

Suspension 101

By Lee Parks and Paul Thede

Illustrations by Alan Lapp

In our Total Control Advanced Riding Clinics that are taught around the country we spend an entire hour dedicated to suspension setup. The reason is that our riding techniques are designed to upset the suspension as little as possible. Because of this, it is equally important to understand how your suspension works from the inside out so you know what external changes are actually doing to the bike so we can set it up for maximum traction.

Why Suspension?

Why do we need suspension in the first place? After all, go-carts go pretty fast with no suspension at all other than tire and chassis flex. Well, go-carts travel over fairly smooth surfaces while motorcycles encounter bumps. This is where the problem lies and this is where suspension makes a difference. Its purpose is threefold: to minimize harshness, maximize traction and maximize control. The ideal setup is determined by a number of factors, including the type of riding (racing or street, for example) and personal preference (some like it stiffer, some like it plusher).

Let's first discuss the "perfect ride." It's firm, with good resistance to bottoming and great "feel" for the road, yet it is plush and comfortable at the same time. Every type of rider can relate to this ideal-firmness for that feeling of control, and plushness because no one likes getting beat up. The terms "firmness" and "plushness" seem contradictory. But are they? Is this type of ride stiff or is it soft? Well, the answer is both—firm to eliminate excessive dive and control bottoming, and plush on the square edge bumps. OK, sounds good, but the real question is, "How can this perfect ride be achieved?" One step at a time. Let's first review some practical physics.

Forces

A closer look at the forces involved in suspension action reveals three distinct types of force: spring forces, damping forces and frictional forces. There are also forces created by acceleration of the masses (component weight) involved, but we will ignore them for the purpose of this discussion.

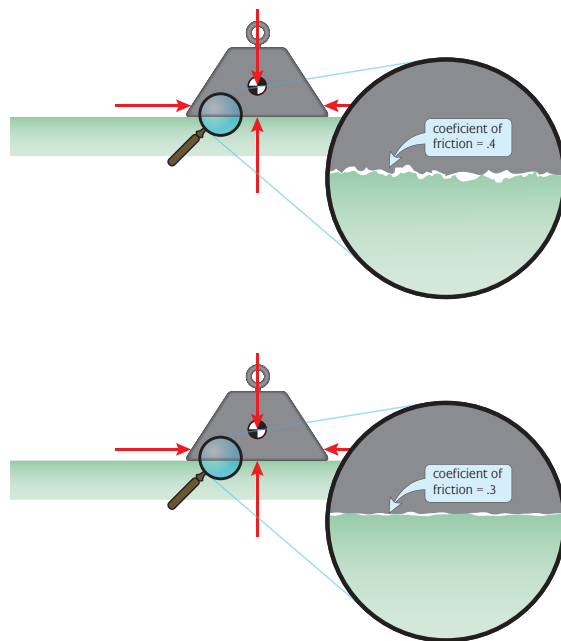
The key point to remember about spring forces is that they are dependent on position only. Springs forces are only affected by what position, or where you are in the travel of the suspension, not by how fast the suspension is compressing or rebounding.

Damping force is caused when liquids are forced through some type of restriction. The key point to remember about damping is that the amount of damping force is dependent on fluid movement, specifically the velocity of the damper. This also means a shock creates no damping force unless there is movement of the damper unit during compression or rebound. Damping is not affected by bike movement or bike speed—only by vertical wheel velocity.

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 any. The higher the load, the greater the friction.

