

Tech Tip: Spring & Dampers, Episode Four

A New Understanding

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Correction:

In Spring & Dampers, Part Two this equation is incorrect:

$$K_{\phi\text{DES}} = WH/(\phi/A_y) + K_{\phi R} + K_{\phi F}$$

It should read:

$$K_{\phi\text{DES}} = WH/(\phi/A_y)$$

Moving on to this month's topic: understanding the basics of damping in a racecar and developing a baseline ride damper curve.

Transmissibility

Before going into the details of damping force versus damper shaft velocity, the concept of transmissibility should be understood.

From driving street cars, we all know that if you hit a speed bump going very slow the body of the car (sprung mass) moves vertically almost as much as the wheels. Hitting the same bump going fast (you know you have done it, especially in a rental car) the body of the car does not move nearly as much. The size of the bump was the same, but the body motions were different depending on the speed at which you hit it. The cause of this is that response of the system (the car sitting on the suspension) is dictated by the frequency and amplitude of the input. Hitting the speed bump faster increases the frequency of the disturbance, producing a different response. To quantify this reality we use the concept of transmissibility.

The transmissibility (TR) is the ratio between output and input amplitude. In the above case, the input amplitude is the height of the speed bump, with output amplitude being vertical movement of the body.

$$TR = \frac{\textit{output amplitude}}{\textit{input amplitude}}$$

Rearranging the equation above gives a method to calculate vertical body movement from input disturbance amplitude and the transmissibility, which you can calculate from the mass, spring rate, and damping ratio.

$$\textit{output amplitude} = TR \times \textit{input amplitude}$$

In our case the input is a displacement of the wheel caused by the speed bump. For example, let's say the speed bump is four inches tall- moving the wheel four inches up, and four inches back down. The input is the wheel movement and the input amplitude is four inches. The distance the mass of the car will move up and down is the output amplitude. The time it takes for the wheel to complete the up-down cycle is the frequency divided by two. As you increase the speed, you increase the frequency- and for sprung mass systems the transmissibility changes with frequency. Figure 7 shows the transmissibility for a spring-mass-damper system with a fixed damping ratio of 0.5- a simple model of the car hitting the speed bump.

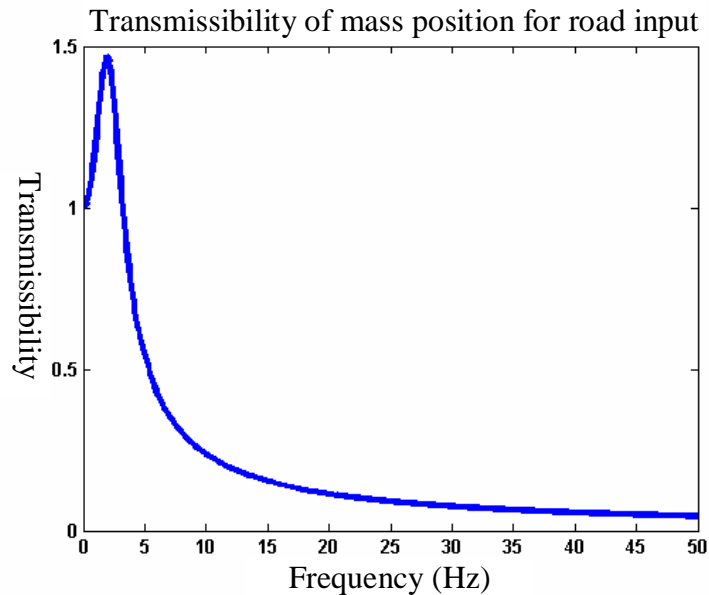


Figure 7. Transmissibility of a spring-mass-damper system

Very Low frequency example

TR = 1 Input amplitude = 4 in

Output amplitude = 1 x 4in = 4 in

The output has the same amplitude as the input, this means the body moves the same as the wheels. This makes sense since you go really slow over the speed bump with nearly no spring deflection.

As you go faster, the frequency increase and you will reach a frequency where the body movement reaches a maximum, this is the resonant frequency. At this frequency the transmissibility is maximum and higher than one (for the interested the resonant frequency is equal to the ride frequency calculated in Spring & Dampers Tech Tip Part 1). In our case the resonant frequency is around two hertz and the transmissibility is 1.45.

