

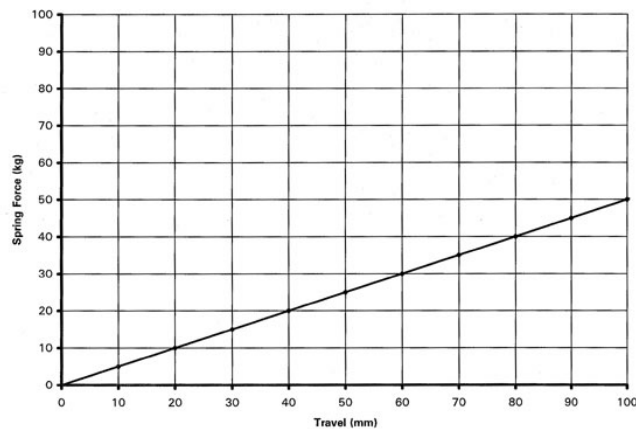
Motorcycle Suspension



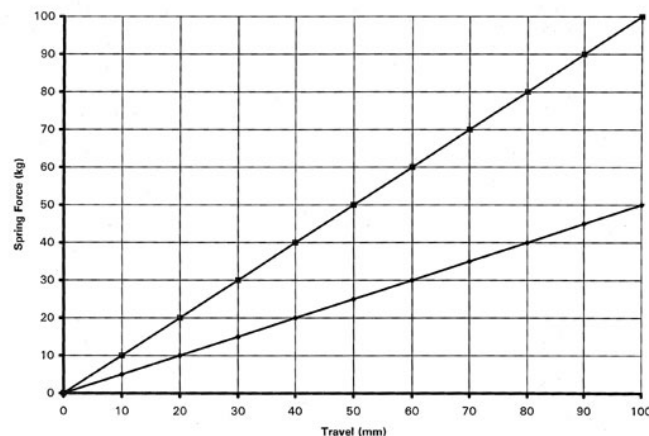
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Springs and Dampers

Answers to commonly asked questions like, "What's the difference between spring rate and preload?" and "Can I make the spring stiffer by adding more preload?" require a little delving into the mechanics of spring forces.

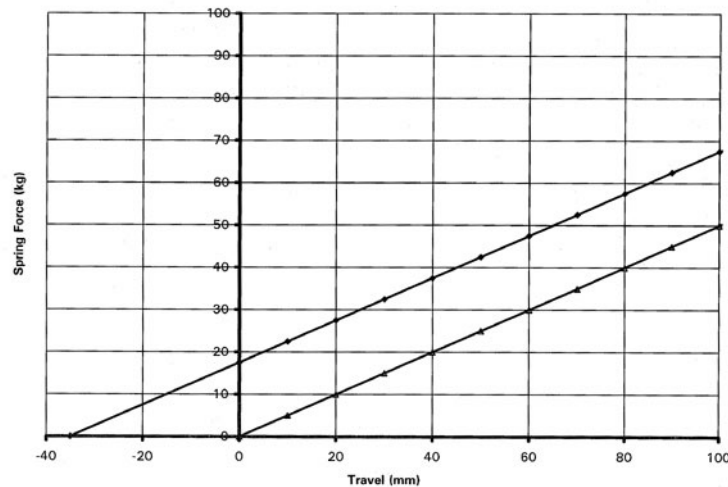


A stiffer spring than the one shown above would also start at zero force, but its compression rate would increase at a steeper angle, as in Figure 2. Notice that at 20mm travel, the softer spring requires only 10kg force, while the stiffer spring requires 20kg. The stiffer spring at 1.0kg/mm is both twice as steep and twice as stiff as the softer spring, which is 0.5kg/mm.



Let's back up a bit and define what spring rate and preload really are. "Spring rate" reflects the stiffness of the spring and is measured in kilograms per millimeter, Newtons per millimeter or pounds per inch. One of the ways to test spring rate is to first measure the spring's "free length" and then put weights onto it, measuring the resulting compression with the addition of each weight. "Straight-rate" or 'Linear' springs maintain a constant rate of compression throughout their travel. If you are testing a linear spring and you plot these points on a graph, you will end up with something that looks like Figure 1.

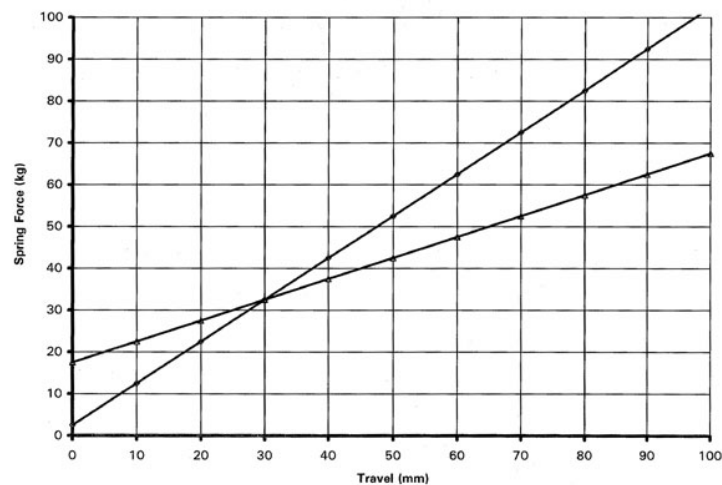
Now let's take the original spring and install it in the fork. As it's installed, it gets compressed, or preloaded, a small amount. "Preload" (or "preload length") is the distance the spring is compressed from its free length as it's installed with the suspension fully extended.



Just a note here on the difference between preload and preload adjusters: All bikes that I am aware of have preload. Some bikes do not have external preload adjusters, but they do have preload. All forks can have preload adjusted internally by changing spring spacer length, though sometimes it takes special spacers. Forks that have external preload adjustment have preload even when set at the minimum adjustment.

The "preload force" is the initial force the spring exerts on the end of the fork tube with the fork fully extended. Referring now to Figure 3 (above), you can see that when preload is added to the spring, it effectively shifts the curve (line) to the left proportional to the amount of the preload force. In this case, the preload length is 35mm and the resultant preload force is 17.5kg at zero travel. In other words, with this 0.5kg/mm spring and a setting at 35mm preload, you would have to put more than 17.5kg force on the end of the fork tube to create any movement at all.

For a straight-rate spring, the relationship between force, spring rate and travel is described by the equation: $F = K \times L$ (or force [F] equals spring rate [K] times length [L]).



When you tighten the adjusting collar on a shock or increase the preload length by tightening the adjuster on the fork, you are indeed increasing the initial force exerted by the springs. This decreases sag, making the bike ride higher. It does not, however, increase the spring rate.

For example, you can achieve a targeted sag on the fork even with a spring that is too light (or soft) if you use a lot of preload. You can also achieve that same sag with a spring that is way too heavy by using very little or no preload. Let's look at just one fork leg on paper. Refer to Figure 4 and notice that the softer spring has 35mm preload and therefore has 17.5kg force at zero travel (fully extended). Let us assume the front end has 30mm of static sag. At 30mm of sag, the total spring force is 32.5kg. This means that each fork spring must push up 32.5kg to create a 30mm sag figure. Any combination of spring rate and preload that gives 32.5kg force at 30mm travel will create the same sag. Notice the stiffer, 1.0kg/mm spring has 2.5mm preload and, at 30mm travel, also creates 32.5kg force. This means they will both have the same sag; however, they will perform totally differently.

