Shocking

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Whether They're Called Shocks, Dampers, or Struts, These Pieces Are Critical for Performance

If you, like many motorsports enthusiasts, were hungry for any racing action as the 1997 season began winding up, you likely paid attention to the practice and qualifying sessions for the Daytona 500. The big story there was the new stronger spring rule mandated by Nascar, and which teams could now get their suspensions to work the best.

The buzz was all about shock absorbers and how they were the key to keeping the rearend stable and predictable so the driver could put the precious horsepower to the pavement.

But Daytona isn't the only place where proper suspension tuning is vital to car control and fast lap times; it has been accurately said that many of the recent gains in suspension control have been made with shock absorbers. They can be the difference between who is on the track and who is on the trailer. But it doesn't matter if you are struggling for the last tenth of a second on track or simply trying to nail those esses through your favorite Sunday drive; suspension motion and transitional control is what handling is all about.

Most enthusiasts begin transforming their street cars into performance machines with the installation of higher performance tires. The next big gain is going to be with a set of performance shock absorbers.

Although the naked eye may not be able to see any difference between average and performance models, inside these shocks you'll find a world of difference. And while automobile manufacturers are making strides each year in bettering suspension designs and improving car control, too many models still come off the line with basic shock absorbers that are better matched to the general public and the financial bottom line. It is up to the individual owner to understand what shocks do and select what will improve his or her car.

BASICS AND TERMS

In the pursuit of shock knowledge there are a few basic ideas to be grasped. The term "shock absorber" is really a misnomer; "damper " is really more appropriate, but for our purposes we will use them interchangeably. The shock doesn't really absorb the impacts taken by the suspension, but dampens those motions by converting the kinetic energy of the spring (up and down motions) into thermal energy (the heat built up by flowing oil through valves). The damper controls the oscillation rate of the spring.

A good way to think of a damper in a performance application is as a timing device. The spring carries the vehicle load and establishes how much the suspension will travel for a given input. The damper times how long the suspension takes to react to the input or to dissipate the energy. An undamped spring will cycle or bounce very quickly and continue to do so until it has used up all of the input energy. The damper restrains the spring and helps it process the energy. The higher the spring rate, the greater the restraining ability the damper must have to control its energy. The more subtle and controlled the spring's motion, the more vehicular control you have.

Many years ago, the term "double-action shock" was used, implying that the shock offered damping action in both directions of travel. More modern suspension understanding has double-action taken pretty much for granted, as most people realize that a suspension requires damping both up and down.

Any time there is a discussion of dampers, the primary words used are rebound (extension) and bump (compression). The rebound damping characteristics control the sprung weight of the car, which is basically everything above the suspension (body, driver, engine, etc.) and part of the suspension weight (half of the spring, shock and some axle weight depending on type). Bump, sometimes known as jounce, controls the car's unsprung weight (wheels, tires, brakes and the other half of the suspension).

In a cornering situation, the vehicle weight transitions from the inside of the turn to the outside. The inside damper extends (rebounds) and thus determines how long it takes for the weight to transfer. Too little rebound valving will let the transition occur too quickly, upsetting the smooth balance of the vehicle. Too much rebound can make the transition too slow or possibly cause lift of an inside wheel.

At the same time, the compression damping plays a lesser role in establishing how far or fast the outside suspension will compress in accepting that transfer. A low compression rate will allow the acceptance to occur quickly and force the spring to do the work, but in the following reaction there will be a greater requirement for rebound as the spring responds back. A high compression rate will make the acceptance slow and act as a booster, seemingly increasing the spring rate.

When you hit an obstacle or undulation in an otherwise straight and smooth road, the damper compresses and determines how easily the wheel goes up into the wheel well or how much it resists the compression and makes the entire body raise.

Too little compression damping can let the suspension travel farther up than needed. Adding more compression damping can help the road-holding ability by reducing how far the suspension moves upward and therefore will need to move downward. Too much compression damping will push the entire car into the air and reduce the footprint of the tire on the ground, which will risk making the car feel like it is skating.

After the wheel stops traveling upward and the spring has stored the energy, it must release the energy and extend and use the rebound function. Too little rebound damping will let the spring go farther and faster than it needs, and it will continue to cycle and bounce until its business is through.

Too much rebound damping can overcome the spring's ability to expand and hold it falsely short. This can make a car literally "jack" itself down and, over a series of bumps, can cause the car to lower itself to a point where it is riding on the bump stops and has no suspension at all.