Resonant frequency example

TR = 1.45 Input amplitude = 4 in

Output amplitude = 1.45 x 4in = 5.8 in

This means that at this frequency the car movement is greater than the input. The driver will feel a harsh ride, and it will feel like the body of the car is catapulted off the speed bump.

High frequency example

TR = 0.1 Input amplitude = 4in

Output amplitude = 0.1 x 4in = 0.4 in

This means that at this frequency the car movement is reduced and the suspension absorbs the bumps. The driver will feel a smooth ride.

Now that we defined what is transmissibility we can use it to find damping values. The first step is to examine the transmissibility for different damping ratios, as shown on Figure 8.

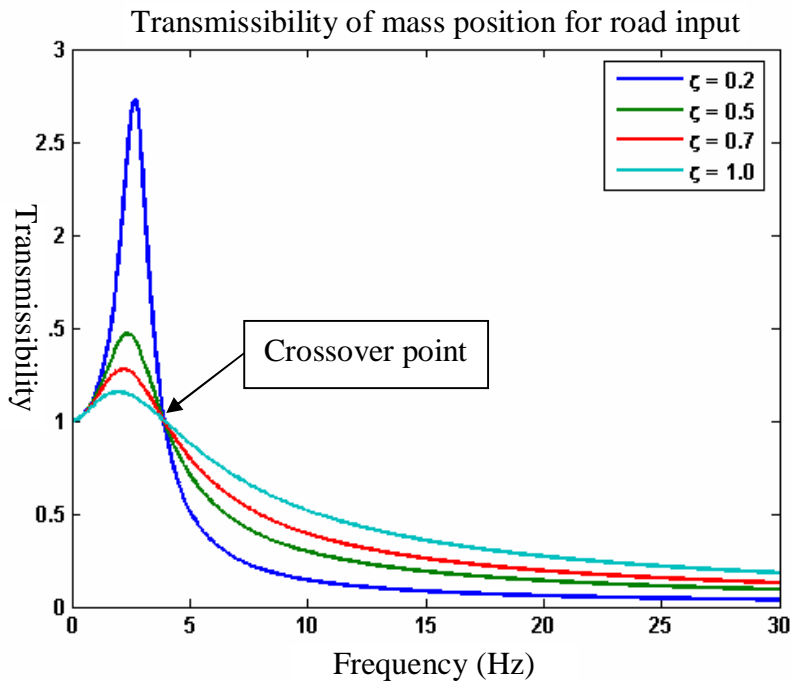


Figure 8. Transmissibility for different damping ratios

In order to tune for maximum grip, you want the lowest transmissibility possible- as the body is bouncing around, the forces on the springs are changing, decreasing the grip. As you can see in Figure 8, there is a crossover point, this is at $\sqrt{2}$ * Resonant Frequency. At low frequencies, if we increase the damping we reduce the maximum transmissibility, which is good, making a higher damping ratio at low frequencies desirable. On the other side of the crossover point, low damping ratios give a lower transmissibility, meaning low damping ratios are desirable at high frequency. Since low frequencies generally correspond to low damper velocity, and high frequencies generally correspond to high damper velocity, you can see now that you want a higher damping ratio at low damper velocity than high damper velocity. The next section shows how to take the above theoretical explanation and apply it to come up with a baseline damper curve.

Baseline Ride Damping Curve

A damper curve is the famous (or infamous) *force vs velocity* curve of a shock absorber. Calculating a baseline damper curve in ride is explained below in several steps. If you have no idea where to start on dampers, or want to know if what you are using is in the theoretically correct ballpark, this should be a big help. To begin, you need the suspended mass supported by each damper (this is the suspended mass per corner on a normal car with one spring and damper

per corner), the ride frequencies, and damping ratios chosen earlier. For more explanation on these three, see the first three Spring & Damper Tech Tips.

The first step is linear for the entire velocity range later to be modified in steps two and three. Calculating the slope of the initial damping curve for step one is shown below in Figure 8.

