Suspended animation

Piero Zambotti takes a close look inside modern fork designs. And now that he's got the fluid out of his eyes, here are some fascinating results...

A safe speed, whether it's on a favourite backroad or a race track, is a measure of confidence. On the road there are many factors that determine the pace, but feedback and control offered through the front end are important. On a race track the limits of traction are far more comfortable to explore when you can sense them easily through the front end, and the suspension control of a fork plays an important role.

The question is what kind of fork setup creates a good feel for traction. Stiff springing helps control the movement of a bike during extreme braking, cornering and acceleration, but a measure of compliance is needed to let the wheels follow bumps. What's needed is damping to control precisely the movement of the springs.

It's not easy, however, to accurately assess damping characteristics. For our feature on shocks in the Sept./Oct. 2001 issue, we obtained the assistance of Dynamic Suspensions Inc. in Markham, Ont., which has a state-of-the-art $80,000 servo-hydraulic dynamometer. (Dynamic builds these dynos; one of its customers is Aprilia.) The actuators can be programmed to cycle a suspension unit at different speeds while load sensors measure damping resistance. Dynamic has plenty of experience in motorsport and automotive suspensions, but had never used
the dyno to evaluate motorcycle forks. With some adaptation, however, the dyno proved quite capable of measuring a fork's damping performance, one leg at a time.

Our test units arrived courtesy of Brooklin Cycle owner Rob Egan, who was the Yamaha team manager and engine builder for Frank Trombino's racing effort last year. Egan supplied three forks: a stock unit from a Yamaha R1; the Race Tech-revalved R1 fork from Trombino's championship-winning open sportbike racer; and the $17,000 Ohlins FG0700 fork from his R1-based superbike, which set the lap record at Mosport last summer en route to victory.

What's in there?
Before we report our suspension dyno results, let's take a quick overview of fork design. There are two common damping systems in forks: damper rod and cartridge. Damper-rod forks are the older and more popular design, typically fitted to cruisers or bikes built on a tighter budget. As the fork moves, oil is forced through specially sized orifices. The resistance creates damping force that controls movement as the fork legs compress and rebound. Doubling the speed of an orifice-type shock or fork produces four times the damping force. Damping that is optimum when cycled slowly will be too stiff when cycled quickly. We frequently comment on this kind of suspension action in road tests, where a fork seems harshly unresponsive when hitting sharp-edged bumps, passing the shock to the rider as if it had extremely stiff springing. Yet this same fork will dive considerably under braking and then bounce back, demonstrating overly soft springing and a lack of rebound damping.

Orifice damping results in cruder spring control than that offered by a cartridge fork, which uses valve-type damping similar to the type found in high-performance shocks. The illustration on the right shows the internal design of a cartridge fork. Each fork leg or stanchion contains a shaft and piston...
that extend from the fork caps and slide within a tubular cartridge immersed in oil within the lower portion of the fork leg. As the piston moves through the cartridge, pressurized oil forces open a shim stack to allow oil to move through ports. In nearly all street bikes, a fork's cartridge piston produces rebound damping only; a one-way free-flow valve prevents the piston from producing any compression damping. The compression damping is produced from a shim stack at the bottom of the cartridge, called the base valve, which meters oil displaced by the incoming cartridge shaft.

Tuning forks
Usually valve-type damping is set up to produce a linear relationship between damping and shock speed, but different shim stacks and pistons give a wide range of options to an owner, tuner or manufacturer.

The aftermarket suspension firm Race Tech researches and develops suspension valving kits with the goal of improving performance, roughly analogous to Dynojet's carburetion research and development work for popular motorcycles. Although a patient, knowledgeable tuner could find suspension valving solutions on his own, a Race Tech kit can save a considerable amount of time.

Race Tech fork kits typically include new pistons and shim stacks for valve-type cartridge forks, but special "emulators" are also available for older damper-rod forks. Emulators fit atop the damper rod, and contain a spring-loaded valve that converts the compression damping from orifice-type to valve-type inside the original fork.

Aside from the stock adjustments available, damping is usually altered by revalving (or rebuilding) the shim stack, but changing the oil weight also remains a useful way to alter damping. Most forks use light 2.5 or 5 weight oil, and heavier oil will firm up damping significantly.

Now for some feedback
Regardless of a bike's ground velocity, abrupt bumps compress suspension at speeds far beyond those that result from even the most extreme braking or cornering, and those hits require suspension to have some high-speed compression damping to prevent bottoming. Yet that sort of control is less important on a paved race track, where suspension moves slowly during heavy braking and cornering. Stiffer low-speed compression damping enhances a rider's feel for traction, which is why racers strip and retune their forks and shocks, searching for a different balance between traction and compliance.

The need for comfortable ride quality determines the stock suspension setup for even the most extreme sport bikes on the market. For both forks and shocks, street suspension typically has linear damping. And this is what we found with the stock Kayaba R1 fork on the Dynamic Suspensions shock dyno, which produced a linear curve that slopes upward from a point just above the origin of the graph (see next page). This is a typical street setup that allows a fork to move freely under slow compression, giving Yamaha Canada racer Frank Trombino and tuner Rob Egan set two Mosport lap records using the forks tested here. The Race Tech modified original fork on the open bike and the Ohlins superbike fork use different valving, but have been set up to produce similar damping characteristics.
Quantifying damping control: Force versus velocity

The suspension dyno moves a damper at a range of speeds, measures the compression and rebound damping forces produced at each speed and plots the damping curve. Positive forces and velocities indicate compression performance, while negative forces and velocities indicate rebound.

