Tech Tip: Springs & Dampers, Part Three
Revenge of the Damping Ratio

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After understanding the first two tech tips in the Spring & Damper series, you know how to choose ride frequencies for your racecar, calculate the spring rate needed for the chosen frequencies, choose a roll gradient, and calculate the stiffness required from the anti-roll bars to produce your desired roll gradient. Now, what is the deal with these “third” springs people and using, and how in the world do I know where to start when it comes to damping on the racecar? Pitch springs will be skipped for now, as damping baselines will be much more useful.

Single Wheel Bump

In the first Spring & Damper tech tip, you learned how to pick a ride frequency and calculate the needed spring rate for your car. What happens if you want a lower ride frequency for grip over bumps, but need a higher ride frequency to keep the car off the ground from aerodynamic load or banking? The “third” spring is a solution. In addition to the ride spring on each wheel, an additional spring can be added that operates in ride, but not single wheel bump. This allows a lower frequency in single wheel bump than overall ride.

For example, the front ride frequency could be set at 1.5 Hz, with each front wheel set at 1.0 Hz to provide a softer suspension for bumps, providing more mechanical grip, without sacrificing overall ride. Attaching a third spring to a T-bar anti-roll bar (ARB) is the most popular method of accomplishing this, shown in Figure 5. Lower single wheel bump frequencies are useful on bumpy tracks where more vertical stiffness is desired- reducing the compromise between vertical stiffness and mechanical grip over undulations.

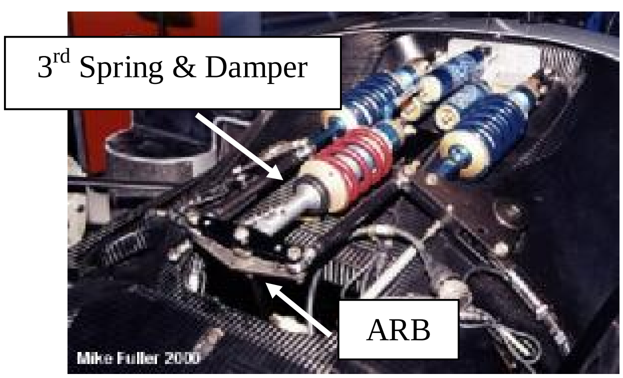

Figure 5. Third spring connected to T-Bar ARB

Once the ride frequencies are chosen, the spring rate needed can be determined from the motion ratio of the suspension, sprung mass supported by each wheel, and the desired ride frequency.

$$K_{ss} = 4\pi^2 f_s^{\,2} m_{sm} MR_s^{\,2}$$

K_{ss} = Single wheel spring rate (N/m)
m_{sm} = Sprung mass on that corner (kg)
f_s = Single wheel bump frequency (Hz)
MR_s = Motion ratio (Wheel/Single wheel spring travel)

Calculating the single wheel spring rates above allows you to calculate the spring rate of the third ride spring. The process below is shown for the front suspension; procedure for calculating the rear is the same.

$$K_{rs} = \left[4\pi^2 f_r^{\,2} m_{fsm} - K_{lss}/MR_{ls}^{\,2} - K_{rss}/MR_{rs}^{\,2}\right] MR_r^{\,2}$$

K_{rs} = "Third spring" rate, front (N/m)	MR_{ls} = Motion ratio of K_{lss}
f_r = Front ride frequency (Hz)	K_{rss} = Right front single wheel spring rate (N/m)
m_{fsm} = Front suspended mass (kg)	MR_{rs} = Motion ratio of K_{rss}
K_{lss} = LF single wheel spring rate (N/m)	MR_r = Motion ratio of third spring

Third Spring Example:

K_{rs} = "Third spring" rate, front (N/m)	MR_{ls} = 1.3
f_r = 2.0 (Hz)	K_{rss} = 30200 (N/m)
m_{fsm} = 300 (kg)	MR_{rs} = 1.2
K_{lss} = 30000 (N/m)	MR_r = 1.5

$$K_{rs} = (4\pi^2(2)^2 300 - 30000/1.3^2 - 30200/1.2^2)1.5^2 = 19.5 \text{ N/mm}$$

What damping should I start with?

Why a racecar needs 10 shocks for complete control….

As you can have four different spring rates- ride, single wheel bump, roll, and pitch, in an ideal situation, you will have four different damping ratios (ζ). The first step is to calculate the desired damping in ride, single wheel bump, roll, and finally pitch.

