Tech Tip: Spring & Dampers, Episode Six
Return of the Race Engineer

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After examining damping in roll last month, we will now look at springs and damping in pitch of the car. As explained last time with roll damping acting in a polar coordinate system, pitch is very similar- except the sprung mass is rotating about the pitch axis instead of the roll axis. Roll damping is a usually overlooked aspect in a suspension system, and pitch damping is overlooked even more so.

Most race series prevent the use of dedicated roll and pitch dampers, but even that being the case, understanding how the whole system works will increase your engineering.

Pitch Springs

Before going into detail, some common confusion about what a pitch spring is needs to be cleared up- you do not want to analyze pitch damping and apply it to the wrong spring. As shown in the third Spring & Damper tech tip, below in Figure 14 is a picture of a car with two single wheel springs, one roll spring (the anti-roll bar), and one RIDE spring. The ride spring in the middle is commonly incorrectly referred to as a pitch spring. It controls ride stiffness on the front of the car- but coincidentally also operates in pitch. A pitch spring controls the relative ride height between the front and rear of the car- and they are rare.

Figure 14. Pitch Spring Misconception

A pitch spring installed on a car, most of the time, is a torsion bar linking the front and rear control arms or rockers together. With this configuration, the spring provides no resistance in ride, or roll, but when the front and rear suspensions move in opposite directions (pitch), the torsion pitch spring resists the motion.

Pitch Damping

As with roll, pitch can be seen as a mass oscillating on a damped spring- derived from $T = I\alpha$ (Torque = Moment of inertia * Angular acceleration) and the natural pitch frequency. Applied to the pitch of a racecar, "T" is the pitch torque, "I" is the pitch inertia of the sprung mass, and "α" is the pitch acceleration.

Similar to all other modes of damping, you want to start off by choosing a damping ratio. The same compromise of response time and overshoot applies here- making 0.65 – 0.7 a good baseline damping ratio in pitch for mechanical grip. Shown below in Figure 15 is developing a baseline pitch damping plot for damping torque versus vehicle pitch velocity.

$$\text{Initial Slope} = \pi^2 \zeta_{pitch} \omega_{pitch} I_{pitch} / 45 \quad \text{Nm/(deg/s)}$$

ζ_{pitch} = Damping ratio in pitch
ω_{pitch} = Pitch frequency (Hz)
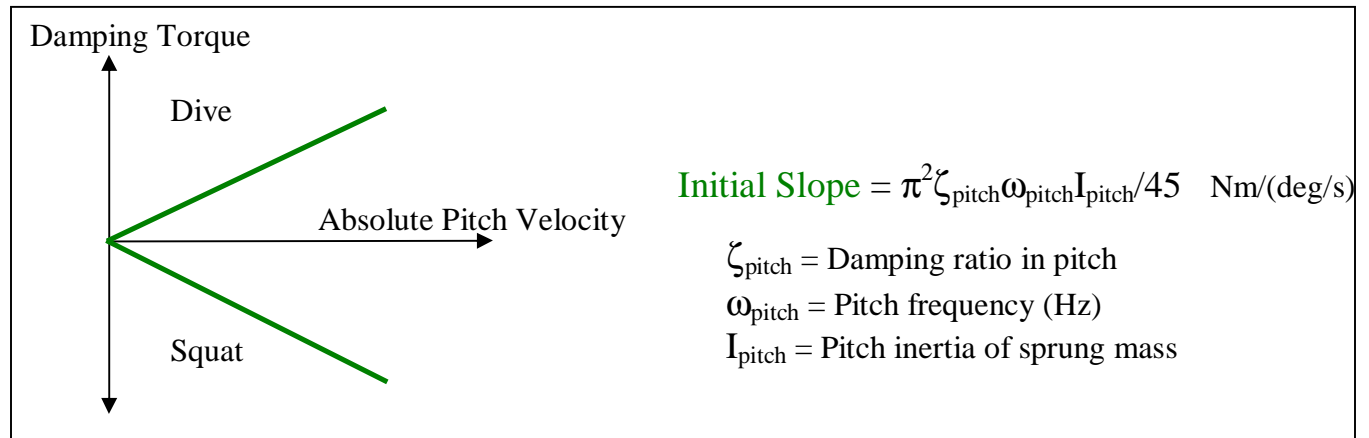I_{pitch} = Pitch inertia of sprung mass

Figure 15. Initial Pitch Damping Curve

Similar to roll damping, pitch damping should start off symmetrical. The only modification necessary is similar to high speed roll-off used for ride and single wheel damping. Since the car has higher frequency pitch vibration happening as the body pitches at a much lower frequency into a braking zone or acceleration, the lower damping ratio at higher pitch velocity tends to even the load on the tires as the car pitches.