DAMPER DESIGNS

There are three basic designs of shock absorbers: twin-tube hydraulic, twin-tube low-pressure gas, and mono-tube high-pressure gas. Each of the three has its own abilities and functions, and you will find all three in street or street-derived racing applications.

One of the most common misconceptions is that a gas shock is filled entirely with gas and no oil. In fact, all three damper designs use hydraulic oil-they just may have a nitrogen gas charge pressurizing the oil in the shock. Do not select a shock simply because it does or does not contain gas. Look into its actual capabilities.

The twin-tube hydraulic, as the name implies, has two cylinders (or chambers) and no nitrogen. The inner cylinder is where the rod and piston live and work, and the outer chamber is a reservoir for oil and air. As the rod travels in and out of the inner cylinder during stroking action, it displaces oil from the inner to the outer cylinder, then draws it back inside. Although this is the oldest of the three designs, it still maintains certain benefits and has a place in performance damping.

The twin-tube low-pressure gas shock is much the same as the hydraulic, except that it has a low pressure (usually 5-15 bar/70-210 psi) nitrogen charge in the outer chamber instead of the air pocket. Some manufacturers seal the nitrogen in a plastic bag, while others will put the nitrogen in solution with the oil.

The original theory behind placing the nitrogen inside was that it would put the oil reservoir under pressure and therefore raise the oil's boiling point, reducing the tendency for heat-related fading or foaming as it passed through the valves. That really isn't much of a concern today as the quality of oil has increased in performance dampers. Plus, modern performance shock design has moved away from needle valves and o-ring seals that are affected by heat and viscosity changes, and most street cars and many race cars simply will not generate enough heat to challenge the oil in a proper performance shock.

However, when the nitrogen gas is in solution with the oil, it can give the added effect of damping really minute harmonics and motions that otherwise would not be big enough to make the damper's piston move.

The final design is the mono-tube high-pressure gas shock. The mono-tube's entire body serves as the chamber allowing for a larger piston area, and therefore it has the ability to transfer more damping information over a smaller stroke area. Displacement of oil by the incoming rod is handled by a chamber at the bottom of the unit that contains a high pressure (20+ bar/ 300+ psi) nitrogen charge and is separated from the oil by a floating piston.

Each design style offers certain advantages and disadvantages, so the best choice will depend upon the intended application.

A twin-tube design, when compared to a mono-tube, has a longer stroke capability and greater oil volume in a similarly sized unit. Therefore, the twin-tube will tend to give a smoother or more forgiving ride characteristic and still supply the firmness for proper handling control in vehicles that see average or long suspension stroke length.

The larger piston area of the mono-tube will give more control over much shorter stroke lengths or at the lowest piston speeds, but also tends to ride more harshly for exactly the same reasons. In racing applications where heat generation is more likely to be a factor, a mono-tube can cool itself more quickly because the shock body is the wall of the working cylinder.

You are likely to find mono-tubes on non-production based racers cars, where control over very short strokes is mandatory and ride quality is not an issue, or on production cars where designers tend not to want as much suspension travel. Some racing shock manufacturers use external reservoirs with mono-tubes to help with displacement lengths and oil volume, but in return add extra weight and some delay to the reaction ability.

Gas pressure in the shock can extend the oil's heat tolerances, but can also affect ride height because the greater pressure can act as a slight booster to the spring rate. Cars that run lower spring rates (drag racers are a good example) don't want the boost, so they usually use hydraulic shocks or must be willing to compensate for the gas pressure.

Mono-tubes can also operate while mounted on their side or at any angle, so they are more conducive to racing pushrod suspensions, while twin tubes must operate from upright to no more than 45 degrees from upright (which is still fine for most production-based suspensions).

VALVING DESIGNS

The piston's speed of travel will determine how much damping force will be created, so the shock engineer can use the opening and closing of several valving tools to get different damping characteristics. They can use bleed-through holes in the rod that let oil entirely miss the piston and its valvings. This affects the lowest piston speeds and deals with low rate transitional control.

Next they can use orifices in the piston and valve discs to control mid-range or medium piston speeds. Finally you have bypass-additional piston orifices and valves used at high piston speeds to release or blow off extra pressure that can't get through the other valves. The bypass sets the maximum damping rate and keeps the ride and control from being overly harsh when the suspension hits really big obstacles.

