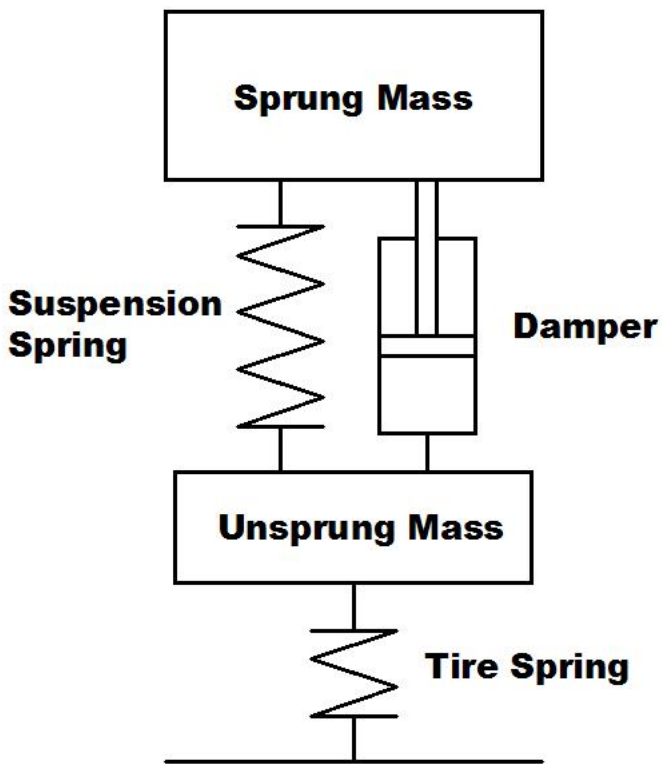
An Introduction to Dampers and the Black Art of Damper Tuning

Dampers are an integral part of any suspension system. They are also the least understood and most confusing part of the suspension. The main function of the dampers is to control the transient behavior of the sprung and unsprung masses of the vehicle. This is accomplished by damping the energy stored in the springs from suspension movement. The damper generates a force defined by the characteristic curve and the velocity of the damper. Dampers are also called shock absorbers, shocks or spring energy dissipaters.

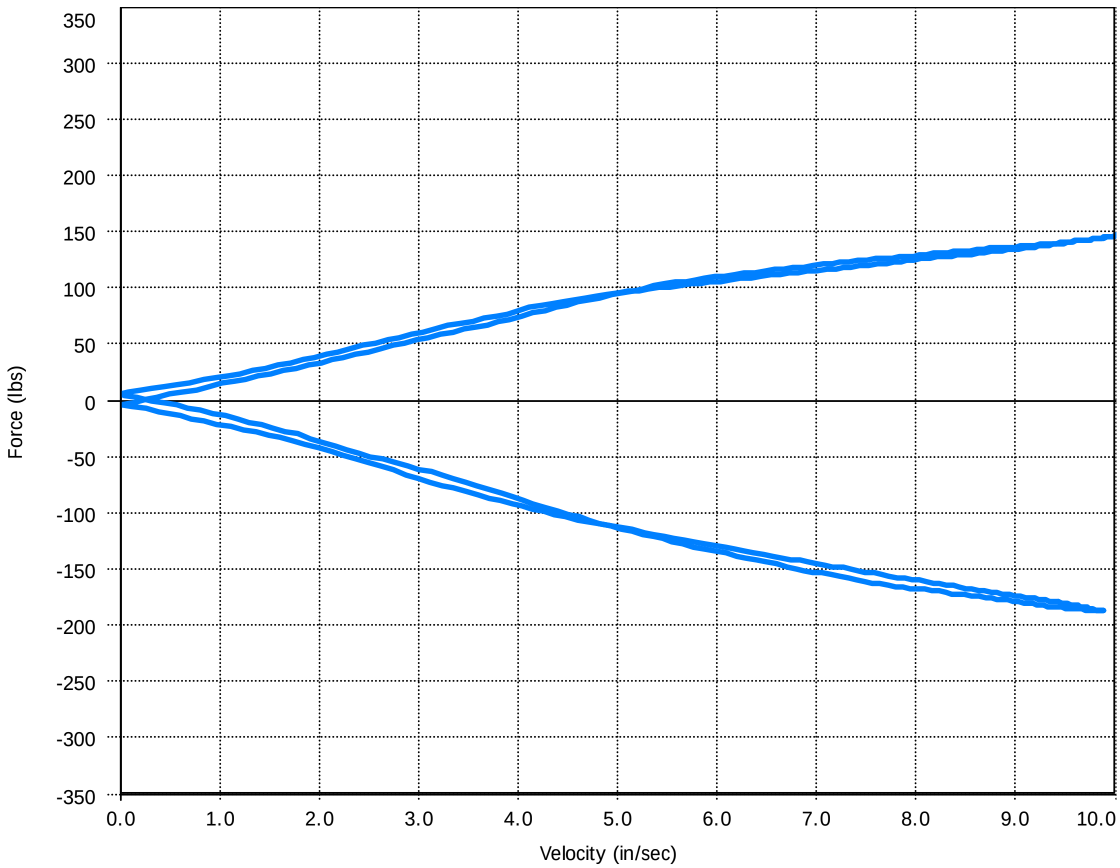
In order to better understand the damper's function, a basic knowledge of the entire suspension system is needed. This system can be broken down into the sprung and unsprung masses, the suspension spring, the tire spring and the damper. The sprung mass is the mass supported by the suspension. This includes half of the mass of the suspension members. The unsprung mass is everything else, including the wheels, brakes, uprights or spindles and the other half of the mass of the suspension members. The suspension spring is in parallel with the damper and acts between the sprung and unsprung mass. The tire spring is between the ground and the unsprung mass.