An undamped system will tend to eternally vibrate at its natural frequency. As the damping ratio is increased from zero, the oscillation trails off as the system approaches a steady state value. Eventually, critical damping is reached- the fastest response time without overshoot. Beyond critical damping, the system is slow responding. An important point to understand that will be useful when tuning the shocks on the car is that once any damping is present, the amount of damping does not change the steady state value- it only changes the amount of time to get there and the overshoot. Examples are shown below, and the effect of dampers on a sprung mass system is shown in Figure 6.

$$C_{cr} = 2\sqrt{K_w m_{sm}}$$

K_w = Wheelrate (N/m) m_{sm} = Sprung mass (kg)

$$\zeta = C/C_{cr}$$

C = Damping force (N) ζ = damping ratio

Wheelrate Example:

$$K_w = K_s/MR^2$$

Kw = Wheelrate (N/mm) Ks = Spring rate (N/mm)
MR = Motion Ratio (wheel/spring travel)

SI Example:

m_{sm} = 300 kg K_w = 90000 N/m

$$C_{cr} = 2\sqrt{90000\ \text{N/m} * 300\ \text{kg}} = 10392\ \text{N*s/m} = 10.4\ \text{N/(mm/s)}$$

English Example:

m_{sm} = 750 lbm K_w = 700 lbf/in

$$C_{cr} = 2\sqrt{700\ \text{lbf/in} * 750\ \text{lbm}/386.4\ \text{in/s}^2} = 73.7\ \text{lbf/(in/s)}$$

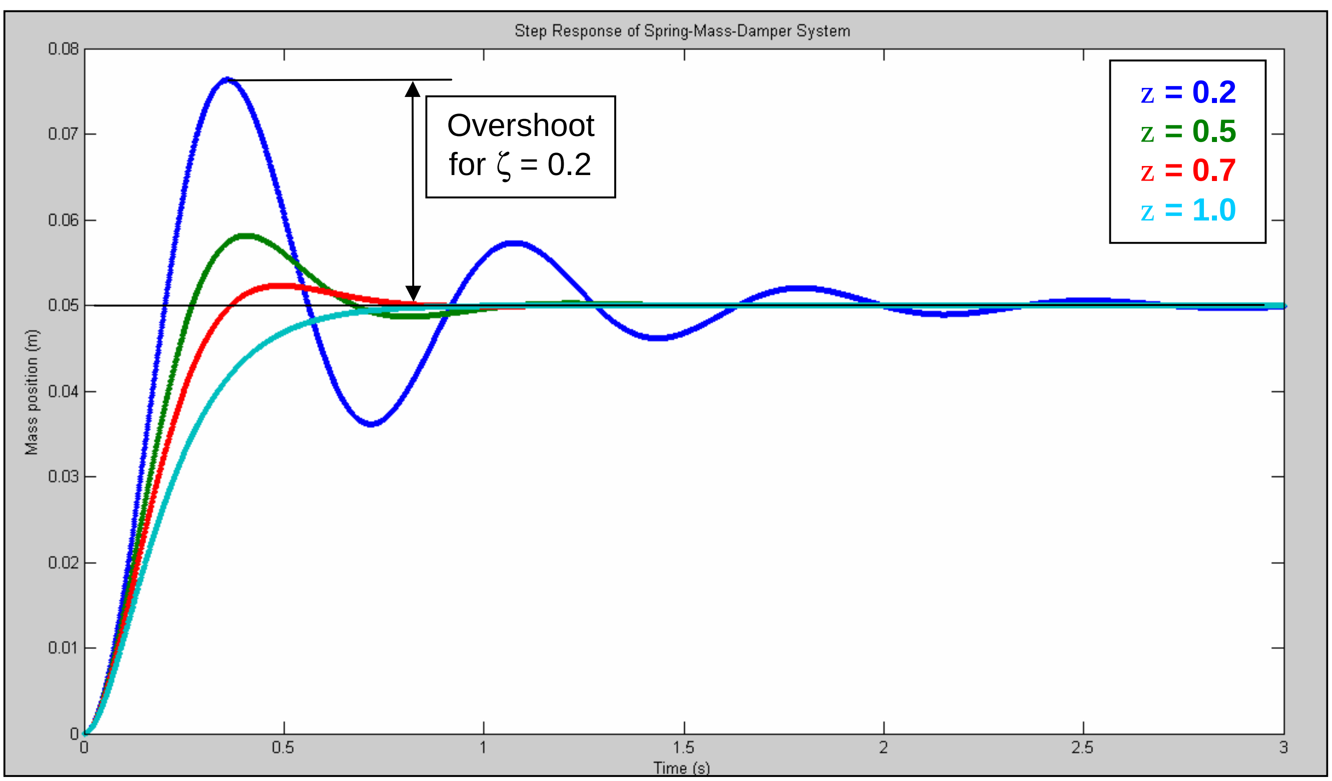

Figure 6. Effect of damping ratio to a sprung mass system

Ride and Single Wheel Bump Damping

The first place to start on damping is ride motion. Choosing a damping ratio is a tradeoff between response time and overshoot- you want the smallest of each. Passenger vehicles generally use a damping ratio of approximately 0.25 for maximizing ride comfort. In racecars, 0.65 to 0.70 is a good baseline; this provides much better body control than a passenger car (less overshoot), and faster response than critical damping. Some successful teams end up running damping ratios in ride greater than 1, this does not indicate that damping ratios in ride should be large, it shows that there is a compensation for a lack of damping in roll and pitch, as the dampers that control ride motion usually also control the roll and pitch motion.

Up to this point in the spring and damper tech tips, you should be able to choose ride frequencies, roll gradients, calculate needed spring and ARB stiffnesses, and now choose a damping ratio in ride.

Next time, the development of a baseline force versus velocity curve for the ride dampers will be explained.