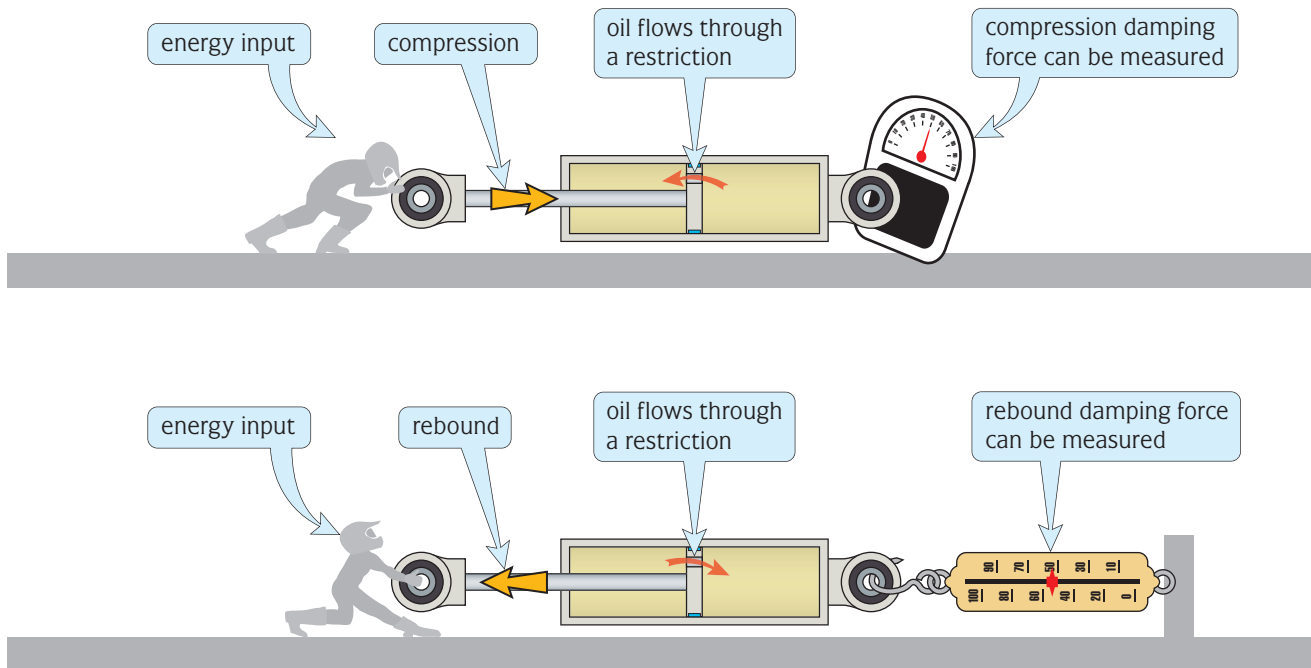
The other factor concerning friction is whether there is movement between the surfaces. These two conditions are known as "static friction" (or "stiction") and "dynamic friction." Stiction is created when there is no movement between the surfaces, and dynamic friction is created when there is movement. Stiction can be readily seen in front forks when you push down on the handlebars. The breakaway resistance, or stiction, is higher than the friction once there is movement. We won't go into too much depth about this aspect except to note that stiction is always higher than dynamic friction.

In some cases frictional forces can be the major problem regarding suspension, larger than the damping and spring forces combined. Low friction materials, better surface finishes, more sophisticated lubricants, and better designs can minimize friction. Suffice it to say that as far as frictional forces are concerned, less is always better.