The quality of the ride will suffer with a spring that is either too soft or too stiff. The spring with a rate that's too soft will dive and bottom easily because the spring doesn't provide enough additional force as it gets deeper into the travel. The spring that has a very stiff rate will feel harsh, like it's hitting a barrier or very stiff spot.

A few more measurements will show if your spring rates are in the ballpark. Set the sag to standard settings (see 'Smoking Joe') and then measure the "free sag." "Free sag" is the amount the bike settles under its own weight. Use exactly the same procedure as when checking static sag, but without the rider on board. Street and road-race bikes require 0 to 5mm of free sag on the rear, but should not "top out" hard. "Topping out" occurs when the suspension extends to its limit. It should barely have enough force to top out without the rider on board. If it takes a lot of force to compress it at all, you can bet it needs a different spring. On the front, expect to see 5 to 10mm of free sag.

When the static sag is correct and the free sag is less than the minimum recommended (e.g., it tops out hard), you need a heavier spring rate with less preload. A lighter spring is recommended when the free sag is more than the maximum recommended.

Most bikes, but not all, are set up with fork springs that are too soft for aggressive riding. Keep in mind that personal preference, conditions and type of riding come into play when setting up suspension. Racers generally use higher spring rates with less preload than street riders. When in doubt, consult a good suspension tuner or if this is not possible...ask Joe.

Static sag for a particular bike and rider combination is dependent only on spring rate and preload. Springs are position sensitive and only care where they are in their travel, not how fast they're being compressed. Damping settings, on the other hand, are dynamic forces. In other words, damping forces only occur when there's vertical suspension movement. This means they do not affect static sag, as sag is measured when there is no movement.

The addition of air into the fork tubes on models with air valves will have a huge effect on both sag and harshness. We don't recommend the use of air as a tuning variable because harshness generally increases a lot for the relatively small benefit in bottoming resistance. It is almost like adding spring preload. The use of additional air is quite effective on touring bikes for temporarily changing the load-carrying capacity, like when riding with pillion and luggage. Oil level changes will affect the total spring-type force, but only as the fork gets to the bottom of its stroke and, therefore, does not affect sag.

Damping:

Whenever the subject is suspension theory, damping is always a major topic of discussion. The terms high-speed and low-speed damping are commonly used but often misunderstood. To help clarify this somewhat muddy subject, let's look at what low- and high-speed damping actually are.

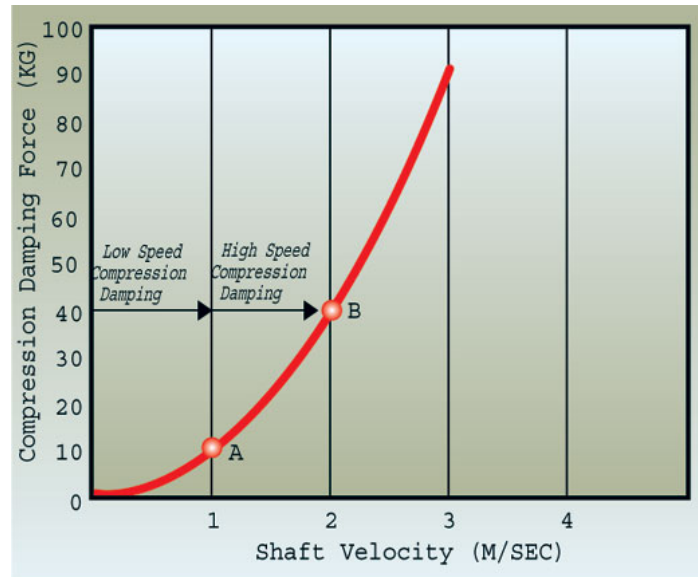


FIGURE 1

Damping is sensitive to velocity, meaning the amount of damping force created is affected by how fast the fork or shock is compressing or extending. Low-speed damping refers to the damping created at lower velocities.

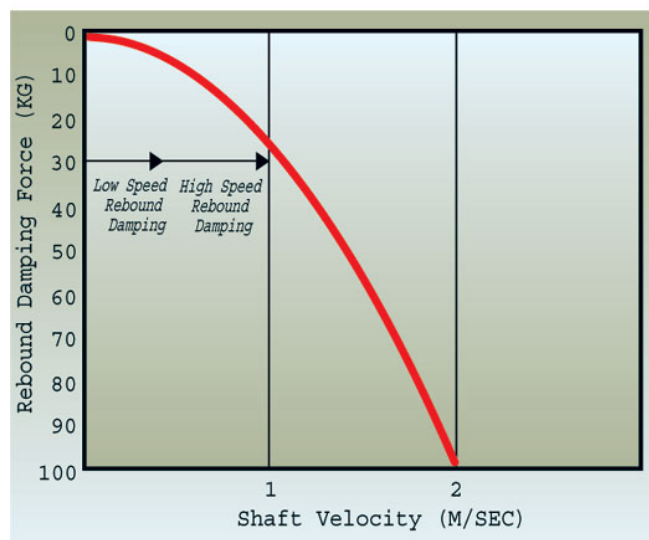


FIGURE 2

It is important to make the distinction that we are talking about shaft velocity, not bike speed. It

makes sense that if you double the bike speed while going over the same bump, you will double the shaft velocity on compression. However, what may not be so obvious is that the shape of the bump is far more important than its size when it comes to the velocity produced. A square-edged bump that is one-inch high is going to produce far greater velocities than a long rounded bump that is also one-inch high.

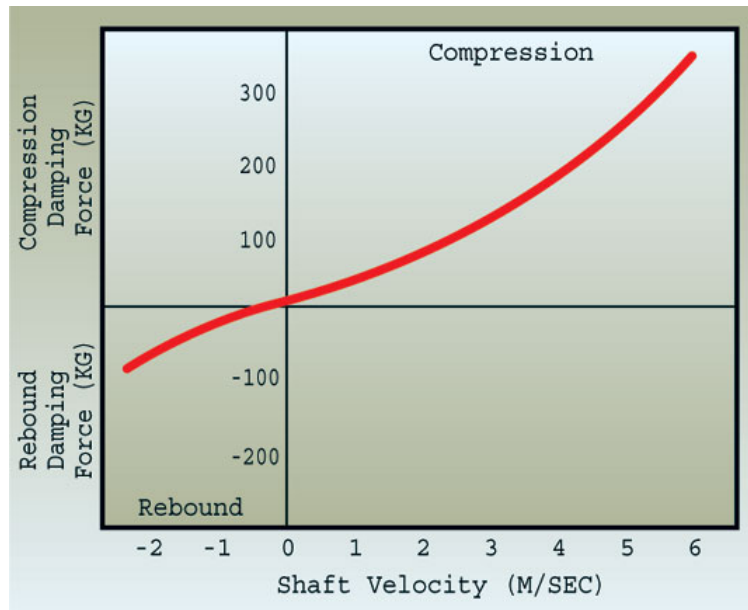


FIGURE 3

Damping is not a linear function. In other words, when you double the velocity, you don't necessarily get twice the damping; you may get as much as four times as much damping. A typical compression damping curve for damping rod-type forks looks something like Figure 1. Notice that each time the velocity is doubled the force increases by a factor of four. Point A at 1 m/s (meters per second) shows a force of 10kg. At Point B, at 2 m/s the force is 40kg.

