SUSPENSION OF A MOTORCYCLE: A PRIMER
(an introductory lesson is pronounced "primm-er" and
a first coat of paint is pronounced "prime-er")

At the end are comments specific to the R1100S and particularly about revalving the "non-rebuildable" Showa shock

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Introduction

In the narrow sense, the "suspension" is the system that suspends the main mass of the bike and rider "above" the wheels and road. Kind of an odd use of the word. The reasons the bike and rider aren't connected to the wheels by a solid connection — as with an ordinary bicycle or as was done at the rear in a hard-tail Harley of yesteryears — fall into two categories.

First if we had no suspension, then when the bike hit any kind of bump or irregularity in the road it might go airborne (or at least, light-on-the-wheels) and that would represent a loss of control and especially unwholesome on curves. So the ideal is to have as much constant weight resting on the wheels as much of the time as possible and for the fewest critical periods of time to go light in weight on the rubber contact patch. Also, I think tires and wheels would take a bad beating if they didn't have springs to rely on.

Second if we had no suspension, the rider would feel every non-gradual road irregularity too large or too sharp or too fast to be "eaten" by the balloon tires. Current bike tires run at fairly high air pressure. To ensure precise handling they are quite stiff in all directions. So current pneumatic tires don't do much of the absorbing of road irregularities. But tires can be chosen that eat more road harshness than other tires without getting you into *squiggly* handling.

Adjusting or tuning the suspension means optimizing for both sets of purposes (handling and rider comfort) recognizing however, that those purposes in some respects inherently conflict. But this is not a simple matter nor do these purposes always conflict. On the contrary, some people are *uncomfortable* when the handling is vague. Similarly, some people can *handle* their bikes better when they are not buffeted all day by every crack in the pavement.

Springs

The easy way today to make a suspension is by interposing a springy element, such as a coil spring, between wheels and bike mass[1]. The rider plus bike mass is the *sprung weight* and the wheels plus lower pieces are the *unsprung weight*. When you have the lightest possible unsprung weight, the wheels are freest to follow the irregularities of the road because they have the least mass (read: inertia) to take flight off the pavement against the downward force of the springs. The same minimalization of inertia in the unsprung weight is beneficial to the restoring action of the springs and dampers.

In the near future, big metal coil springs may change or disappear because their role can be handled much better by an active/smart mechanism driven by a dedicated fast suspension computer. This has not been possible until recently.

As the primary suspension element, the springs determine whether the ride is soft or hard and the handling is optimal across the many contrasting road environments. The spring is the main variable in the comfort versus handling decision. A soft suspension, not unlike sleeping on a soft mattress, is like floating on a cloud. But then the feel of the road and precision of handling become indistinct, just as support for keeping your spine in the correct alignment becomes indistinct on a soft mattress.

As with mattresses, some discerning people do not consider excessive softness like an old Pontiac to be their personal notion of "comfortable." Conversely, some minimum element of comfort and ergonomic goodness is needed for driving well.

In a simple world, you would unhitch your shocks and ride around with various force ratings of springs till you found the balance of ride comfort and handling you liked. Then you would move on to adjust the shocks.

But this can't be done because a bike can't be ridden safely let alone tested for extreme conditions without operational shocks present (granted, I've never really tested this idea except when too lazy to repair faulty shocks). Also, while the springs and the shocks do very different things, the phenomenological riding experience is a confounding of the two. That makes it challenging to choose or adjust the springs and shocks independently because you will have a hard time separating stiffness after hitting a rock and whether it arises from a stiff spring or from a highly damped shock.

Having said all this, choosing springs for a given bike often boils down to a simple matter of choosing a spring that works with the load (the weight of you and any passengers and luggage) and puts you into the suspension design geometry chosen by the designer. In other words, that makes the suspension sit at the right height and satisfies the bike steering geometry, puts the shocks in the center of their travel, etc. In turn, this often means just fudging the spring a bit weaker or stiffer depending on if you are respectively

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[1] The old Citroen cars made amazing smart springy elements from a somewhat complex body of plumbing using oil and air. But hard to beat the orderly behaviour of spring steel.

lighter or heavier than the person the bike was designed to seat. Or you can have any spring, but sometimes you can adjust the suspension so as to bring the bike into the right geometry, regardless of the spring and how it works for you.