Note how much more compression damping force the Race Tech R1 fork produces at low speeds compared to the stock R1 fork. That gives valuable traction feedback while on the edge. The Ohlins' full-stiff compression adjustment produces nearly rigid damping, but suspension engineer Jon Cornwall says that in practice the useful tuning range starts five or six clicks out. Available rebound damping is softer than Race Tech's, but Cornwall says that the Ohlins' much stiffer springs don't need more rebound. “People use rebound to hold the bike down in corners, and that's not correct."

a soft, plush response. This is not what Frank Trombino wants for his race bikes, however.

The fork on his open sportbike R1 uses a Race Tech kit that dramatically changes the damping curve displayed by the dyno. With near full-stiff compression damping adjustment, the Race Tech fork produced more than twice the amount of compression damping at low damper speeds. Forks set up for hard sport riding or track use are valued to produce heavy low-speed compression damping to reduce fork dive under braking and improve traction feedback while the suspension moves slowly during cornering transitions.

The Race Tech fork starts out with much more low-speed compression than the stock unit, but the dyno curves show how Race Tech has developed a very gently sloped compression curve so that high-speed compression damping performance remains very similar to the stock fork's response. The sharply increased low-speed damping comes at the expense of some ride comfort, but the tradeoff is valuable for a race bike.

On the rebound

The very existence of compression damping is a relatively modern phenomenon, at least compared with rebound damping, which historically was valued as more important. Early telescopic forks from the '40s and '50s had no compression damping and simply used stiff springs to control chassis movement. But even those early forks had rebound damping circuits, because without them, compressed springs would bounce back and oscillate vigorously. Whether it's for a Chevy van or a GSX-R1000, rebound damping force is usually two or three times greater than compression damping for a given speed of suspension movement. Frequently it seems people diagnose suspension problems as the result of a lack of rebound damping, but they can easily be chasing down the wrong trail. One of the notable findings about the megabuck Ohlins superbike fork was how moderate its rebound force was compared with the Race Tech R1 fork, especially considering that the Ohlins fork uses stiffer 1.0 kg/mm springs as opposed to the Race Tech's 0.85 kg/mm springs. A common rule of thumb is that stiffer springing requires more rebound damping, but this isn't necessarily the case.

The Ohlins fork displays a huge range of compression damping, producing almost rigid damping resistance with the compression screw dialled all the way in. Rob Egan says he never used the upper ranges of adjustment and only needed “four to six clicks in from fully dialled out” to find the right compression setup.

But why so little rebound damping in contrast? A fork has a highly progressive spring rate because of the air volume within that compresses as the fork approaches bottoming. This produces a much stiffer spring rate lower in its travel. Too much rebound damping will trap suspension low in its travel and increase harshness, while also reducing ground clearance and the travel available for bumps. The increased harshness that results can lead some people into thinking...
Dynamic Suspensions Inc. had never adapted one of its systems to use with forks before, and was curious about the potential. Aprilia is one manufacturer that has purchased a Dynamic dyno for R&D. Ohlins now uses a suspension dyno at every grand prix race.

they need to reduce compression damping, when actually they may need more compression and less rebound.

Former Canadian racer Jon Cornwell is a suspension engineer for Ohlins who works with Ducati’s factory superbike team; he tuned for world champ Carl Fogarty and currently works with Ben Bostrom. He was unsurprised by the relatively mild rebound capability of the Ohlins fork on Trombino’s superbike. “Nine times out of ten more rebound is bad,” he says. Cornwell is adamant that stiffer fork springs do not require stiffer rebound valving.

Rob Egan says he chose soft rebound adjuster settings on the stiffer, linear-valved but softly sprung Race Tech fork, versus near-maximum rebound adjustments on the softer, digressive-valved but more stiffly sprung Ohlins fork.

It’s worth noting that the powerful range of rebound available on the Race Tech fork could conceivably lead a tuner astray if the adjuster was turned in excessively, which would be easy to do.

Adjustability range
To gauge the range of damping the external adjusters offer, we cycled each fork leg at a given speed nine times, adjusting the compression and rebound screws one turn between each run. The stock R1 fork has a very limited range of compression damping; a small difference in damping force exists between full-stiff and one click out, but the differences between further settings were practically nil. Very narrow ranges of compression-damping adjustment are common in production forks and shocks. The cartridge or shock-absorber shaft doesn’t displace much oil when it compresses, and since that displaced oil is what flows through a compression adjuster, highly precise adjuster hardware is needed to change damping in useful increments. Given a similar level of manufacturing investment, rebound needle adjusters offer much more accurate settings, because they’re located on the piston and can flow up to five times more oil than that displaced by the cartridge shaft.

We noticed virtually no difference between the separate legs of the two different R1 forks, but there was a significant variation between the legs of the Ohlins fork. Egan said that one of the Ohlins fork legs had not been rebuilt for half a season, while a blown seal had forced service on the left leg. The fork leg with fresher oil produced much smoother compression and rebound curves. Jon Cornwell mentioned that Ohlins racing forks have very small (1.5 mm diameter) compression ports that are prone to clogging, and they demand more frequent maintenance than production units.

The problem of precise compression adjustment in fork cartridges is most difficult when the suspension moves slowly and flow volume is at a minimum. A recent development to address this is slowly making its way from off-road bikes to pavement. Some racing forks now contain a “midvalve,” a specially designed cartridge piston that has a compression shim stack in place of the usual free-flow valve (see illustration on page 51). By creating compression damping from the midvalve as well as the base valve, a tuner can obtain more control over the compression damping curve. Soft, easy-flowing midvalve response allows precise low- and mid-speed compression damping, while the base valve can offer stiffer valving for high-speed control over a sudden impact.

Jon Cornwell says he has performed much R&D work with midvalves on Ohlins road racing forks. Cartridge construction, valve-type damping and external adjusters on high-performance forks have all been solutions prompted by off-road demands. It would not be surprising if midvalve damping soon appears on future generations of production street bikes.