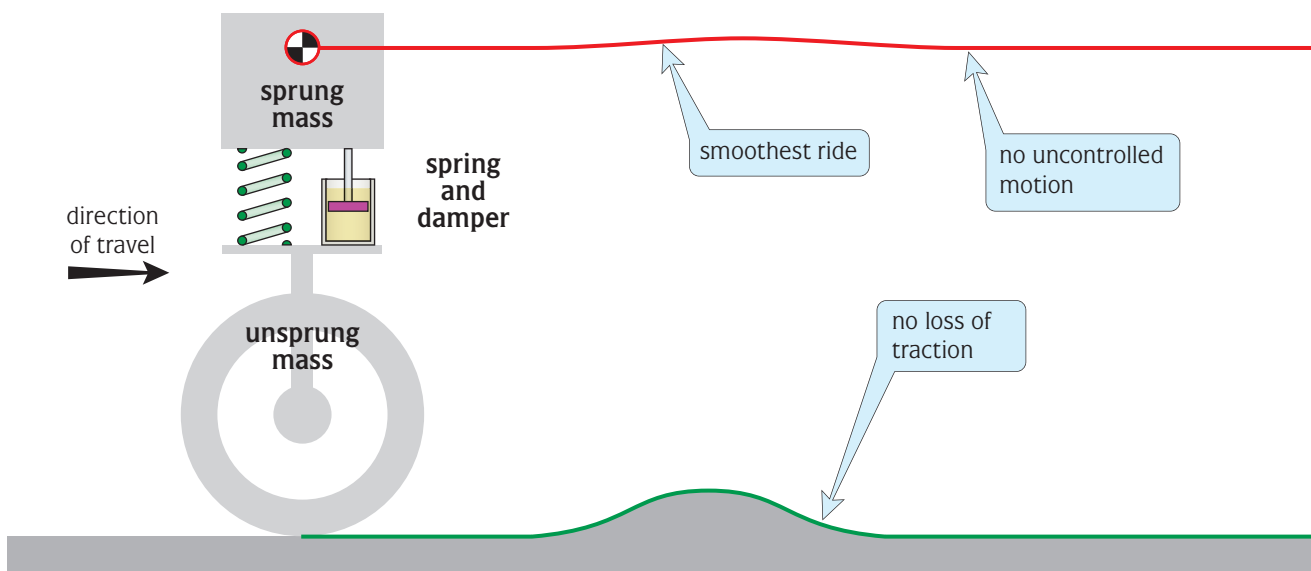


Energy

Forces are important, but it's essential to understand the larger picture—energy. Springs store energy when they're compressed. They release energy when they recoil. Damping, on the other hand, turns mechanical energy into heat and then transfers it to the air. Friction also turns mechanical energy into heat, but its characteristics are quite different from damping forces. Why is this knowledge of energy important? A number of reasons. First, a shock gets hot as it works and that's OK, it's supposed to. However, shock fade, when the shock loses its damping capability, is undesirable. A well-designed shock absorber with high quality fluid can get hot and still not fade perceptibly.



An understanding of energy helps to greatly simplify the subject of suspension. When a tire contacts a bump, the suspension compresses. As it does, the spring stores some of the energy, while the damper turns some of the energy into heat. The wheel slows down, stops compressing, changes direction, and starts extending or rebounding. The spring releases energy and the damper creates rebound damping, once again turning mechanical energy into heat. If everything goes perfectly, the center of gravity of the motorcycle follows a straight line, with the wheel moving up and down beneath it. Perfect contact is maintained with the road surface. That's how it's supposed to work, but it's easier said than done.



Adjusting Static Spring Sag

The right suspension setup is one of the keys to riding fast and safely. No matter what shock or fork you have, they all require proper adjustment to work to their maximum potential. Suspension tuning isn't rocket science. If you follow step-by-step procedures you can make remarkable improvements in your bike's handling characteristics. The first step is to set the sag and determine if you have the correct rate springs. Static sag is the amount the suspension compresses between fully topped-out and fully loaded, with the rider on board in the riding position. It is also referred to as "static ride height" or "race sag." If you've ever measured sag before, you may have noticed that if you check it three or four times, you can get three or four different numbers without changing anything. The reason this happens is due to friction in the forks, shock(s) or linkage. Paul Thede recognized this as a problem back in the '80s and has developed a method that takes friction into account. We'll start by setting the sag for the rear suspension.

Rear Suspension

Step 1 - Extend the suspension completely by getting the rear wheel off the ground. Sometimes it helps to have a few friends around to accomplish this task. Bikes with side stands can usually be rocked up on the stand to unload the suspension. Make sure that you're careful when doing this. Most roadrace stands will not work because the suspension will still be loaded by resting on the swingarm rather than the wheel. Using a measuring tape, measure the distance from the axle vertically to some point on the chassis (metric measurements are easiest to use). When measuring try to hold the tape measure as close to vertical as possible as this will produce the most accurate measurement. This measurement is called "L1". Record the L1 measurement as this number will be used as a reference point later in the process (see figure 1).

Step 2 - Remove the bike from the stand and put the rider on board in riding position. Have a third person balance the bike from the front. To be most accurate one must take into account the friction of the suspension linkage. This is where our procedure is different from the standard method of measurement. Two additional measurements are required to calculate friction.

Push down on the rear end about 25mm (1") and let it extend very slowly (remember the rider should be aboard). Where the suspension stops, measure the distance between the axle and the mark on the chassis that you used previously. It's important that you do not bounce the rear end during these measurements as this will cause an inaccurate reading. This measurement is called "L2".

Step 3 - Have your assistant lift up on the rear of the bike about 25mm (1 inch) and let it down very slowly. Record a measurement where the suspension stops. This measurement is called "L3".