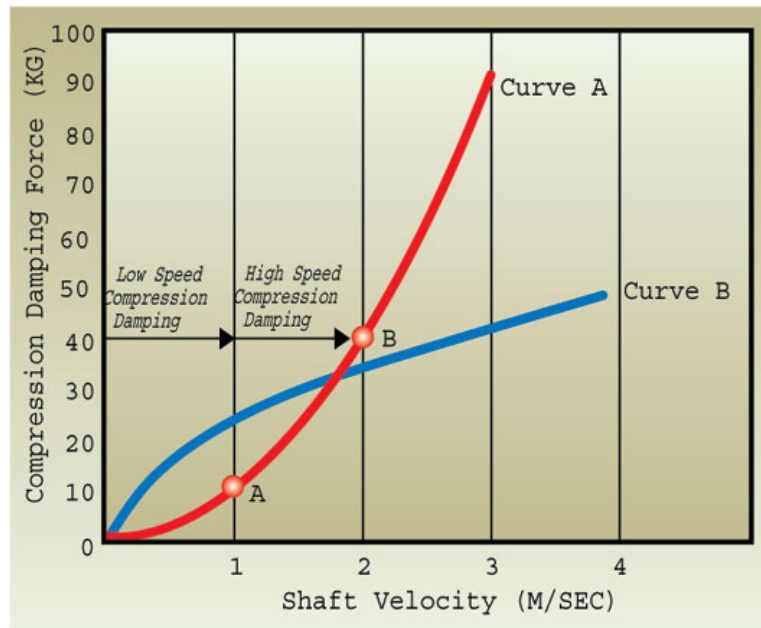


FIGURE 4

So what part of the curve is low-speed and what part is high-speed? Good question! These are not specific terms defining specific velocities, they are relative terms. If the maximum compression velocity of the fork is 6 m/s, we could arbitrarily say that anything less than 1 m/s is low speed and anything above that is high speed. It would also make sense that there is a mid-speed damping and even a low-low-speed damping and high-mid-speed damping, etc. The point is, even though the terms high- and low-speed damping are not specific velocities, they do allow suspension tuners and designers to communicate with the rider when discussing sensations or symptoms. Dyno tests have shown that velocities as low as 0.05 m/s are very important when making changes to a damping curve.

Remember that compression (or bump-damping) occurs when the wheel contacts a bump and compresses, and rebound or tension damping occurs as the spring forces the shock or fork to extend. The fact that the compression velocity is forced by the size and shape of the bump means it sees a very wide range of velocities. Rebound, on the other hand, is largely controlled by the spring force and therefore sees a much smaller range of velocities. Typically, rebound may see one third of the velocity of compression. For this example, where compression sees 6 m/s, rebound may see 2 m/s. This means the transition to high-speed rebound damping might best be thought of, in this example, at around 0.5 m/s (see Figure 2). The rebound graph is inverted because we call compressive forces positive and tensile forces are considered negative.

To get a more complete picture of the entire damping curve, you would simply put the two curves together as in Figure 3. Each time the shock goes through a complete cycle, it passes through zero twice—once at the bottom of the stroke and once at the top of the stroke. When the wheel hits a bump, the shock accelerates to a maximum velocity, slows down and then stops compressing. At this point, the vertical velocity of the shock is zero. It then changes direction, accelerates in the negative direction, slows down and stops again when it's done extending. As you can imagine, every stroke of the shock does not use all the travel and certainly does not reach maximum velocity.

Be aware that high speed at the rear shock on one bike may not be high speed for another. This is because of another factor: leverage ratios. If the velocity at the wheel is the same for two models of motorcycles with different linkages, the shaft velocity can be radically different. A shock linkage with high leverages will have shorter shaft-travel and lower shaft velocities than a bike with low leverages.

If you refer to curve A on Figure 4, you will recognise the compression damping curve of a damping rod-style fork. Curve B is more preferable because it has more low-speed damping for a good, firm controlled feeling, and less high-speed damping for a more comfortable ride on square-edged bumps. You would expect this type of ride out of a well-tuned cartridge fork.

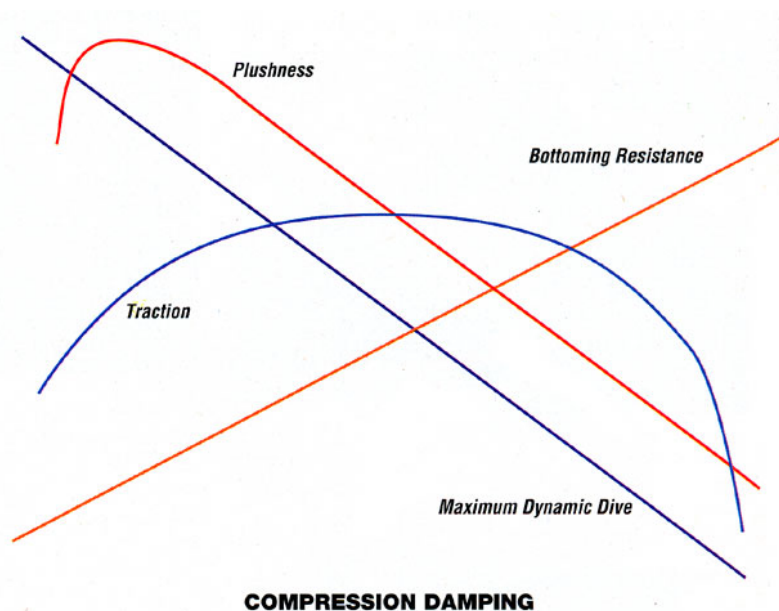
Most current sport bikes have external adjustments for both compression and rebound damping, as well as spring preload. So where are? and what do the damping adjustments do? On forks, the screwdriver-actuated adjustment at the top is typically rebound damping, the one on the bottom near the axle is compression damping. On the shock, the adjuster on the reservoir is for compression and the one on the shaft eyelet is rebound. These adjusters are generally low-speed adjusters with the exception of the shock compression adjustment, which is usually high-speed (and fairly ineffective). Low-speed adjusters typically affect the entire range of damping, meaning they raise or lower the entire curve. They do affect high-speed damping, but they're much more noticeable at low-shaft speed because their percentage change is much greater.

Once you recognise what adjustment you have and its effect, you can begin to fine-tune your suspension. But remember just because you have external adjusters doesn't mean you have much control of the damping curve. In Figure 4, for example, you could never make Curve A look like Curve B with any kind of standard external adjusters. Remember also that with adjusters you can make an improvement in one area and actually make it worse in another with the same setting change. When playing with adjusters, record your initial settings, make one change at a time and record all your results.