On twin-tube shocks, footvalves are used to control the flow of oil from one cylinder to the other and set up much of the compression damping rate. By working with these tools, control is obtained based upon the functional suspension and damper stroke lengths and the expected piston speeds.

An Indy or Formula 1 car will typically see piston speeds of 0-3 ips (inches per second) and strokes of under one inch. Combine that with very high vehicle speed, and you must have superior valving control and immediate response. A production-based racer (SCCA Improved Touring, IMSA Endurance Challenge, etc.) or autocrosser will work in the 0-8 ips range, based on track and driver smoothness. A street car typically runs at 8-15 ips, with jumps into the 20s for really rough roads. Compare that to up to 60 ips seen by a motocross bike racer. Add these requirements to the number of suspension designs and geometries, and you will quickly see that no one damper design or valving can cover all of the bases. Proper valvings are developed and needed for each situation.

Shock absorbers are tested for design and control by a shock dynamometer. The damper is tested at a single or multiple piston speeds with the damping forces noted. When printed in graph form comparing speed to damping force (measured in Newtons or pounds), certain trends become evident.

Figure 1 shows the basic three types of graphs: progressive, linear and degressive. The progressive graph is typical of what one might find on a low priced, commodity grade shock. The valving does very little up to a certain point, then gets progressively firmer at a rate faster than the increasing speed. This will have minimal low-speed control but lots of damping at really high speeds. It would not be a good selection for a performance car and would probably ride hard on really big bumps.

A linear graph forms a straight line that grows at matching rates for damping and piston speed, so it will serve better as a performance handling shock. It displays much better low piston speed capabilities, but will still feel pretty hard over big bumps.

The degressive graph initially grows at one rate at low speeds, but then the rate of damping slows down and begins leveling off at high speeds. This is going to give very good low- and middle-speed transitional control, but will not be harsh or upsetting at high piston speeds. This is the type of performance graph you are most likely to want.

Figure 2 shows a comparison of shock dynamometer graphs for the rear shocks from a second-generation Honda CRX Si. The red line charts the original-equipment selection by Honda; it reveals an emphasis on sportiness, but generally not awe-inspiring handing. Next (blue line) is the rebound-adjustable Koni street shock, which puts greater emphasis on low and medium piston speed, as well as vehicle transitional control and a ride quality that will be firm but not harsh. The broad adjustment range lets the owner compensate for other modifications, including wheel and tire and suspension upgrades. This is a popular selection for tuned street and autocross cars and offers the option of revalving if the owner wants more development.

The green area is for the Koni rebound-adjustable road racing shock developed for Firehawk/Endurance Challenge, Improved Touring or similar racing. These shocks can also be made independently compression adjustable if the owner so chooses. The most noticeable change is the large addition of bump stiffness and not as much rebound change. The firmer valving is used to help keep the car flat and stable while using much heavier springs. They also help the rear end rotate the car more quickly. Road racing front-wheel-drive cars need the added help with rotation for cornering, so the front wheels can be pointed straighter for putting the power down sooner and better. As you'd expect, these shocks are made for the relative smoothness of race tracks and so ride harshness is not an issue.

APPLICATION

Now that you have attended Shock Tech 101 class, you need to ask the question: "Do I need better shocks?" If your aim is better handling, and your car is not one of the high-performance packages already fitted with adjustable performance shocks (1997 Neon ACR, Mustang Cobra R, Camaro 1LE, etc.), then the answer is likely "yes." You now have several choices: research what is available and make your selection (good idea); or develop you own shocks (if you really want to and think you are smarter than the engineers).

Technically, if you are armed with the correct geometry, spring, other measurements and math equations, you could calculate your suspension and get the "critical damping" (exact damping required for a specific spring) and other neat numbers. The trouble is that this only gets you into the ballpark, because there are so many variables that you can't define.

A critically damped car may technically cover the spring's capabilities, but would be so harsh at most piston speeds that you wouldn't want to ride in it. Manufacturers have teams of engineers who develop products based on lab findings, test tracks and real world seat-of-the-pants feel. A damper is no good if it has "that Cadillac ride" but no low-speed handling control, or if it has slot car response on perfect roads but turns your brain to guacamole at the first bump.

Damper adjustability enables you, the driver, to further tune the engineer's decisions to fit your driving style and pavement situation. Even more importantly, you can tailor your shocks to work with other performance modifications.

