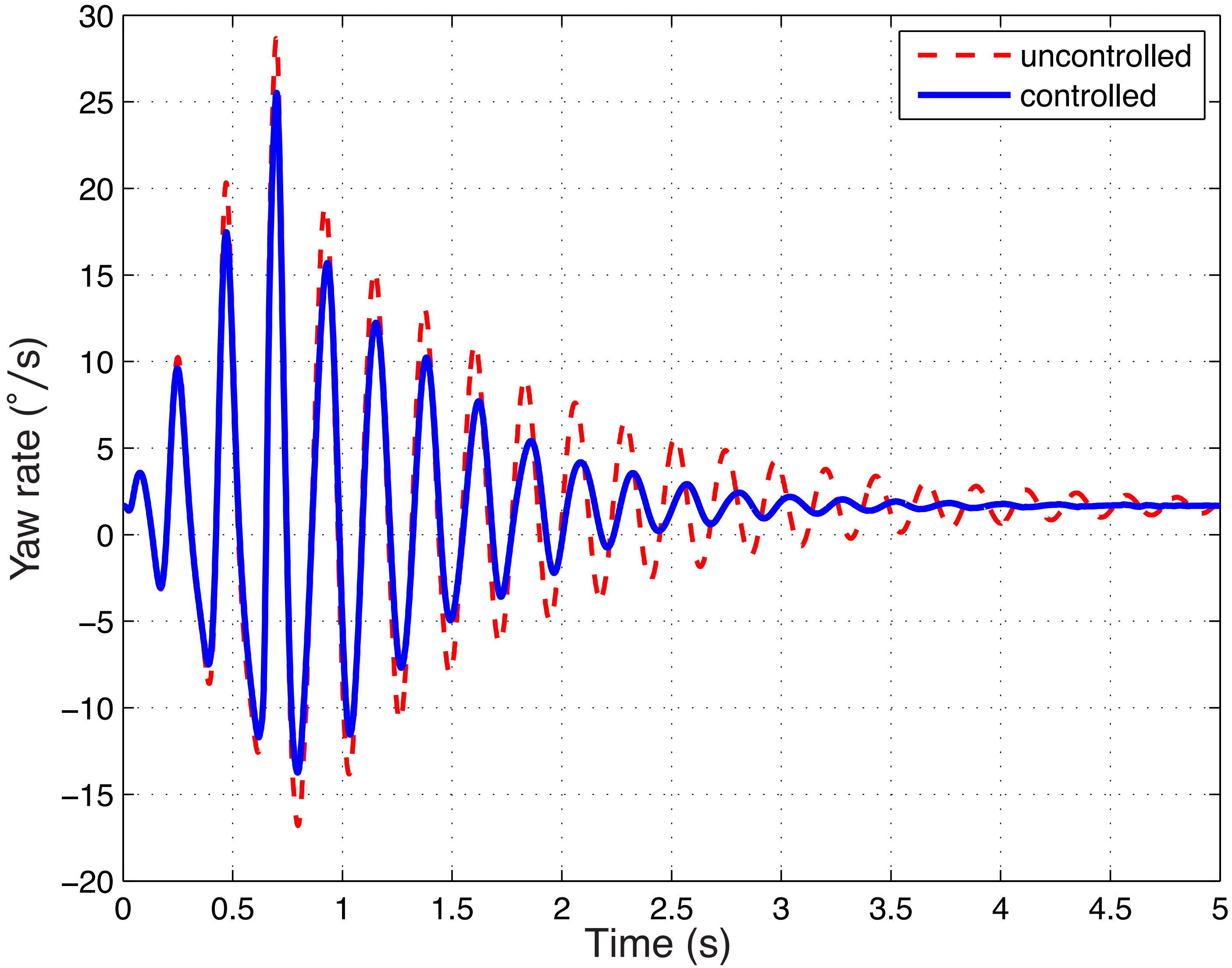
Simulation results – 75 m/s speed, 15 deg lean