Compression Damping:

Remember that damping is viscous friction. It turns mechanical energy into heat and is sensitive only to shaft velocity, not position in the stroke. The fundamental difference between compression and rebound velocity profiles is due to the fact that compression is forced by the shape of the bump, while rebound, though affected by other forces, is pushed mostly by the spring. This means that, for compression damping, the shape of the bump is far more important than its size. A square-edged bump results in extremely high shaft velocities, while even a big dip will typically cause fairly low velocities.

Traditionally, many have considered compression damping a necessary evil. In other words, less was better. This thought process was created because of the style of damping that was prevalent in the past. To study the effect of altering the compression damping, let's look at damping as a whole; i.e., ignore the fact that the shape of the curve is important. The amount of compression damping affects traction, plushness, bottoming resistance and dynamic dive.



Consider bottoming resistance first. It makes sense that the more compression damping, the more resistance to bottoming (refer to the curve). It may seem obvious, but you need enough, yet not too much. The compression damping force is added to the spring forces to resist bottoming. At the same time the bottoming resistance increases, the feeling of plushness decreases. But what the heck is going on with the plushness curve on the left of the graph at minimal damping? With very little damping, the plushness can actually decrease. This occurs only on big hits when there is bottoming. On small hits, less damping still means more plushness.

Let's look at how compression damping affects traction. Imagine you're riding along and you hit a bump. If there is too little compression damping, the wheel will not meet enough resistance as it compresses the fork or shock spring. Not enough energy has been dissipated at the crest of the bump. Because the wheel itself has mass and the mass is moving upward, it wants to remain in motion and continues to move upward, compressing more than the amount required to handle the bump. This means the tire will become unloaded and possibly even lose contact with the

ground as it crests the bump. This unloading produces a loss of traction.

As compression damping is increased, this phenomenon decreases and traction improves. If there is excessive compression damping, there will be too much resistance to movement and the wheel will not move the entire height of the bump. This means the center of gravity of the motorcycle (the sprung mass) will be displaced upward. Not only can this be the cause of an uncomfortable or harsh ride, but this upward velocity of the chassis will tend to unweight the wheel, losing traction. In extreme cases, the wheel will come off the ground entirely and skip over the bumps. This is one of the reasons why in bumpy turns at extreme lean angles you may have experienced difficulty holding an inside line. The bike will tend to drift to the outside of the turn.

With too little compression damping, the wheel continues moving up farther than it should, while with too much compression damping, the entire chassis moves vertically. In either case, you lose traction.

The last curve on the graph is called maximum dynamic dive. This is distinctly different than static sag, which is measured with the bike standing still. Maximum dynamic dive is the amount the suspension compresses when hitting bumps or under braking. For example, under braking the front end will dive. More compression damping allows the chassis to dive less. The maximum amount of travel used is determined by a combination of the spring forces and the compression damping force.

If there is no damping of any kind and the brakes are applied, the front end will dive and begin to oscillate. If you're braking for a long time, the friction will eventually stop the oscillation and you would notice the fork is compressed. Since damping is nonexistent when there is no suspension movement, the amount it ends up being compressed is totally determined by spring forces. Maximum dynamic dive, however, is affected by compression damping as well. More damping means the forks will compress more slowly and not as much. Obviously, less damping will produce the opposite results.

If you're hitting a series of bumps with too much compression damping, the suspension will actually extend as the wheels hit successive bumps. This is the opposite of the condition called "packing," when there is too much rebound damping and the suspension is being sucked down, not having time to return fully before the next bump.

Obviously, there are trade-offs. As bottoming resistance increases, plushness decreases and maximum dynamic dive decreases. At some point between the extremes, traction is maximized. Street bikes will be best suited by being biased with less compression damping than a race bike. Remember, you will pay prices with both too much and too little. One of the biggest misconceptions about compression damping is that the faster you are, the more you need. A better goal would be to determine proper spring rates and use only as much compression damping as you need to control bottoming and dive.

Keep in mind that compression damping is dependent on movement. If there is no movement, there is no damping. Be aware also that the shape of the damping curve is critical, in not only how much damping you have, but how progressive it is as well. But that's another story.

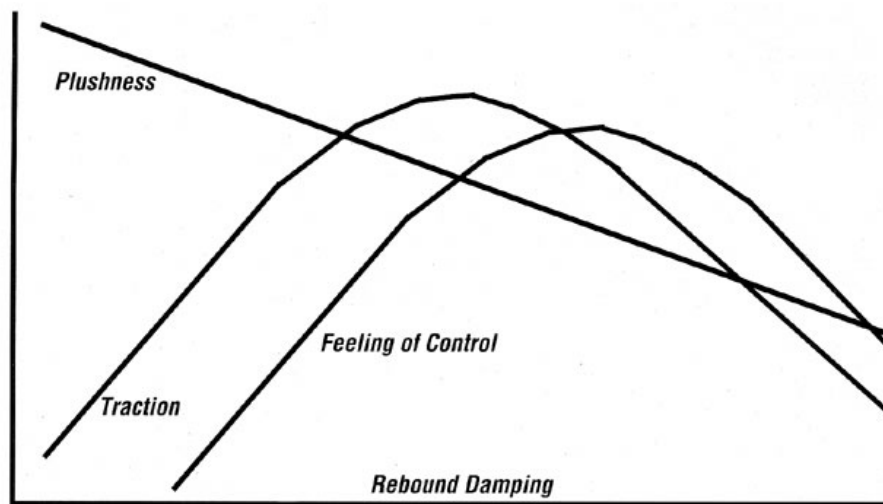
Rebound Damping:

Reviewing briefly, damping is viscous friction. It turns mechanical energy into heat and is sensitive only to shaft velocity, not position in the stroke or vehicle speed. This is fundamentally different than a spring, which stores energy and is only sensitive to position in the stroke.

Damping in modern motorcycle suspension components is created in different ways but always involves a fluid. The configuration can be as simple as shoving oil through a hole as with old style damping rod forks, or can be as sophisticated as a multi-stage bending shim piston configuration in combination with an internally or externally adjustable bleed circuit. Before we get into the more advanced subjects, let's take a look at rebound damping.

Remember that compression (or bump damping) occurs when the wheel contacts a bump and the suspension compresses. Rebound (or tension damping) occurs as the spring forces the shock or forks to extend. Most current sport bikes have external adjustments for both compression and rebound damping as well as spring preload. On most forks, the screw adjustment at the top is rebound damping (not to be confused with the larger spring preload adjuster); the one on the bottom near the axle is compression damping. (An exception would be a Marzocchi or Paioli fork.) On the shock, the adjuster on the reservoir is for compression and the one on the shaft eyelet is rebound. These adjusters have their limits and affect only a portion of the entire damping. In other words, external adjustments can't make up for poor internal valving design; the adjustments merely fine-tune the valving action.

Of course, external adjustment can never make up for extremely worn-out dampers either, so if your bike is wallowing along like a '63 Cadillac Fleetwood Brougham with blown-out shocks, you might want to do some rebuilding or replacement before you spend the rest of your life playing with "clickers."