The engineers probably made their decisions based on a stock car, but if you have added performance wheels and tires, springs, anti-roll bars or-heaven forbid-more horsepower, then you need to become the engineer. If your class rules limit modifications and you require the car to do something it was not designed to do, you can use shock adjustment to attain the desired effect.

A good example is a stock class autocross car. This situation involves shoveling a car designed to get Grandma to the market through a ultra-twisty track at speeds that would cause Grandma to faint. Getting the understeer or oversteer out of a 1995 Sniveling Wombat to make it a fast-rotating Snarling Wombat can be accomplished with proper adjustable shocks.

Stiffer suspension is not always better. As a matter of fact, once you are in a desired range of performance and everything is working properly, a slightly softer setup can give you more leeway for unexpected situations. Simply clamping the car down as hard as it can go may mask the suspension's true abilities and functions, and the result will be a flat-running, harsh-riding, high-compromise skateboard.

Developing the appropriate settings for your combination can take some experimentation, but will be very rewarding in terms of lap times and fun. Beware of the recommended "ultimate setup." There is no perfect combination for all cars and drivers. That setup will likely get you in the ballpark, but again, your variables will define your own needs.

If Driver B is faster in the same kind of car, don't expect the same adjustments to be the answer. He may have gotten his suggestions from Driver A, who may have known what he was talking about or who may have been covering up some other inadequacy. As racers we tend to want to mimic "the fast guy," but at best this can put us even with him; at worst, it can put us way off base-even if you can trust the info he supplies. You should take what you have learned and find the fast way for you.

TUNING

The goal you are seeking is getting your car to react to the ground, so you must remember that suspension tuning is actually making your tire work harder and more efficiently. Realize that a very soft suspension can give the tire too much motion to do its job, and a very stiff suspension can give too little.

An example of working the tires in a different way is a test we did last year with one of the North American Touring Cars. The track was smooth, and the suspension was plenty firm. In successive tests and adjustments, we slowly raised the rebound until good balance was achieved, but then a hot lap produced a nasty hopping motion.

Although the pavement was smooth, Touring Cars have a tendency to use curbing and berms to their greatest advantage. After firmly popping a berm, the car launched slightly and then hopped on landing. We realized that the hopping motion wasn't from spring bounce (which would mean it needed more rebound), but was actually from the tire's sidewall flexing because the suspension was firm enough that the only compliance to dissipate the energy came from the tire. A softer tweak on the rebound let the suspension and tires do their own jobs, permitting the car to stay on the ground and the driver on the throttle.

The initial setup was good for smooth driving, but when the berm variable was introduced, an adjustment needed to be made. By the way, the driver, Randy Pobst, won the North American Touring Car championship on those shocks.

The rule of thumb says that greater rebound damping loosens that end of the car, so a front-drive car that won't turn in can use some more rear rebound. Couple that with enough front rebound to slow body roll, but not so much as to cause inside wheel lift, and you are on your way.

A tail-happy rear driver could probably use more front rebound (to loosen the front) and less rear rebound (to reduce rotation) in the pursuit of balance.

Your other thumb tells you that if you can isolate handling responses to corner entry and corner exit, then you know which end to work on. In a decelerating corner entry situation, the rear suspension is extending and transferring its load to the front, so adjusting the rear rebound can control the transfer rate. On accelerating at the corner exit, the front is extending as the weight is transferred to the rear (usually more subtle unless you have big power or soft springs), so the front rebound will be adjusted.

Increasing compression damping will also affect how quickly the other end of the car accepts that weight transfer. Too little compression can overwork or literally stun the contact patch, while too much can give too little input and also start acting like added spring rate.

If you are allowed to change springs, do so and let them do their job and share the work. If your rules mandate that you can't change springs, consider more compression, but remember the other compromises involved. Ride quality and skittishness on intended and unintended bumps must be factored in.

Manufacturers can alter the different valving tools in the adjustment procedure to get their desired effect. Some use bleed holes in the rod to make the changes and therefore vary the amount of oil missing the piston valves. The clue for this style is if it adjusts both compression and rebound in one motion. Other manufacturers (usually more racing oriented) will adjust valving independently, either by making only rebound adjustable and using an optimized, preset compression for many situations, or with a double-adjustable unit that allows independent adjustments. This style usually effects changes with rod bleed and orifice and valve stack spring preload pressure, and therefore can make changes over the more possible piston speeds.