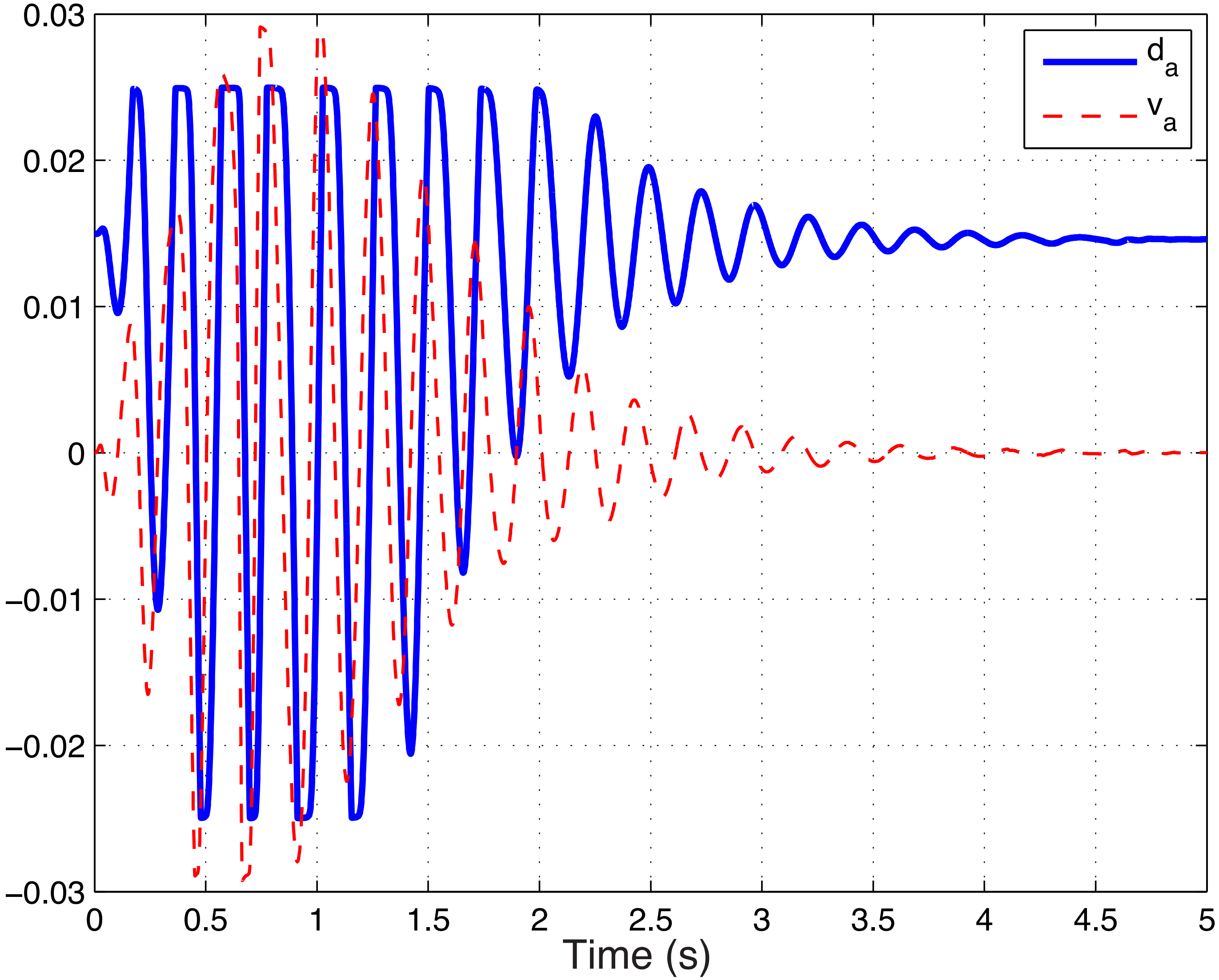


Sinusoidal road forcing at $t = 0$ to $t = 0.623$ s, peak amplitude 5 mm, forcing frequency tuned to weave.