Let's look more closely at rebound damping. The major trade-offs involve traction, a feeling of control and plushness. If you look at the graph you'll see they're all plotted on the same graph.

There are no numbers on the y axis because these are largely subjective quantities. In other words, we are discussing "feelings." You will notice that traction starts out at a low amount at very light (quick) rebound damping settings, increases to a maximum, then decreases again. Why? At very light rebound settings, the chassis is uncontrolled. When the wheel hits a bump the shock is compressed. Then the wheel extends without any control; in fact, it extends too far. Because the sprung weight of the chassis has mass and is moving upward, it wants to pull the wheel off the ground, thereby losing traction.

If you direct your attention to the right side of the traction versus rebound damping curve, you will note that at high rebound damping, traction has suffered. This is due to the wheel not being able to follow the ground simply because it can't respond quickly enough. The suspension compresses as it hits a bump. Then, it can't follow the ground (return to its original position in the travel) fast enough after the crest of the bump to maintain traction. When this is excessive it is called "packing." Somewhere between these two rebound damping extremes, traction is at maximum.

You may have noted from your own riding experience that when rebound damping is very light, the feeling of control is minimized. The bike "feels loose." As you increase rebound damping, the feeling of control increases. The chassis isn't moving around nearly as much and the bike feels more "planted" and stable. When rebound damping is very slow, meaning there's a lot of damping, traction is so poor that the feeling of control suffers as well. Once again, somewhere between the two extremes the feeling of control is maximized.

The third quantity is plushness. At very light rebound damping, the wheel moves very quickly and the feeling is plush and mushy. As rebound damping is increased, there is more and more resistance to movement, and at maximum damping the wheel is "packing" so much, the chassis is sucked down in its travel and has not recovered for the next bump. This means the following bump has to overcome the added spring force due to this compression and the result is a jolt to the chassis upon impact.

The key thing to note here is that there is a trade-off. As you can see, maximum traction does not necessarily occur at the same damping setting as maximum feeling of control. Herein lies a problem.

Quite often riders have mistaken ideas about how much damping should be used. They think the faster they are (or the faster they want to be), the more damping they need. Nothing could be further from the truth. In fact, after a certain point, traction, control and ride quality (plushness) are all sacrificed. And, even with rebound damping settings in the ballpark, in other words, between the two peaks, there is a trade-off. Of course, there is room for personal preference, but there's not much value in having all three qualities suffer.

Here is one word of caution: The only way you will ever know if you have less traction is if you are at the limit of traction. This is a very delicate thing. If you are not at the limit of traction-i.e., sliding the tire-you can't feel the difference in traction. So street riders will want to focus on the feeling of control and save traction experiments for racetrack days.

The job of suspension engineer and suspension tuner is to make these two peaks-traction and the feeling of control-as close to the same point as possible. This is done by reshaping the damping curve internally and requires an understanding of high- and low- speed damping and valving piston design.

Back to Basics:

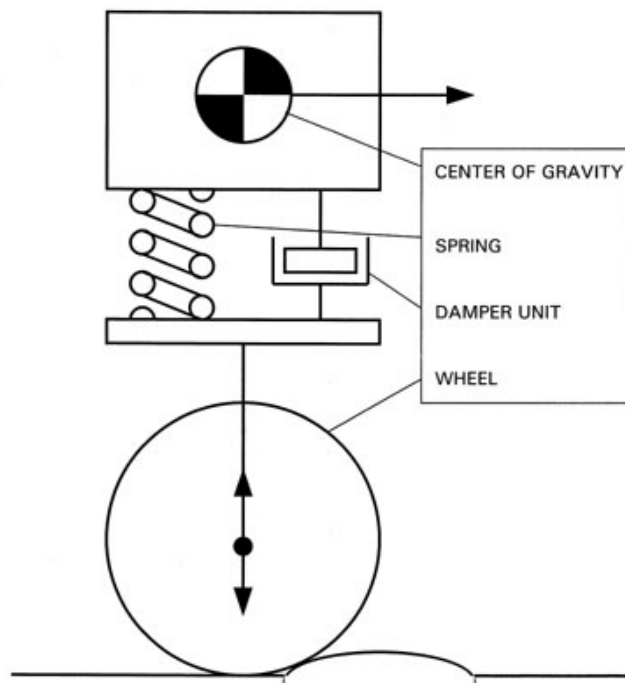
Rocket Science, voodoo, black art...suspension in general, and damping specifically, have been shrouded in mystery for years. Enhanced control, better traction and more compliance translates into lower lap times as well as improved safety and comfort. Many race team managers consider their best investment to be in suspension, both in knowledge and in better hardware. All the horsepower in the world does you no good if you can't apply it to the ground.

FORCES:

The key thing to note about spring forces are that they are dependent on position only. Springs only care where they are in the travel, not how fast the suspension is compressing or rebounding.

Damping is viscous friction. It is caused when liquids are forced through some type of restriction. The key thing to remember about damping is that it is dependent on fluid movement. This means a shock creates no damping force unless there's movement-movement of the damper unit in compression or rebound as opposed to bike movement. Damping cares about vertical wheel velocity, not bike speed.

The third type of force is frictional force. Frictional forces depend on the perpendicular load on the surfaces in question and the materials involved, including lubrication, if available. The higher the load, the greater the friction. More slippery materials, better surface finishes, more sophisticated lubricants and better design can minimize friction.



The other factor when considering friction is whether there is movement between the surfaces. The two conditions are known as "static" and "dynamic" friction: static friction (stiction) when there is no movement between the surfaces, and dynamic friction when there is movement. Stiction can be felt in forks, for example, when you push down on the handlebars. The breakaway resistance, or stiction, is higher than the friction once there's movement. We won't get too in-depth about this aspect except to note that static friction is always higher than dynamic friction. Suffice it to say that, as far as frictional forces are concerned, less is better.

Before go any further, let's define a couple of terms. The compression stroke, sometimes called the bump stroke, occurs when the wheel contacts a bump and the suspension compresses. The rebound or tension stroke occurs when the suspension is extending.

ENERGY

Those are the forces involved, but what about energy? Springs store energy when they're compressed. They release energy when they recoil. Damping, on the other hand, turns mechanical energy into heat. Why is this knowledge of energy important? A number of reasons. First, when a shock gets hot, it's OK. It's designed to. Fade, on the other hand, is not good. Fade is when the shock loses damping. A well-designed shock with good fluid can get hot and still not fade perceptibly. Second, an understanding of energy helps make the subject of suspension simpler.

Let's consider a bump that's two inches high. When the tire contacts the bump, the suspension compresses. As it does, the spring stores some of the energy while the damper creates compression damping and dissipates some of the mechanical energy into heat. The wheel slows

down, stops compressing, changes direction, and starts extending, or rebounding. The spring is releasing energy and the damper is creating rebound damping, once again turning mechanical energy into heat. If everything goes perfectly, the center of gravity of the motorcycle goes along in a straight line with the wheel moving up and down beneath it, maintaining constant traction.