The days of the old 50/50 (same rebound damping as compression damping) and 90/10 drag race shocks have gone by. Today a 50/50 shock would have either way too much compression or, more likely, too little rebound. A 90/10 design just isn't paying attention to the evolution of suspension design and aerodynamics.

Today, street performance shocks have rebound damping rates that are two or more times greater than compression damping rates. The single action of adjusting bleed to affect bump and rebound is, by definition, a 50/50-style change, so the overall damping proportion will change as more bleed is dialed in. Independent adjustments allow the alteration of one characteristic while not affecting the other; this is therefore more precision and involves less compromise.

Rebound and sprung weight adjustments will cover 90-plus percent of most autocross and grassroots racers' needs. Making compression adjustments of the unsprung weight has traditionally been the realm of more hard-core race tuners, but as the stakes in the pro and national levels of autocross and club racing go up, so does the need for more tweaking and tuning ability.

As you can see (and probably know from firsthand experience), simply jumping into a car and counting on your heroic driving abilities to carry you to the front is the stuff of daydreams. Proper research and use of your suspension system is a safer spot to place your bets. Some of the most pivotal yet much misunderstood parts of your suspension package are the dampers.

If your goal is a favorite road or competition class, maximizing your dampers' capabilities will take you far and fast. Autocross is a great example-it is vehicle transitional control at the limit. A nationally-recognized autocrosser recently confirmed this by stating that suspension control is everything, and handling gains get you seconds whereas horsepower gains usually just get you to the next corner. Road or oval track racing is not as extreme in transition, but the vehicle speeds are higher and the necessity for control at the limit makes damper understanding critical.

Your car manufacturer probably didn't have you in mind when they chose the original dampers, so it is up to you to select and tune the best performance set for your unique needs.

Figure 1

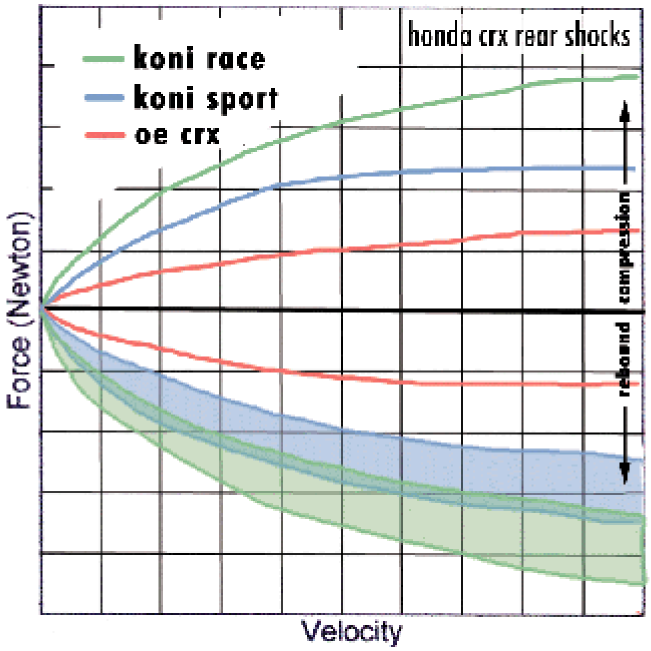
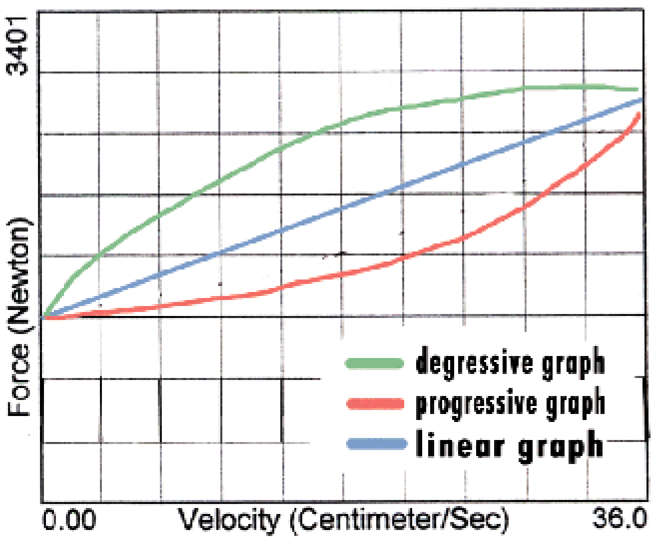


Figure 2



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