Ignoring such physical spring parameters as size, weight, and color, springs have only a single basic parameter and that is amount of deflection for each measure of weight carried. That is expressed as something like “kg per mm of compression” or “pounds per inch.” A steel spring is a predictable linear kind of thing. It acts in accordance with that single parameter over most of its length and at all times and reasonable temperatures. But at the point of compression when the turns of the spring start binding against one another, that is when a coil turn starts resting against the adjacent turn, things get “progressively” stiffer.

Springs come from the spring factory with their basic parameter and no other specification (except non-performance parameters such as size, weight, color, etc.). They keep that specification their whole life although springs seem to get tired and sag after some use.

Squeezing a spring — as with “pre-load” — has no effect what so ever on spring rate. But it does affect the amount of force needed to compress the spring a further bit. When you sit on a bike, the spring compresses according to the weight of the bike and rider. The “further bit” will always be same whether you have pre-loaded by a mechanical adjustment or just sat on the bike. Therefore, pre-load has no effect on how stiff the spring feels to you but only on the height of the bike and how well it conforms to the designer’s geometrical intentions.

Springs can be adjusted at home — at least to make them softer. Grinding away some metal very evenly and along the longest possible stretch of the spring does this. But that can end up being very hazardous to ride on unless you are fully familiar with the way steel is heat-treated and a few other issues that can cost you your life if wrongly modified. But if you know what you are doing, it is a simple if tedious procedure to reduce spring force by say, 10-15%. And it is not hard to measure your progress with a bathroom scale and a tape measure.

Springs can be stiffened by inserting blocks of metal between a turn or two to cause them to bind or bind at lighter loads. You can buy generic little steel wedges and insert them between coils to re-animate elderly car springs. But for compelling mechanical reasons, this is a very unsatisfactory and risky thing to do.

You an easily create dual-rate springs at least for springs that are held constrained inside tubes such as with telescopic front forks. Dual-rates allow you to be very soft for small bumps, even high-speed sharp edges to road cracks. But as soon as the springs have compressed some, they transition to great stiffness and resist brake dive. But if you know enough about springs to design dual-rate springs, you don't need any more help from me.

Finally, you can buy so-called “progressive springs.” These become stiffer as the more closely wound turns begin touching one another and become stiffer yet as more turns get forced to touch together… in effect shortening the springy steel length. Quite often, it is a false illusion that a progressive spring is acting progressively: no stiffening happens until a lot of compression has already taken place and thus there is not much effect until the bike is already into very heavy compression. And you wouldn’t feel it there anyway. Dual-rate springs work much better and you can fine-tune them very conveniently.

Dampers

But springs bounce and continue to bounce and sometimes bounce right out of control; at a certain frequency and load pairing known as "resonance” they just go on oscillating. Riding behind an old Pontiac, you can see what happens when a car is very under-damped.

So for a bike, you just can't get the springs right unless you damp — but not over-damp — their oscillations. To that end, springs are controlled by dampers also known, in a stupidly chosen term, as “shock absorbers.” These dampers do the opposite of absorbing shocks; in fact, they resist the compression of the springs as the springs try to eat the shock by compressing. These are highly complex and over-sophisticated mechanical devices — a sure sign they are ready for computerization along with the heavy springs.

While springs are simple items and easy to understand and dampers are complex, the basic work of suspension is still done by the simple springs. I emphasize this because owners are forever searching for the superior shock when they should be searching for the right rate of spring. The springs have to be right for your weight, riding behavior, the nature of your suspension mechanism, and so on, and getting the springs right has a primacy over getting the shocks right.

The shocks have to damp but not over-damp or under-damp the springs. The shocks provide the secondary — but critical — factor of damping. They slow down the movement of the springs exactly like a spoon pushed into room-temperature honey. Because they slow the motions of the bike they make the suspension feel harder or stiffer it is not easy to distinguish the stiffness of the spring from the feeling of hardness caused by stiff shocks. Honey is a liquid but if you jabbed a spoon at the honey pot quickly, it would feel fairly solid and hard and if done slowly, it would feel soft. Pretty much the same point for shocks. For real slow rises in the pavement, they are insensible and inactive. But for real fast bumps, they act as stiffeners both for the initial compression of the springs and for the rebound or over-shoot of the springs back to ride height.