The suspended motorcycle system can be modeled as we have shown in the accompanying figure. The center of gravity is separated from the wheel by the spring and the damper unit. Each of these components has mass. Everything above the spring is considered "sprung" mass and everything below the spring is considered "unsprung" mass. Half the spring is sprung and half is unsprung. The portions of the damper attached to the sprung mass is considered sprung, and the portions attached to the unsprung mass are unsprung.

If there is too much compression damping or the spring is too stiff, there will be too much resistance to movement and the wheel will not move the entire two inches. This means the center of gravity of the motorcycle (the sprung mass) will be displaced upward, giving an uncomfortable or harsh ride and, due to the upward velocity of the chassis, possibly pulling the wheel off the ground, losing traction.

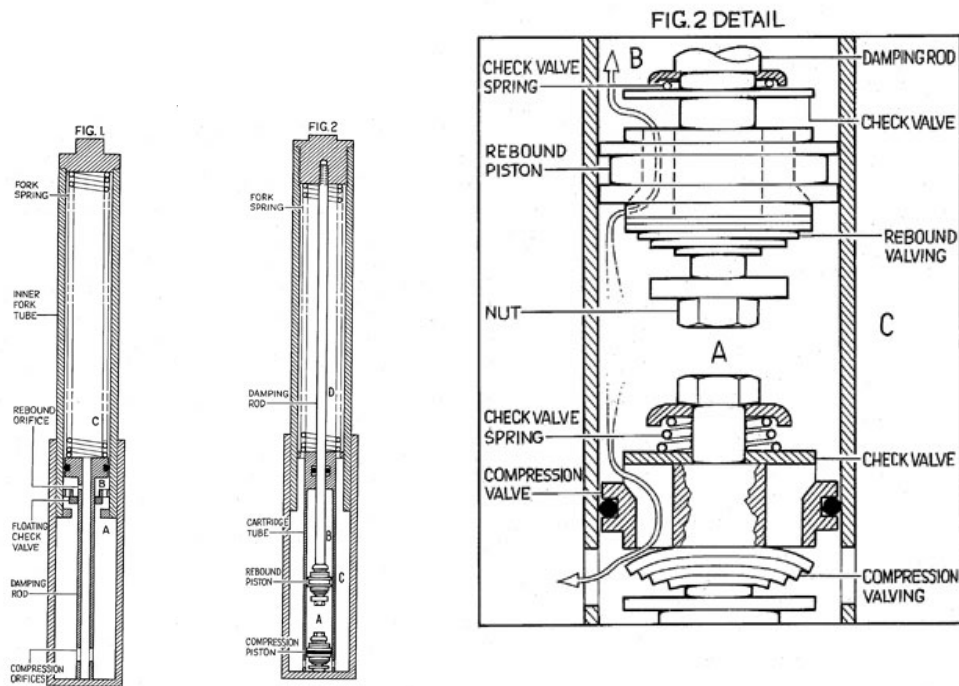
If there is too little compression damping or the spring is too soft, the wheel will not have enough resistance as it's being compressed. Not enough energy has been stored or dissipated at the crest of the bump. Because the wheel itself has mass and that mass is moving upward, it wants to remain in motion, continuing to move upward, compressing more than the two inches required to handle the bump. This means the wheel will lose contact with the ground as it crests the bump, and lose traction in this situation as well.

If the compression damping and spring are perfect and the suspension gets compressed, the spring still stores energy. If there were no rebound or too little rebound damping (the suspension extends too fast), the spring would recoil and release this stored energy unchecked. This would cause the center of gravity of the motorcycle to move upward quickly. As a result, this movement of the chassis would cause the tires to unweight and lose traction.

If the rebound damping is too high (comes back too slow), the wheel crests the bump and can't follow the back side of the bump, once again at the cost of traction. This is compounded when there is a series of bumps as opposed to just one bump. This condition is called "packing." As the suspension is rebounding, it is extending too slowly after it crests the first bump. By the time the wheel hits the second bump, it is still partially compressed. As it hits the second bump, it has to overcome the additional energy stored in the spring. This makes the ride harsh and, in extreme situations, excessive rebound damping can suck down the center of gravity of the motorcycle, adversely affecting chassis geometry.

One thing you might have noted is that excessive rebound damping can give a sensation similar to excessive spring rate or excessive compression damping. This could get interesting. In fact, we've just barely started to cover the subject. It's important to have a well-defined testing procedure as well as a more thorough understanding of damping and its practical effect on handling and ride. Until then, one step at a time.

Cartridge Forks:



I am often asked the question, "Why cartridge forks? What's so great about them?" Riders know they're better but don't know why. Let's clear the air.

Let's say you're bopping down the road, you charge into a corner and hit the brakes, the front dives radically and the bike feels like a wallowing pig. Then later on you hit a square-edge bump and it feels like your wrists are going to break. Wait a minute. First the bike was too soft, then too harsh. What gives?

Well, perhaps the problem is your basic fork design. Internally, there are two types of forks, damping-rod and cartridge. If you have an old-style damping-rod fork, you're fighting an uphill battle (there are excellent solutions for that design but we won't get into that now).

A damping-rod fork is fairly simple: all that happens is oil is shoved through fixed orifices. This type of damping is called "velocity-squared" damping. The faster the wheel moves vertically, the more oil is shoved through the holes.

This is an important point. The speed of the bike is not nearly as critical as the shape of the bump. If you have a 2-inch high bump that's square-edged, the wheel has to move vertically very quickly, even at low speeds. On the other hand, if the 2-inch bump has a ramp that's 2 feet long, you can imagine that the vertical wheel velocity is much less. Now, of course, the bike speed does matter: if you double the bike speed over a particular bump, you will double the vertical wheel velocity.

If the vertical velocity is doubled, the oil-flow rate through the damping holes is doubled. The interesting thing about fluid flow through fixed orifices is that the damping resistance is not doubled but instead increases with the square of the velocity; in other words, it increases by four

times. This situation is sometimes referred to as hydraulic lock. At some point the damping force increases so rapidly that the entire bike deflects instead of the suspension absorbing the bump.

The problem is that "fixed-orifice" damping-rod forks are too progressive. Fixed-orifice forks have very little "low-speed" damping and a lot of "high-speed" damping (vertical wheel speed). With very little low-speed damping, the fork dives excessively, and with a lot of high-speed damping you'll get a harsh spike: the worst of both worlds.

Another limitation is revealed during revalving. Typically, revalving a damper-rod fork involves enlarging or reducing the holes, or installing thinner- or thicker-viscosity suspension fluids (there are other solutions). This decreases or increases the damping through the entire speed range, so the bike is better at handling the spike but will be even worse under hard braking, or vice versa. These changes will get you in the ballpark but almost always have compromises.

One solution is a cartridge fork. Mechanically, most cartridge forks use bending-shim-type construction instead of fixed orifices. This means there's a damping piston with a series of shims (they look like thin washers). The shims are stacked up against the face of the piston. When the oil flows through the piston, it forces the shims to deflect away from the piston face. This creates damping at very low velocities. At very high wheel velocities, the shims deflect more and don't create as much high-speed damping as fixed-orifice-type designs, meaning that the spike on square-edge bumps is reduced. With a cartridge fork, the damping is less progressive than with damping rods.

