Tech Tip: Springs & Dampers, Part One

The Phantom Knowledge

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When out on the track, you can spend an entire weekend tuning spring rates and shock settings, and shave a second from lap times. But, how do you know if you are even in the right ballpark, and maybe a completely different spring and shock setup could cut two seconds per lap, especially when working with an unfamiliar car?

In the first of a series of tech tips on springs and dampers, we will explore how to develop baseline spring rates for ride to provide a solid foundation to tune from.

Ride and Single Wheel Bump

The first step in choosing spring stiffness is to choose your desired ride frequencies, front and rear. A ride frequency is the undamped natural frequency of the body in ride. The higher the frequency, the stiffer the ride. So, this parameter can be viewed as normalized ride stiffness. Based on the application, there are ballpark numbers to consider.

- 0.5 - 1.5 Hz for passenger cars
- 1.5 - 2.0 Hz for sedan racecars and moderate downforce formula cars
- 3.0 - 5.0+ Hz for high downforce racecars

Lower frequencies produce a softer suspension with more mechanical grip, however the response will be slower in transient (what drivers report as "lack of support"). Higher frequencies create less suspension travel for a given track, allowing lower ride heights, and in turn, lowering the center of gravity.

Ride frequencies front are rear are generally not the same, there are several theories to provide a baseline. Two examples below show exaggerated plots of what happens with unequal ride frequencies front and rear as the car hits a bump. In Figure 1, we can see the *undamped* vertical motion of the chassis with the front ride frequency higher than the rear. The first period is the most dominant on the car when looking at frequency phase, due to effects of damping to be explained later.

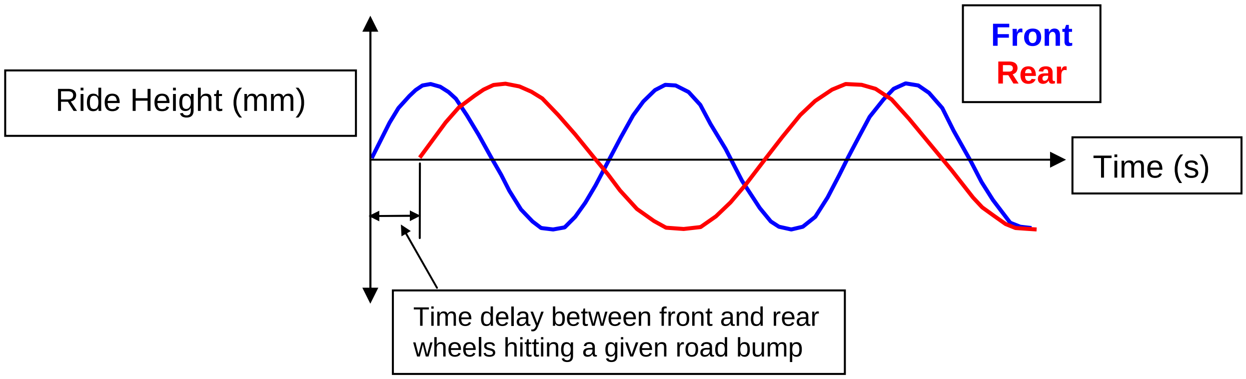

Figure 1. Higher Front Ride Frequency

The out of phase motion between front and rear vertical motion, caused by the time delay between when the front wheel and rear wheel hit the bump, is accentuated by the frequency difference. A result of the phase difference is pitching of the body. To reduce the pitch induced by hitting a bump, the rear needs to have a higher natural frequency to “catch up” with the front, as shown in Figure 2. This notion is called producing a “flat ride”, meaning that the induced body pitch from road bumps is minimized.

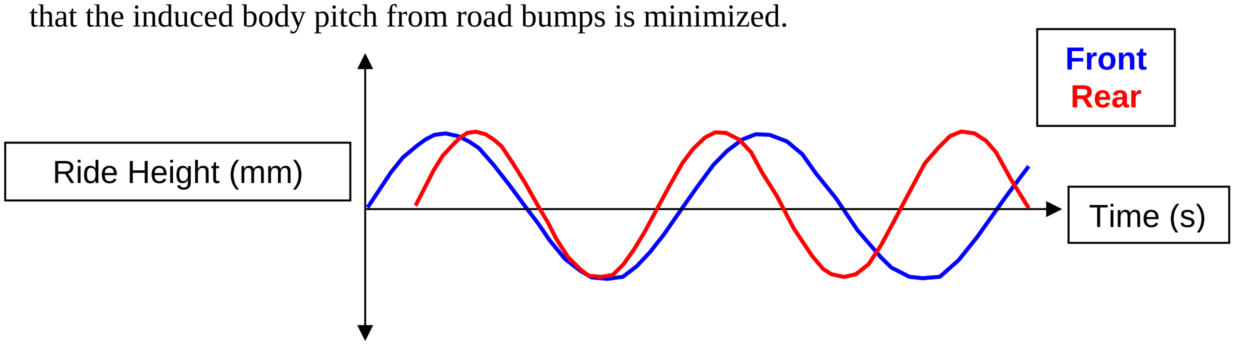

Figure 2. Higher Rear Ride Frequency

For a given wheelbase and speed, a frequency split front to rear can be calculated to minimize pitching of the body due to road bumps. A common split is 10 – 20% front to rear.