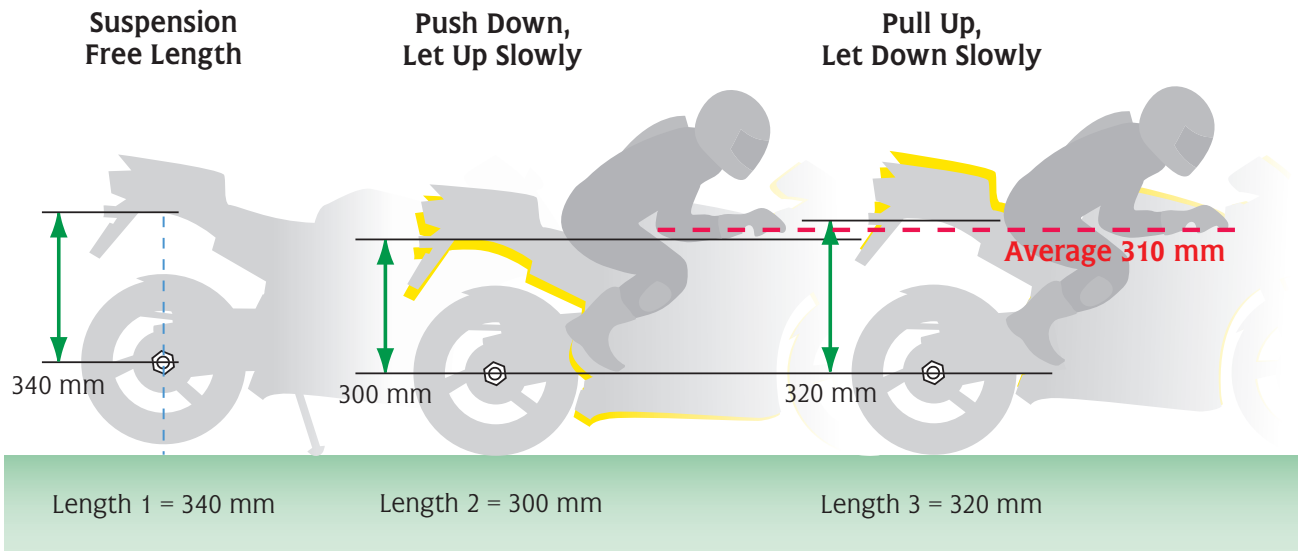
Step 4 - The true sag is in the middle of the two measurements, L2 and L3. In fact, if there were no drag in the linkage or on the shock shaft, L2 and L3 would be the same. To get the actual sag number, find the midpoint by averaging the two numbers and subtracting them from the fully extended measurement of L1.

Static Spring Sag = $L1 - [(L2+L3)/2]$.

Step 5 - Adjust the spring preload using whatever method applies to your bike. Spring collars are common, and some of these need special tools to be adjusted. In a pinch, you can use a blunt chisel to unlock the locking collar and turn the main adjusting collar. For most road race bikes, rear sag is should be 28%–30% of the total wheel travel or typically 25–30mm. Street riders usually use 30%–33% of the total wheel travel or 30–35mm. Remember, bikes with longer suspension travel such as Buell Ulysses will be a higher number. If you have too much sag, you need more preload; if you have too little sag, you need less preload. Bikes set up for the track are a compromise when riding on the street. The firmer settings commonly used on the track are generally not recommended, or desirable, for street use.

If you adjust the preload to its stiffest setting and you still have too much sag, you need stiffer springs. If you adjust the preload to its minimum setting and you can't get enough sag, you need lighter springs.

Example of Setting Sag



$$L1 - \left(\frac{L2 + L3}{2} \right) = \text{Sag} \qquad 340 - \left(\frac{300 + 320}{2} \right) = 30$$

Front Suspension

Front-end sag is measured in a similar manner to the rear suspension. However, it is much more critical to take seal drag into account on the front forks because it is more pronounced and has a greater effect on your measurements. Use the same three measurements as on the rear but in this case use one measuring point on the lower fork leg and one point on the upper fork leg. For inverted forks it's easy to use the exposed shiny portion of the lower fork leg for your measurements. On traditional forks, you can use the top of the fork wiper to the lower triple clamp as your measuring area.