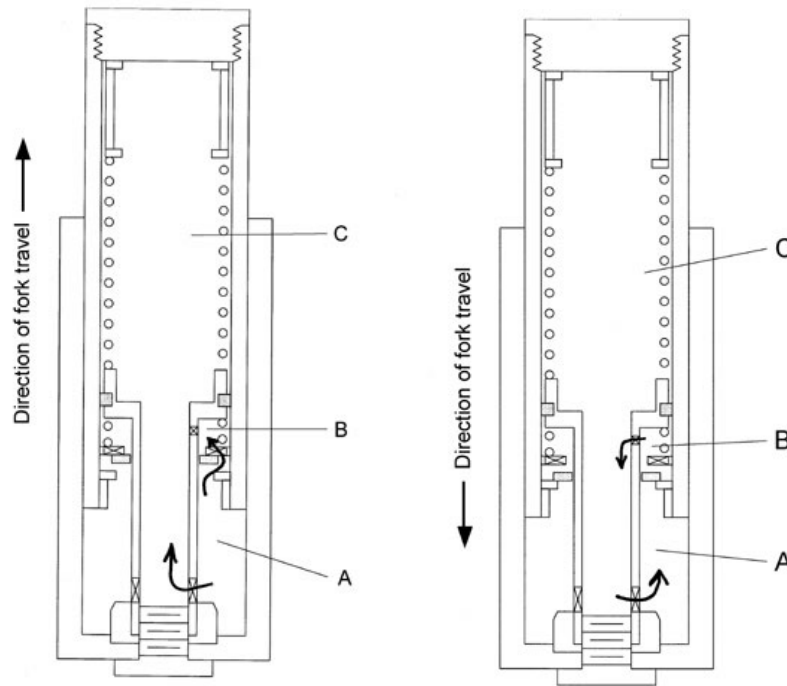
An added advantage of a cartridge fork is that the damping curve can be modified, or revalved, in a much more precise manner. For example, if you need less high-speed compression damping but the low-speed is perfect, the high-speed can be modified without affecting the low-speed compression because each circuit is affected by different shims when properly set up.

So, if your bike already has a cartridge fork, great. Inherently, the cartridge fork is headed in the right direction; it has more tunability and can be dialed in to your riding requirements and ability.

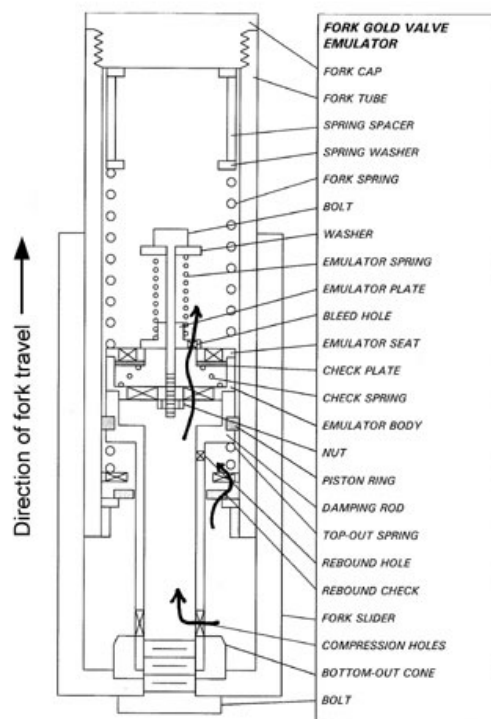
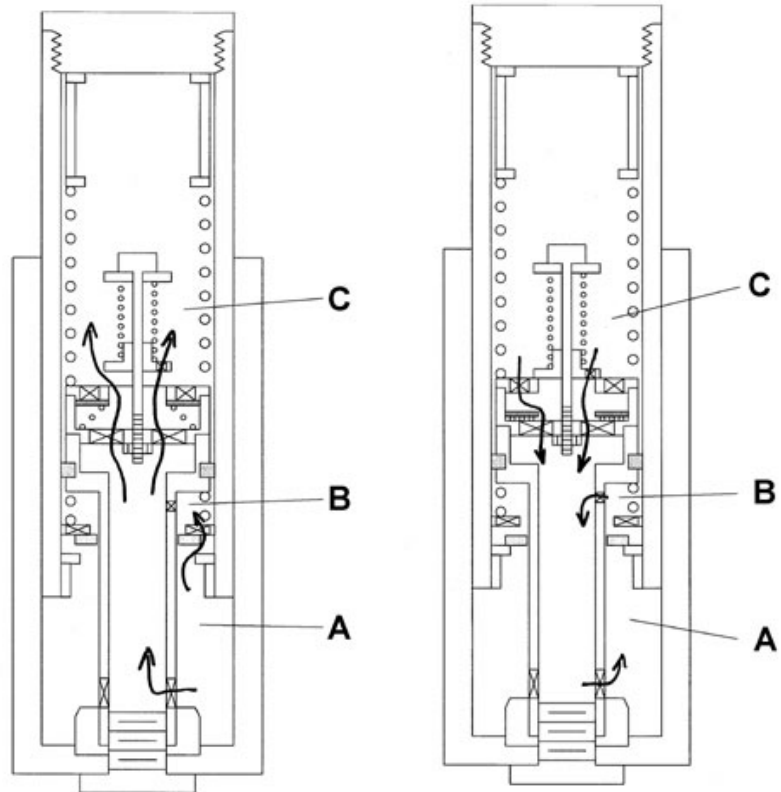
Does this mean any cartridge fork is better than any damping-rod fork? No, that depends on the valving and setup, including spring rate and oil level. Being a savvy suspension tuner requires a knowledge of advanced engineering theory, the experience of extensive testing and art. Something to remember is, the best you've ridden is the best you know. Is there any hope for the damping-rod fork? Yes, but it takes more than a little creativity, and . . . well, that's another story.

Damping Rod Type Forks:

Let's begin by talking about the "ideal" ride. Most riders prefer a ride that is firm yet not harsh, plush yet not mushy, with good resistance to bottoming. How can suspension be all those things? One answer is bending shim-style valving in the form of the cartridge fork. But what if you currently own a damping rod fork? For this application Race Tech's Gold Valve Cartridge Emulator is another solution.



Let's first look at how standard damping rod forks work by looking at the fluid path through the fork. On the compression stroke (figure 1), chamber A is getting smaller as the inner fork tube displaces fluid. This fluid is virtually incompressible and has to go somewhere. The bulk goes through the compression orifices at the bottom of the fork then heads up through the center of the damping rod and shoots out like a geyser into chamber C. All the compression damping is created by shoving oil through these fixed orifices. This is the damping rod's Achilles' heel. The type of damping this creates is called "velocity squared" damping and is extremely progressive-in fact, too progressive (see "Technicalities," SR, Aug. '94). A small portion of the fluid goes past the open floating check valve into chamber B, as chamber B is getting larger.