This is a two degree of freedom system with forces acting on the top and the bottom. Because the system has two degrees of freedom the sprung and unsprung masses are able to move independent of each other. The force on the sprung mass is a function of the load transfer of the vehicle. This load transfer is defined by the accelerations a vehicle sees on the track. These accelerations can be either longitudinal, for example braking and acceleration, or lateral which is generated during cornering. The magnitude of this load transfer is based on the center of gravity of the vehicle, the magnitude of the acceleration, the weight of the vehicle and the track or wheelbase depending on the direction of the acceleration. The force acting at the bottom is based on the profile of the road surface and the speed of the vehicle.

The forces resulting from the accelerations generate a relative displacement, velocity and acceleration between the sprung and unsprung masses. The suspension spring and the damper generate forces to resist this force. The force generated by the spring is based on the relative displacement while the force generated by the damper is a result of the relative velocity. The magnitude of the spring force is a result of the rate of the spring. The magnitude of the damper force is slightly more complicated.

The force generated by the damper is a function of the characteristic curve of the damper. This is the curve that is seen in shock dyno plots such as the one below. The characteristic curve can take many shapes depending on the internal construction. This includes the design of shock piston, shim stacks and other internal orifices. As the oil flows through these passages internal pressure is developed which results in the forces generated by the shock. A deeper discussion of this construction is beyond the scope of this article.




This plot was created using a Roehrig Engineering 2VS Shock Dyno and their Shock6.0 software. The positive force on the graph is for the compression stroke while the negative force is for the rebound stroke. The velocity shown on the graph is the relative velocity of the damper shaft which is also the velocity between the sprung and unsprung masses. These forces can be different in both directions. Generally the rebound forces are greater than the compressive forces. This can be attributed to the idea that the compression damping controls the unsprung mass while the rebound damping controls the movement of the sprung mass. Because of the lower mass of the unsprung mass, less force is required to control this motion. Another contributing factor is the fact that during compression the forces of the spring and damper are in the same direction while during rebound the spring and damper forces act in opposite directions.

The shock only generates a force when there is a relative velocity between the sprung and unsprung masses. These transient maneuvers are during corner entry and exit, passing maneuvers and braking and acceleration, as well as whenever bumps or rough road is encountered on the track. One could say that in real life, there are only transients. These transients can be split into low and high speed ranges. The low speed range, approximately 0-5 inches per second, characterizes the handling while the high speed range, greater than 5 inches per second, characterizes the ride. These ranges are only approximations used for analysis and may be different than what is seen when on the car.