This method of checking sag that takes friction into account also allows you to check the drag of the linkage and seals. It follows that the greater the difference between the measurements L2 and L3 (pushing down and pulling up), the worse the friction. A good linkage (low friction) for rear suspension should have less than 3mm (0.12") of difference, and a bad one has more than 10mm (0.39"). Forks in good condition have less than 15mm difference, and forks with more than 40mm difference need to be carefully inspected and rebuilt. (Gee, I wonder why the ride is so harsh?)

Using different sag settings on the front and rear will have a huge effect on handling characteristics. More sag on the front or less sag on the rear will make the bike turn more quickly. Less sag on the front or more sag on the rear will make the bike turn more slowly. Increasing sag will also decrease bottoming resistance, though spring rate has a bigger effect than sag in bottoming suspension. Racers often use less sag to keep the bike higher off the ground for more ground clearance and because road racers work with much heavier braking and steering forces than we see on the street, they use a little stiffer setup. Be careful not to go below 25% of the total travel for sag as uncontrollable wheelies and stoppies may result from hard acceleration and hard braking, respectively.

It's important to stress that there is no magic, correct number. You may like the feel of the bike with less or more sag than described in these guidelines. Your personal sag and front-to-rear sag bias will depend on several factors including: type of riding, chassis geometry, track or road conditions, tire selection, rider weight and riding preference.

MEASURING STATIC SPRING SAG

REAR SUSPENSION

Step 1. Suspension Fully Extended L1 _____

Step 2. Rider On-board, Push Down, Let UP L2 _____

Step 3. Rider On-board, Lift Up, Let DOWN L3 _____

Static spring sag is half way between L2 and L3 minus L1. Or you can use the formula below.

$$\text{Static Spring Sag} = L1 - [(L2+L3)/2]$$

Static Spring Sag, Rear = _____

REAR SETTINGS

	Travel	% of Total Travel
Off-Road Bikes	95-100mm	30-33%
Off-Road 80cc Mini's	75-80mm	30-33%
Competition Bikes	30-35mm	28-33%
Road Race Bikes	25-30mm	23-27%

Rear Suspension Stiction (mechanical condition) = L3 - L2

Stiction _____

Rear Suspension, Good Condition = 3mm (.12")

Rear Suspension, Poor Condition = 10mm (.39")

FRONT SUSPENSION

Step 1. Suspension Fully Extended L1 _____

Step 2. Rider On-board, Push Down, Let UP L2 _____

Step 3. Rider On-board, Lift Up, Let DOWN L3 _____

Static spring sag is half way between L2 and L3 minus L1. Or you can use the formula below.

$$\text{Static Spring Sag} = L1 - [(L2+L3)/2]$$

Static Spring Sag, Front = _____

FRONT SETTINGS

	Travel	% of Total Travel
Off-Road Bikes	75-85mm	25-28%
Off-Road 80cc Mini's	65-70mm	25-28%
Competition Bikes	30-35mm	28-33%
Road Race Bikes	25-30mm	23-27%

Front Suspension Stiction (mechanical condition) = L3 - L2

Front Suspension, Good Condition = 15mm (.59")

Front Suspension, Poor Condition = 40mm (1.57")

MEASURING FREE SAG

Free sag is the distance of travel that the bike settles under its own weight without the rider. If static sag is correct, free sag will test for the correct spring rate. Use the same procedures as when measuring static sag.

FRONT, FREE SAG

Suspension Fully Extended (L1) Use Measurement
From Static Sag Worksheet

Step 2. Push Down, Let UP L2 _____

Step 3. Lift Up, Let DOWN L3 _____

Free spring sag is half way between L2 and L3 minus L1

Front Free Sag _____

Front Suspension Should Be = 5 to 10mm of Travel

REAR, FREE SAG

Step 1. Suspension Fully Extended (L1) Use Measurement
from Static Sag Worksheet

Step 2. Push Down, Let UP L2 _____

Step 3. Lift Up, Let DOWN L3 _____

Free spring sag is half way between L2 and L3 minus L1

Rear Free Sag _____

Rear Suspension Should Be = 0 to 5mm of Travel

Suspension should not "top out" harshly. "Topping out" occurs when the suspension extends to its limit. It should barely have enough force to top out without the rider on board.