The above theory was originally developed for passenger cars, where comfort takes priority over performance, which leads to low damping ratios, and minimum pitching over bumps. Racecars in general run higher damping ratios, and have a much smaller concern for comfort, leading to some racecars using higher front ride frequencies. The higher damping ratios will reduce the amount of oscillation resultant from road bumps, in return reducing the need for a flat ride. Damping ratios will be explained in the next tech tip in detail. A higher front ride frequency in a racecar allows faster transient response at corner entry, less ride height variation on the front (the aerodynamics are usually more pitch sensitive on the front of the car) and allows for better rear wheel traction (for rear wheel drive cars) on corner exit. The ride frequency split should be chosen based on which is more important on the car you are racing, the track surface, the speed, pitch sensitivity, etc.

As an example of ride frequency split front to rear, Figures 3 and 4 shows a simple example of a single degree of freedom vehicle model over an impulse disturbance. The ride frequency difference is 10 percent, 70% critical damping, 100 km/h speed, and 1.75 m wheelbase.

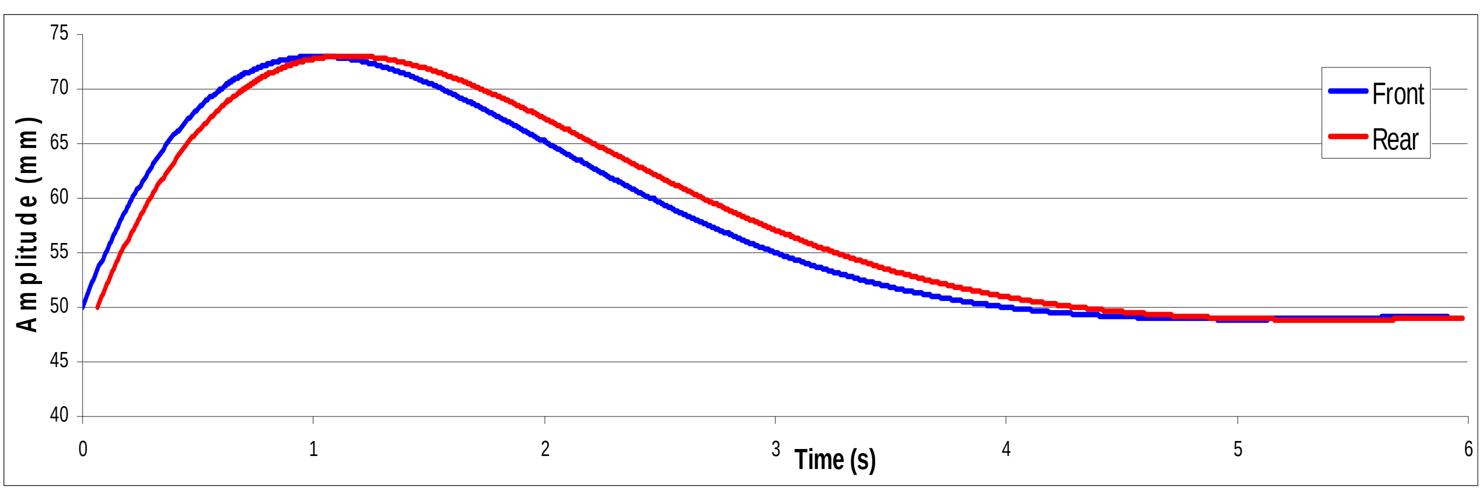

Figure 3. Front ride frequency 10% higher than rear

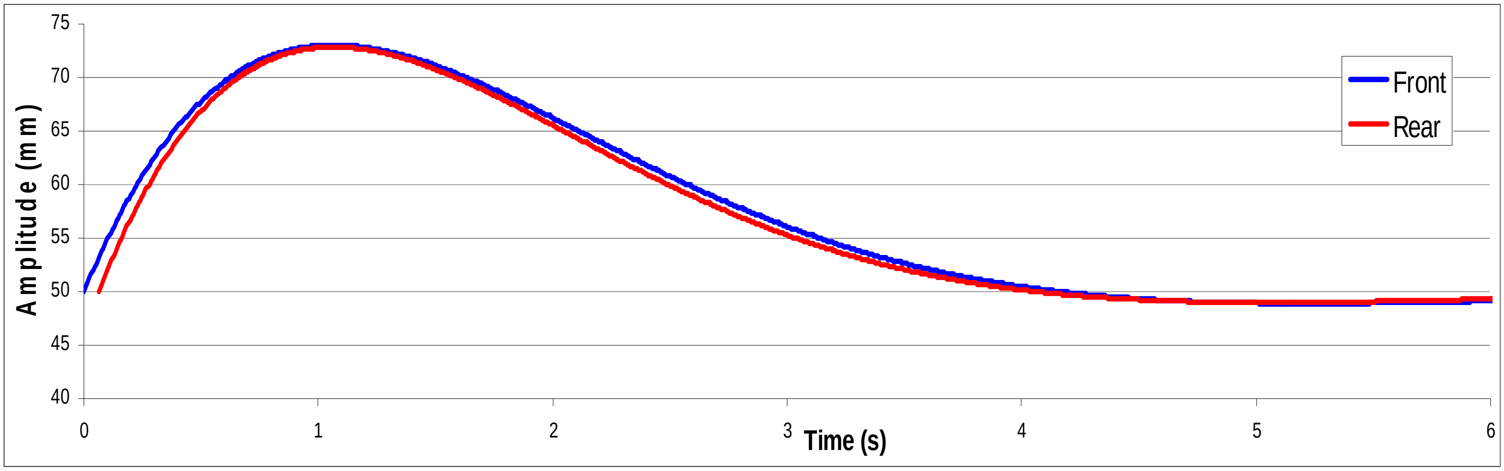

Figure 4. Rear ride frequency 10% higher than front

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.

Starting with the basic equation from physics, relating natural frequency, spring rate, and mass:

$$f = 1/(2\pi)\sqrt{\frac{K}{M}}$$

f = Natural frequency (Hz)
K = Spring rate (N/m)
M = Mass (kg)