In order to determine what shock would be best for a given setup, there are several important variables needed to determine this damping coefficient. This value is a function of the sprung mass, unsprung mass, tire spring rate and the wheel rate. The wheel rate is the suspension spring rate modified by its installation ratio. The installation ratio, also known as the motion ratio, is the ratio of the wheel travel to the shock travel. The spring rate of the anti-roll bar is also important when analyzing damping characteristics under roll. This rate is also modified by its installation ratio. The final necessary variable is the damping ratio. This ratio determines how stiff the shock is in relation to the rest of the suspension. When this ratio is one, the system is considered critically damped. This value also determines where the shock falls in terms of the compromise between ride and handling. A common starting value for the damping ratio for a track car is 0.65. The analysis and calculations involved for determining the desired damping coefficient will be covered in a following article.

Now that the theory has been covered, it is time to talk about what all of this means in practice. In general, the best option for upgrading your spring and dampers is coilovers. This will provide the car with a much higher spring rate as well as a stiffer shock. Manufacturers always list the spring rate included, but seem to always forget to mention anything about the damping coefficient. While this does not mean that any of the coilovers on the market are bad, it just adds a little bit of uncertainty to the process. With the knowledge of the damping coefficient, the buyer would have a better idea of whether the shocks match them and their car.

A shocks valving determines how the car will ride and handle. An overly stiff shock in compression will not absorbs the bumps very well and can contribute to the well known bouncy ride. A shock very stiffly valved in rebound can cause an initial loss of traction as well as contribute to a sort of jacking down effect where the unsprung mass is pulled closer to the sprung mass after a series of bumps. This only occurs when there is too much rebound versus compression and spring rate. This will also contribute to a loss in traction once the shock bottoms out.

Softly valved shocks are also very bad for the performance of a car. While the shock does not affect the load transfer or amount of load transfer, it does determine the rate at which this load is transferred. A soft shock will have that lag feeling following a steering input. Instead of the car taking the desired attitude through a turn, the driver has to wait for the car to catch up to the input. While this type of behavior may be acceptable for a normal passenger car that will never see above 0.3gs, this is completely undesired and unacceptable for any vehicle that will even think about driving on a race track.

This leaves a relatively small window for ideal damping. In this window is the compromise between ride and handling. For a race car, a harsher ride is a very understandable decision in exchange for better handling. This is where adjustable dampers make life much easier. With an adjustable damper, the driver has the ability to affect the magnitude of the damper's characteristic curve. Many of the market's current offerings feature adjustable dampers, although they are single adjustable and more times than not change both rebound and compression at the same time. While the adjustability is still a good feature this type adds another compromise into the mix. A single adjustable damper that only affected rebound could be better in some cases than one that adjusts both compression and rebound at the same time. Some of the higher priced coilovers offer a double adjustable setup which will allow independent adjustment of rebound and compression. This will help the driver to dial in the car more accurately than with a single adjustable shock. If you go further up in cost, three and four way adjustable dampers become available. This will allow independent adjustment of low-speed and high-speed compression and rebound. Most shocks like this cost more than a decent set of coilovers putting them out of range for most enthusiasts.

No matter what dampers are on the car, they must be dialed in correctly in order to perform the best. The best way to do this is to start with the dampers on the softest setting. The driver should then drive a set course and really try and feel how the car enters the corner and how it feels over rougher road. If the car feels too soft, increase the damping progressively until the car feels a little too stiff. Once this point has been reached back off the adjuster a click or two and the damping is then set. Each corner might need a slightly different setting to feel the same. The front and rear might also feel best at different points. If a shock is single adjustable, then the body movement and the wheel movement must be analyzed at the same time. For a double adjustable setup then the two motions can be decoupled. While this may sound unscientific, it must be understood that the driver is a very important part of the equation and how the driver feels in the car will greatly affect its behavior.

Hopefully this article was able to explain the basics of dampers and how they relate to the performance of the car. While this is only scratching the surface, it is necessary to understand the basics before diving deeper into the confusing world of shock absorbers. Several more articles concerning damper tech and other suspension basics will be covered in following issues.

On a related note, Theory in Practice Engineering is currently exploring damper options for several popular cars and will hopefully have offerings available in the near future. For updates please visit www.theoryinpracticeengineering.com.

Tim Johnsrud
jrud@theoryinpracticeengineering.com