Too Little Free Sag

When static sag is correct and the free sag is less than the minimum recommended, (e.g., it tops out hard), a heavier spring rate with less preload is needed.

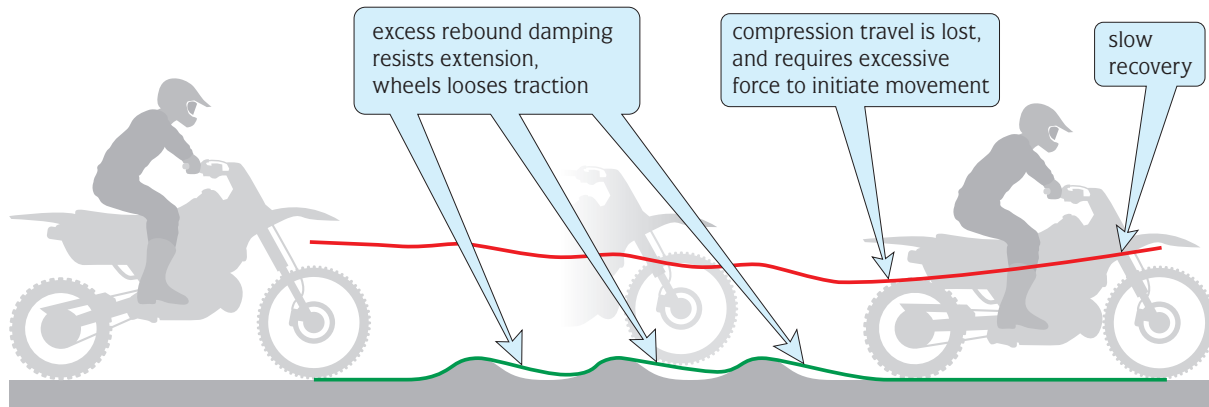
Too Much Free Sag

When static sag is correct and the free sag is more than maximum recommended a lighter spring with more preload is needed.

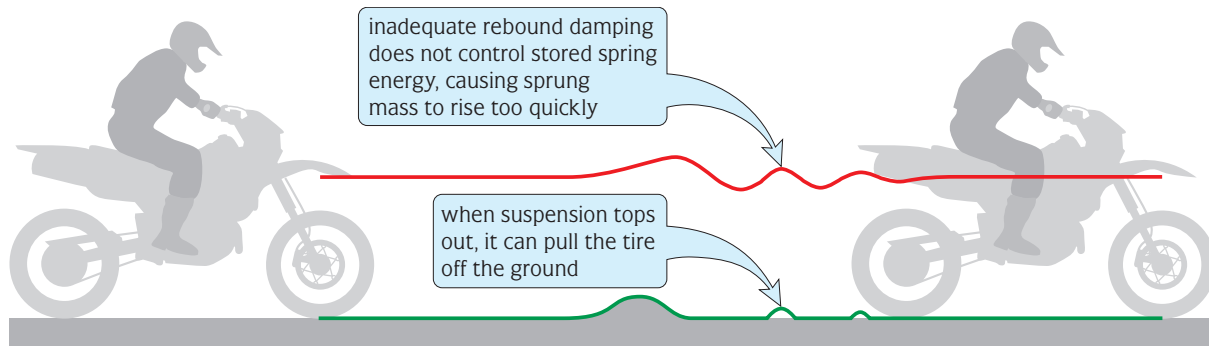
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Suspension Troubleshooting