Shocks can be made with any degree of stiffness just as honey can be heated to make it less viscous (or shocks can and do get heated and they get softer likewise). Further, you could design shocks that are soft at slow speeds but firmer at high speeds, soft for small movements but firm up by some rule for larger movements. All kinds of possibilities exist, given enough money, size, weight, complexity, maintenance effort, and inventive cleverness. And if, once the shocks are installed, you think you can possibly explain to the user how the hell to make the adjustments correctly.

As an illustrative instance, on an R1100S, when you go from stock to an Ohlins strut (combination spring and shock), you get a stiffer spring but a softer shock. Seemingly paradoxically, the ride comfort is experienced as plusher yet the handling is experienced as more precise. Wouldn't it be nice if the stock shocks could “age” into something softer and so be just right at least one period in time? Pity they don't. This model is discussed in more detail below.

Sophisticated shock absorbers provide the rider with some adjustments. Some of these adjustments relate to ensuring the various parts are initially set to or returning to the geometry chosen by the design engineer (and/or rider) and with respect to the weight of bike and rider(s). These are mostly set during installation.

Of a more dynamic nature are some ride adjustments. These are divided into compression damping (when hitting a bump) and rebound damping (returning to normal ride after the bump reaction has been “eaten” and beyond). Really sophisticated shocks also let you control separately faster bump compression (called “high speed” but referring only the speed at which the bump-up happens, not road speed) and slower bump compression.

Both compression and rebound are critical to good suspension. And, even though you see only one (or one pair) of shock absorbers on your wheel, the mechanisms that controls compression and rebound damping are quite separate mechanisms. They are both tucked inside the shock although they share the same pool of damping oil and a few other parts.

The engineering of *rebound* damping — returning to stasis after a bump is absorbed — is by far the simpler of the two. At the moment a bike's spring finds itself compressed and ready thus ready to rebound, all it has to think about is (1) the bike plus rider weight (which doesn't change much for a given set-up), (2) the strength of the spring (which doesn't change for years) and (3) in a secondary way, the unsprung inertia. Therefore being predictable and falling within a narrow range of requirements, the rebound damping can be handled by fairly simple mechanisms.

Compression, on the other hand, can be initiated by many kinds of “forces” ranging from a large, tall rock on the road (*high speed compression* called into action) to fairly gradual changes in road pavement (*slow speed compression*) and all combinations in-between. In all cases, the ideal is for both bike and rider to remain totally unfazed by either fast or slow road perturbations and to ride along at a constant height as if not even noticing the perturbation. At the same time, the wheels should be sticking with good downward force on the road despite the perturbation attempting to throw the wheels skywards. Having separate systems for addressing the low speed and the high speed perturbations gives the rider more opportunity to tune the suspension to their liking, to their riding or bike circumstances, to having a passenger, to the roads, and/or to achieve some ideal of performance that's right for the circumstances.

Valving

There are all kinds of ways of damping a spring. As in days of yore, you can have a screw-tightened friction damper where a two-sided sheet of sandpaper can be tightened to some linkage and so you get the right amount of friction. Strictly speaking, this isn't compliant "damping" and related to the speed of the bump but brute force "resistance." It isn't really suitable.

At the simplest, a light spring can be damped by covering it with viscous stuff or stuffing rubber foam into it. At the most complex, you can have computer-controlled mechanisms.

For a very long time, shocks have been oil-filled. The oil is forced to pass through orifices of different sorts. The nature or size of the orifice(s) and the viscosity of the oil at riding temperature are chosen to produce the desired degree of control.

You can simply have a single or group of holes when the damping demand is clear-cut – as is the case for rebound damping. But in the case of compression damping, if a big or fast "demand" for damping shows up, the highly pressured fluid may "lock" in the hole and not flow at all rendering the suspension very rigid. That can happen in the kind of simple front fork dampers that used to the norm when the means of control for both compression and damping are by pushing oil through small holes.