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On the rebound stroke (figure 2), chamber B is getting smaller and the floating check valve is closed. The fluid escapes from this chamber two ways: through the rebound hole in the damping rod and through controlled leakage between the damping rod and the check valve itself. The restriction in flow out of chamber B creates rebound damping.

During the rebound stroke, chamber A is getting larger. This creates a negative pressure differential (the pressure is greater in chamber C than in chamber A) and causes fluid to flow down the center of the damping rod, through the compression holes refilling chamber A. A problem that emerges during the rebound stroke is cavitation. If the compression holes are too small, the fork has a hard time refilling the chamber fast enough and an air pocket or vacuum is created. The smaller the holes or the thicker the oil, the bigger the problem.

Emulators work in an entirely different way. On compression, chamber A is getting smaller and fluid is going through the compression orifices and up the center of the damping rod. Emulators take advantage of this fluid path. They're tunable valves that sit on top of the damping rods and are held in place by the fork spring. By enlarging the compression holes in the damping rod, their effect is virtually eliminated from the damping picture. This transfers the job of creating damping to the Emulator itself and allows much greater tunability and a radically improved damping curve.

During low-speed damping (low suspension movement speed, not necessarily low bike speed), the fluid goes up the center of the damping rod and runs into the Emulator (figure 3). Until enough pressure builds to lift the spring-loaded check plate off its seat, the fluid goes through the bleed hole. This is a relatively small hole that creates damping at low velocities.

When suspension velocities increase (figure 4), enough pressure builds behind the plate to overcome the Emulator spring preload and the plate lifts off the seat. The stiffness and preload on this spring determine high-speed compression damping.

On the rebound stroke, damping is created in the same way as without the Emulator (figure 5). The Emulator's benefit on rebound occurs because the compression orifices have been radically enlarged and the Emulator is designed to be very "free flowing." The pressure differential between chamber C and chamber A causes the Emulator check plate to open easily and refill chamber A. This means the problem of cavitation is drastically reduced or entirely eliminated.

There are four tuning variables for damping: oil viscosity, which is selected to properly control rebound damping; the preload on the Emulator spring, which controls low- and mid-speed damping; the Emulator's spring stiffness itself, which controls high-speed damping; and the bleed-hole size, which affects low-speed damping. This gives the tuner tremendous control of the damping curve and the Emulator is simple to install and adjust.

Terminology:

Axle Offset-the distance between the centerline of the fork tube and the center of the front axle on offset axle forks (mostly used on dirt bikes).

Base Plate-a thick washer or plate that the valving shims sit on.

Base Valve-the compression-valve assembly on cartridge forks or older-style "twin-tube" shocks.

Bladder-a flexible membrane separating the suspension fluid from the nitrogen in a shock absorber. Allows the shock to be pressurized to eliminate cavitation.

Bleed-a free flow orifice that allows fluid to pass easily at low flow-rates. It is usually the lowest-speed circuit.

Bottoming Cone-a hydraulic device designed to give additional damping resistance when the fork or shock reaches bottoming.

Cartridge Fork-a more sophisticated type of fork that utilizes pistons with bending shims to create compression and rebound damping. The basic design allows the manufacturer to produce a less progressive damping curve than a damping rod fork. Note: Some cartridge forks create very similar curves to a damping-rod fork.

Check Valve-a one-way valve that easily opens in one direction and shuts off completely in the other direction.

Clickers-external adjusters usually controlling low-speed rebound damping or low-speed compression damping on forks. On shocks, the clickers usually control low-speed rebound and high-speed compression damping. Many bikes have no clickers. Note: Some clickers don't click. Unless otherwise marked, most adjusters create maximum damping when they are screwed all the way "in" (clockwise).

Damping Circuits-a path of resistance for suspension fluid. There may be five or more compression circuits and three or more rebound circuits in a shock or cartridge fork. The effect of each circuit generally overlaps creating massive flexibility and sometimes complexity as well.

Damping Piston-the valve on which the shims are stacked. It is sealed on its outer diameter with a piston ring usually made of a Teflon composite if the piston is sliding in a chamber (as with a shock or the rebound piston on a cartridge fork). On a compression piston on a cartridge fork, it is stationary and therefore is sealed with an O-ring.

Damping Rod Fork-a simple type of fork that utilizes a tube with holes in it to create compression and rebound damping. The basic nature of creating damping by shoving fluid through holes produces a damping curve that is extremely progressive.

Fork Bushing-a low-friction, load-bearing sleeve. It is a steel band with a coating of bronze and a layer of Teflon on it. Most forks require two per leg. Nitrogen-an inert gas used to pressurize shock absorbers to eliminate cavitation. Argon or any inert gas could also be used. Piston Ring-a sealing ring on a shock piston or a cartridge-fork rebound piston. Usually made of a Teflon composite. It seals with pressure behind it, similar to the piston ring in a motor.

Piston Rod (damping rod or rebound rod)-the rod in a cartridge fork attaches to the fork cap and usually carries the rebound piston as well.

Preload Adjuster-a method of adjusting the preload externally. These can be ramped or threaded.

Preload Spacer-material used to adjust preload internally. Thin-wall steel or aluminum tubing is commonly used. Many aftermarket spring companies use PVC as spacer material which works fine if the ends are finished flat and square, and a flat washer is used on both ends of the spacer.

Reservoir-a canister or portion of a shock absorber with a compressible chamber usually filled with high- pressure nitrogen. This allows for displacement of the fluid by the shock shaft since oil is incompressible.

Shim (clamping shim)-The "last shim" in a valving stack, farthest away from the piston and closest to the base plate. All the other shims must bend on the clamping shim.

Shim (valving shim)-usually a thin, spring-steel washer used in a damper to create damping. When used in combination with other shims, it is referred to as "valving." It is located on a damping piston or base valve. Shock Absorber-a hydro-mechanical device that uses a fluid to create resistance. Key point: The damping force is sensitive to velocity. The mechanical energy is turned into heat.

Shock Body-the outer cylinder of the damping unit. Usually made of aluminum or steel.

Shock Bumper-a mechanical cushion made out of rubber or urethane, designed to give additional spring-type resistance when the fork or shock bottoms out.

Shock Linkage-a series of mechanical levers designed to change the leverage the wheel has on the shock as the swingarm pivots through its range of travel.

Shock Shaft-the hard, chrome-plated rod in a shock. The valving is attached to the internal end and the eyelet is attached to the external end.

Spring-a mechanical device, usually in the form of a coil, but sometimes as a leaf, torsion bar, or air. Springs have remarkable memory and therefore are position sensitive. As a result, springs store energy.

Suspension Fluid-used inside a shock absorber for two purposes: 1) To create damping when forced through orifices or valving; 2) to lubricate. The fluid must be incompressible.

Top-Out Bumper-a rubber or urethane bumper commonly used in shocks to cushion the shock when it reaches full extension.

Top-Out Spring-a coil spring commonly used in forks to cushion the fork when it reaches full extension.

Triple Clamp Offset-the distance between the centerline of the steering stem and the fork tube. The more the offset the less the trail for a given fork geometry. Usually measured in millimeters.

Valving-the mechanical hardware that creates damping. It is a combination of holes, ports, shims, springs, check valves, etc.