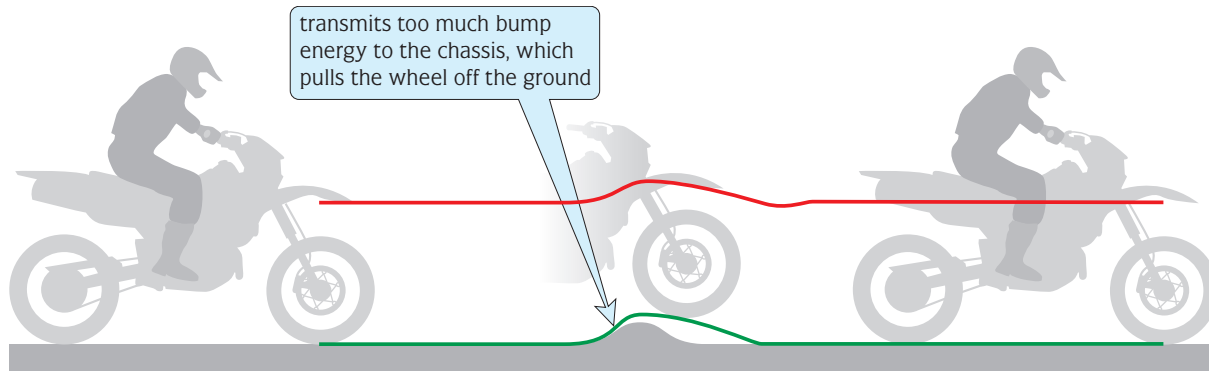
Too Much Rebound Damping—Packing



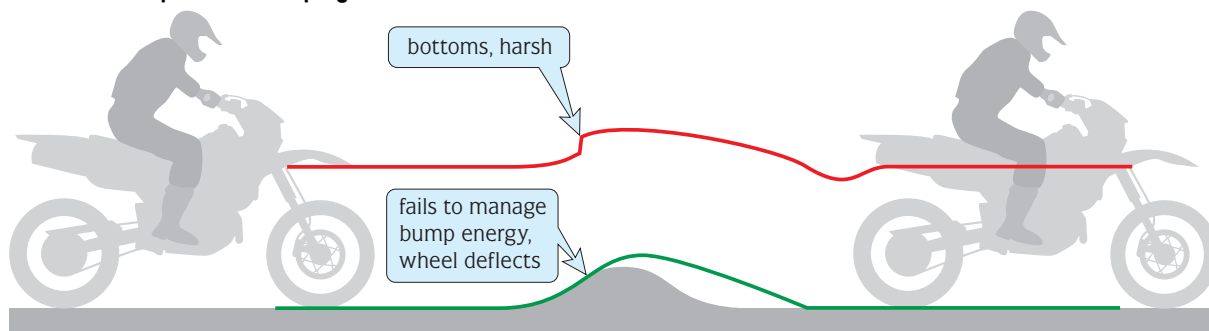
Too Little Rebound Damping—Pogoing



Too Much Compression Damping



Too Little Compression Damping



PROBLEMS WITH FORKS

1. Suspension too Soft, Bottoms, Wallows

- Oil level too low
- Not enough low or high-speed compression damping
- Spring rate too soft
- Not enough spring preload
- Dirt in valving, broken valve, bent valve, burr on piston or shim
- Damping rod bushing worn out
- Compression valve o-ring broken
- Damping rod not attached to fork cap

2. Front End Too Stiff - Harsh, Nervous, Twitchy

- Compression damping adjustment set too high
- Internal compression damping too high
- Spring rate too stiff
- Too much low speed rebound damping
- Oil level too high
- See (#6, Sticky Forks)

3. Dynamic Ride Height too Low, Oversteers

- Spring rate too soft
- Not enough spring preload
- Not enough low speed compression damping
- Low speed rebound too high
- Anything that makes the rear higher than the front

4. Dynamic Ride Height too High, Doesn't Turn Well,

- Understeers, Pushes
- Too much spring preload
- Spring rate too high
- Too much low speed compression damping
- Rear of bike riding too low
- Anything that makes the rear higher than the front
- See (#6 Sticky Forks)

5. Dives Under Braking

- All bikes do this to some extent
- Total "dive" is controlled by spring forces (rate, preload and air/oil relationship) only
- See (#3 Dynamic Ride Height too Low)

6. Sticky Forks

- Axle clamp not centered - fork tubes misaligned
- Fork brace broken or out of adjustment
- Fork seals not broken-in or poor design (aftermarket)
- Fork seals not lubricated
- Poor quality fork oil or needs replacing
- Bent fork tubes, axle, triple clamps (crash damage)
- Fork sliders dented or pitted
- Poor fork bushing design (aftermarket)
- Triple clamp too tight

- Bushings damaged, dented or worn out
- Metal imbedded in fork bushings caused by:
 - Preload washers not located properly
 - Aluminum preload washers used
 - Steel spring spacer contacting aluminum fork cap
 - Fork cap threads "shedding" on installation
- Cartridge rod bushing too tight
- Spring guide rubbing on I.D. of spring (guide grows from use of solvent when cleaning)
- Fork spring too large an O.D.