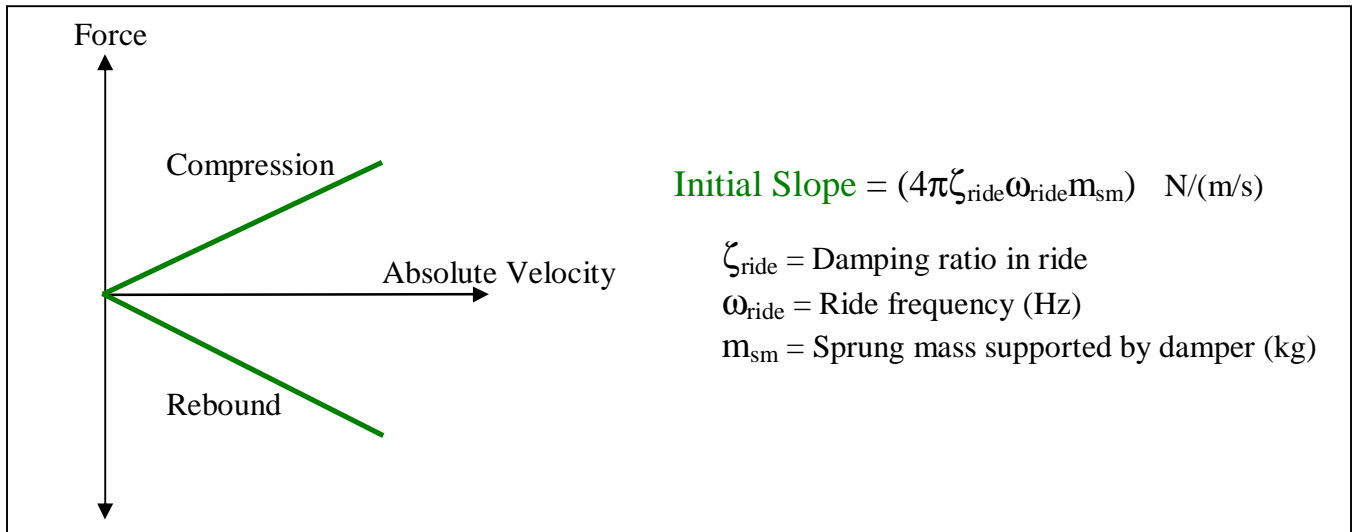


Figure 9. Initial Damping Curve

The basic curve above has the same damping ratio in compression and rebound. In reality, it is more desirable to have a lower damping ratio in compression and higher damping ratio in rebound. A guideline for modifying the above plot is shown in Figure 9. These produce an average damping ratio the same as above, but the damping forces produced in rebound travel being twice that of compression damping forces. When the suspension is compressed, energy is being stored in the spring, and during rebound energy is being released from the spring. Since the job of a damper is to absorb energy for the purpose of controlling resonance, less damping force is required by the damper during compression due to the energy going into the spring. Similarly, more damping force is required by the damper during rebound, as it has to control resonance and the energy being released by the spring.