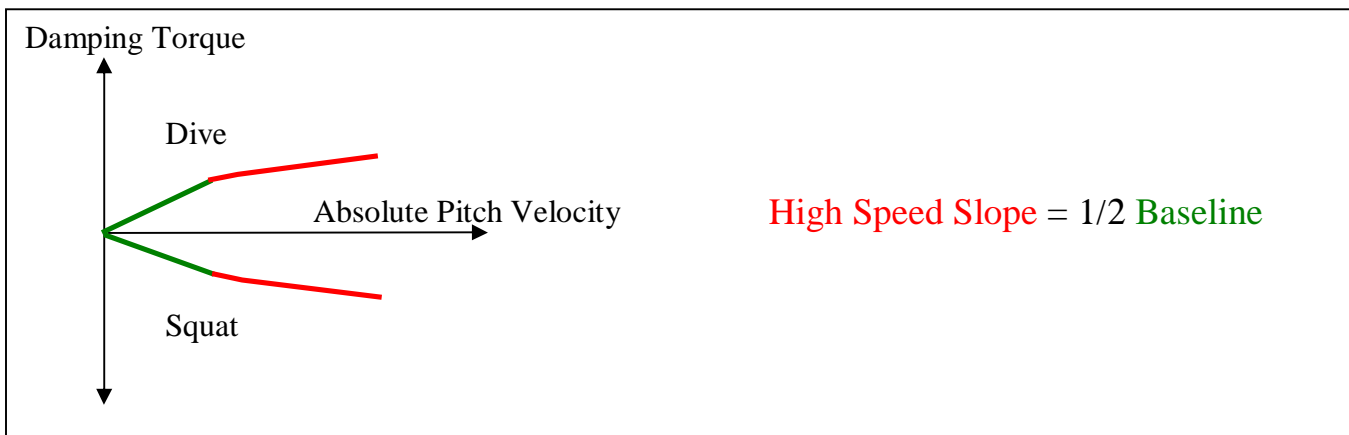High Speed Slope = 1/2 Baseline

Figure 16. Modified pitch damper curve

The damping curve calculated above is a good baseline for most cars- in some situations the pitch damping can deviate, for example, a high damping coefficient in pitch could be useful on a very high downforce car due to aerodynamic pitch sensitivity- stiff pitch damping will slow down the pitch, and hence the aero balance change. However, for most racecars the above baseline is a good place to begin. Once you calculate the baseline for damping torque vs vehicle pitch velocity, use the below equation to calculate the damper curve for the pitch damper itself.

$$F_{pitch\ damper} = F_{wheel} / MR^2$$

$F_{pitch\ damper}$ = Damping torque of pitch damper (Nm)
F_{wheel} = Pitch damping torque at the wheel from Figure 16. (Nm)
MR = Motion ratio of pitch damper- body pitch/pitch damper angular displacement

Before calculating your desired pitch damping baseline plot, you need your pitch frequency. Using the pitch stiffness ($K_{\theta des}$) calculated similarly to roll stiffness used in the Spring & Damper Tech Tip Part 5.

$$\omega_{pitch} = 1/(2\pi)\sqrt{\frac{180*K_{\theta des}}{\pi*I_{pitch}}}$$

Example

SI
m_{sm} = 1500 kg $\qquad$ ω_{pitch} = 2.8 Hz $\qquad$ ζ_{pitch} = 0.7 $\qquad$ I_{pitch} = 410 kg m^2

Initial Slope = π^2 * 0.7 * 2.8 Hz * 410 kg m^2 / 45 = 176 Nm/(deg/s)

English
m_{sm} = 3300 lbm $\qquad$ ω_{pitch} = 2.8 Hz $\qquad$ ζ_{pitch} = 0.7 $\qquad$ I_{pitch} = 9704 lbm ft^2

Initial Slope = π^2 * 0.7 * 2.8 Hz * 9704 lbm ft^2 / 45 = 108 lb-ft/(deg/s)

Most cars do not use a dedicated pitch damper, necessitating a compromise in damping between ride and pitch. However, for complete control of the car handling one pitch damper is needed for the left and right suspension, adding in the previously counted eight dampers, brings the count in total to ten dampers on the car for complete control.

This concludes the series of Spring & Damper Tech Tips. We hope they have been useful in helping people understand suspension systems more, and keep posted for a new tech tip topic next month.

As always, for more in-depth knowledge, OptimumG offers 3-Day seminars around the world, in-house seminars, a 12-Day Workshop, simulation, track support, and consulting services.