7. Hard to Turn

- See (#4 Rides High)
- Rear end rides too low
- Spring rate too stiff
- Too much preload
- Too much tire pressure
- Seat height too low or handle bars too high
- See (#6 Sticky Forks)

8. Front end Feels Loose

- Not enough low or high-speed rebound damping
- Damping rod bushings worn out
- Steering bearings loose or worn
- Tire pressure too low
- Chassis flex
- Worn out rebound piston ring
- Fork fluid needs changing
- Fork oil cavitation

10. Steering Head Shakes

- Chassis not straight
- Misalignment of front and rear wheels
- Fork flex, chassis flex or swingarm flex
- Fork oil level too high
- Bottom out mechanism too long
- Too much rebound damping
- Not enough low-speed rebound damping
- Too much high-speed compression damping
- Poor tire compound or wrong type of tire
- Tire not mounted on rim correctly
- Wheel out of balance
- Brake rotor bent or warped
- Worn out or loose steering head bearings
- Anything that makes the front end lower than the rear
- Death grip on bars while riding
- See (#7 Sticky Forks)

11. Deflects on Square Edge Bumps

- Too much high-speed compression damping
- Spring rate too stiff
- Too much spring preload

Too much low speed compression damping
See (#6 Sticky Forks)

12. Leak Fork Seals

Nicks, pits or rust on fork tubes
Bent fork tubes
Worn bushings or seals
Improper seal installation

PROBLEMS WITH SHOCKS

1. Rear End Kicks or Skips

This is the most commonly misdiagnosed as not enough rebound damping, however, is usually caused by too much high-speed compression damping and/or too stiff a spring
Too much high or low-speed compression damping
Spring rate too stiff
Too much spring preload
Too much rebound damping (not too little)
Linkage bearings worn, too tight or no lubrication
Tire pressure too high
See (#7 Sticky Rear Shock)

2. Rear Bottoms Out

Too much static sag
Not enough low or high-speed compression damping
Spring rate too soft
Piston ring o-ring or piston ring worn
Suspension fluid worn out
Shock seal leaking
Loss of nitrogen causing oil cavitation

3. Rear End Tries to Swap w/Front

Too much high-speed compression damping
Not enough low or high speed rebound damping
Spring rate too stiff or too soft
Rear shock bottoms out
See (#7 Sticky Rear Shock)

4. Rear End Feels Loose

Not enough low or high-speed rebound damping
Not enough low speed compression damping

5. Poor Traction

Too much low-speed compression or rebound damping
Not enough low-speed rebound damping
Tire pressure too high
Poor tire selection/compound
Tires worn out
Too much spring preload
Spring rate too stiff
See (#7 Sticky Rear Shock)

6. Not Tracking

Too much low-speed rebound damping
Too much low or high-speed compression damping
See (#7 Sticky Rear Shock)

7. Sticky Rear Shock(s)

Linkage not maintained (if applicable)
Swingarm bearings not maintained
Shock eyelet bearings not lubricated
Floating brake rod or backing plate not lubricated
Missing or improper bearing spacers
Bent shock shaft

If you are interested in more detailed information regarding motorcycle suspension modifications for your bike, order a copy of the book "Total Control" or the forthcoming "Motorcycle Suspension Bible" from www.totalcontroltraining.net or go to www.racetech.com to get specific recommendations and solutions for your motorcycle.

About the Authors

Lee Parks is a national roadracing champion and the author of the best-selling riding-skills book "Total Control." His critically acclaimed Total Control Advanced Riding Clinics are taught throughout the country to street riders and road racers alike. He currently teaches and speaks at motorcycle events and military bases all over the world and most recently has been giving advanced riding seminars at the International Motorcycle Shows.

Paul Thede is the owner and chief engineer of Race Tech. Paul's background includes a degree in Mechanical Engineering, 40 years on motorcycles, professional motocross racer, and he is a published author and teacher. He has become a "professor" of sorts amongst suspension technicians. In fact, many of Race Tech's protégés have acquired positions at top-level motorsports race teams and suspension manufacturing companies.