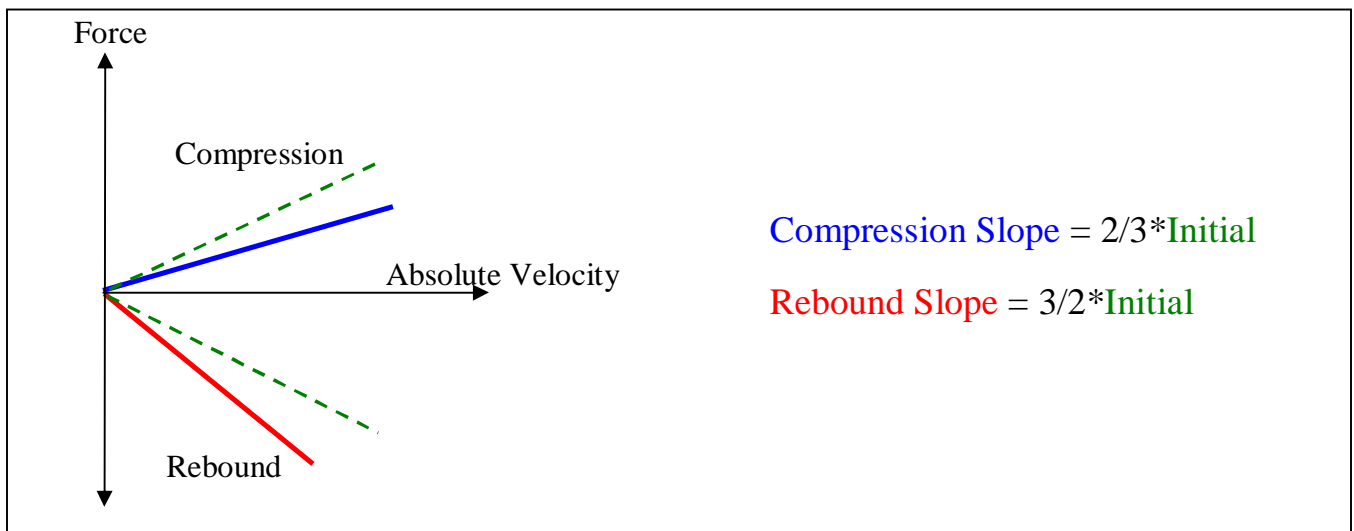


Figure 10. Modified shock curve

Unfortunately, the new shock curve is still not ideal- it will cause harshness over small amplitude, high frequency road disturbances. It is desirable to reduce the damping ratio at high shock speed (above the Low/High speed split velocity) to reduce this effect. Referring back to the transmissibility example above, remember you want the lowest transmissibility for mechanical grip. Lower frequencies on the transmissibility plot usually translate to lower damper velocities, where a damping ratio of approximately 0.7 is ideal. However, at higher frequencies that usually translate to higher damper velocities, lower damping ratios around 0.2 produce lower transmissibility. The split between low and high damper velocity should be initially set to isolate body motions (low velocity) and track bumps (high velocity), or if you're feeling adventurous, correlate the crossover point on the transmissibility graph to a damper velocity as a split point to start from.

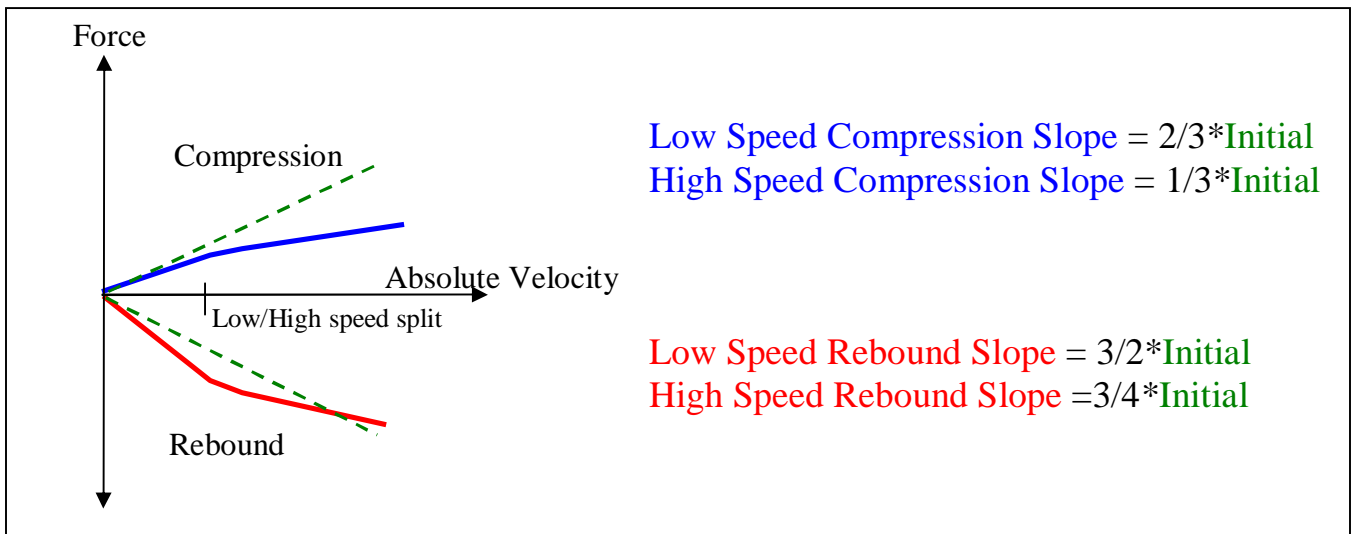


Figure 11. Modified high speed shock curve

Now you have a baseline force versus velocity curve for the shocks in ride. Next month, calculating a baseline curve for roll and pitch damping will be explained. On a car where rules allow, and you choose to do so, a suspension system can be designed where damping adjustments can be made that isolate ride, roll, and pitch. Finding an ideal baseline for roll and pitch damping are discussed below, however, most cars due to their suspension design are forced to make a compromise between the three (this explains the point mentioned above with successful cars using non-ideal damping ratios in ride).

With one ride damper for each wheel, and one on each “third spring”....6 shocks so far.

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