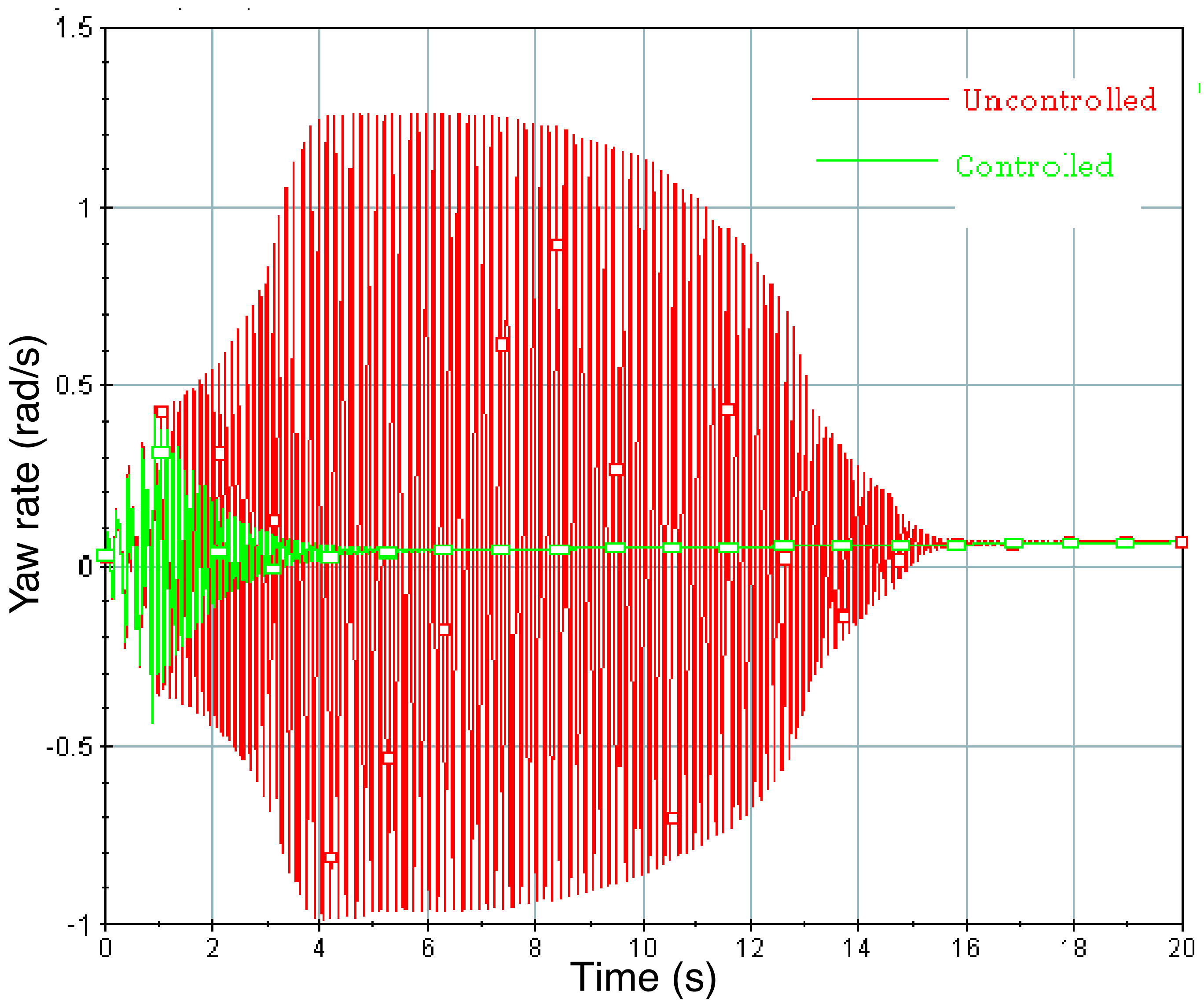
Simulation results – 75 m/s speed, 15 deg lean



Actuator displacement, velocity



Simulation results – 75 m/s speed, 15 deg lean



Conclusions

- A variable geometry rear monoshock suspension system introduced;
- Actuator displacement control law designed;
- Improved cornering weave mode stability in prospect;
- Power, force requirements attainable;
- Energy regeneration possible.