Solving for spring rate, and applying to a suspension to calculate spring rate from a chosen ride frequency, measured motion ratio, and mass:

$$K_s = 4\pi^2 f_r^2 m_{sm} MR^2$$

K_s = Spring rate (N/m)
m_{sm} = Sprung mass (kg)
f_r = Ride frequency (Hz)
MR = Motion ratio (Wheel/Spring travel)

Shown below in Table 1 is an example using the above calculation. Table 1 shows spring rates needed for a traditional suspension with one ride spring per wheel, and a motion ratio of one. As the suspended mass per corner and ride frequency are changed, the corresponding spring requirement is shown.

Sprung Mass per corner

	100	300	500	700	900	1100	lbs.	Motion Ratio:
Ride Frequency (Hz)	45	136	227	318	409	500	kg	1
1.0	10.3	30.8	51.4	72.0	92.5	113.1	lb/in	
	1.8	5.4	9.0	12.6	16.2	19.7	N/mm	
1.5	23.1	69.4	115.7	161.9	208.2	254.5	lb/in	
	4.0	12.1	20.2	28.3	36.3	44.4	N/mm	
2.0	41.1	123.4	205.6	287.9	370.1	452.4	lb/in	
	7.2	21.5	35.9	50.2	64.6	79.0	N/mm	
2.5	64.3	192.8	321.3	449.8	578.3	706.8	lb/in	
	11.2	33.6	56.1	78.5	100.9	123.4	N/mm	
3.0	92.5	277.6	462.6	647.7	832.7	1017.8	lb/in	Spring Rates
	16.2	48.5	80.8	113.1	145.4	177.7	N/mm	
3.5	125.9	377.8	629.7	881.6	1133.5	1385.3	lb/in	
	22.0	65.9	109.9	153.9	197.8	241.8	N/mm	
4.0	164.5	493.5	822.5	1151.5	1480.4	1809.4	lb/in	
	28.7	86.1	143.6	201.0	258.4	315.8	N/mm	
4.5	208.2	624.6	1040.9	1457.3	1873.7	2290.1	lb/in	
	36.3	109.0	181.7	254.4	327.0	399.7	N/mm	
5.0	257.0	771.1	1285.1	1799.1	2313.2	2827.2	lb/in	
	44.9	134.6	224.3	314.0	403.8	493.5	N/mm	

Table 1. Spring Rates vs Sprung Mass and Ride Frequency

Now, you can create baseline spring rates for your car in ride motion. Next month, single wheel bump springs and ride damping will be explained; eventually over the series, spring rates and damping in ride, roll, and pitch will be covered.