Sophisticated modern shocks have big holes but these holes are covered by very thin springy washers or carefully calibrated stacks of washers. If there is great or fast pressure on the oil to flow through the hole(s), the springy washer(s) give way and the aperture enlarges on demand. Configuring of these stacks of washers, having a strategy of having "high speed" and "low speed" groups of stacks, and providing the user with the means to control them a matter of skill in design. Giving the user adjustment over no compression functions (most stock shocks), one general control of compression damping, or control separately over different stacks of compression dampers is a matter of clever design and budget.

Even with no adjustments, you can still pre-adjust the shocks to suit yourself by customizing the stacks of washers. This requires disassembling the shock and that is no easy thing to do even when the shock is designed to be rebuildable. Many shocks, particularly gas-filled units, are not designed to be rebuildable but can be re-built anyway. My impression is that you can adjust the stacks in a shock and end up being as happy ever after as if you had a fingertip control for fine-tuning compression damping at every daily whim.

While talking about practicalities, there appear to be only minor differences between mega-dollar shocks and mini-dollar shocks as far as basic performance goes. With mega-dollar after-market shocks, you get a knowledgeable service network, exchange or rebuild parts, more durable pieces, higher resale value and various intangible but sometimes valuable benefits… except to the performance of the shock per se. In other words, if your stock shock works nicely for you, an Ohlins will add nothing tangible for most such people. But it will be a great and good investment if you race or if you tinker compulsively.

Rebound Damping

Rebound damping is simple to do since, as mentioned above, the forces are fairly predictable and don't vary much. Most shocks just have a plain hole through which is forced the shock oil during rebound. If you want to rebound slower, you shove some obstacle into the hole such as a tapered needle that makes the orifice smaller. Most shocks work by shoving a tapered needle into the hole using the ordinary kind of screw action: screw it *in* by turning clockwise and more of the needle body will block the hole.

It defies the talent of the best communicator to describe in any intuitive way the results you get when tuning rebound action. Are we making the ride harder or softer by opening the hole and thus increasing the speed at which the rebound bounces back? On some shocks, "softer" means the hole is more constricted and so the speed or rebound is slower (softer?) and the bike is in the compression position a bit longer before returning to the homeostatic ride-height level.

Fortunately, the range of adjustment or the significance of the adjustment for rebound damping tends to be minor and so few can feel much difference between soft and hard rebound anyway or in the absence of extreme road challenges. After-market shocks allow the user more range for satisfying or for screwing-up this simple function.

Compression damping

By contrast with rebound damping, when you run over a two-by-four piece of lumber in the road, the meaning of "hard" and "soft" apropos compression damping is as clear as could be and felt by hands and body immediately. A fancy shock will let you adjust for hardness and softness and, if really fancy, for the amount of hardness separately for fast and slow compressive bumps.

Comments on the R1100S and Ohlins shocks

The BMW R1100S, 1998-2004, is a sporty bike with wonderful handling resulting from the Telelever front end. From the front, the Telelever looks kind of like ordinary telescopic forks. But if you look underneath, you'll see an A-frame, two ball joints, and a single damper. Together, these make the bike react something like the much appreciated (and sometimes lamented) Earles forks used in the glory days of BMW (post-war till 1970) which were a leading-link design that looked different[2].

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[2] A big no-no in the conformist world of bikers who delusionally think they are individualists.

The R1100S model has nice springs and dampers and if they happen suit your taste as much as the designer's taste[3], you are lucky. But that is a crap shoot, since people come in all different sizes and tastes. Many people find the suspension excellent for the highway but jarringly stiff for the city and rougher roads ("many people" really means just me). In essence, this means the springs are OK for riders of maybe 185-210 lbs but the high-speed compression (on sharp bumps) is too stiff.

The front and rear struts have only rebound damping adjustment. Rebound damping being a simple matter, requires nothing but a tapered rod entering a round hole to provide adjustment in the finger-in-the-dyke-leak manner. On these reasonably nicely made gas-filled Showa shocks, the range of adjustment is moderate so the consequences of fooling with the adjustment never takes you too far astray. The rear also has hydraulic ride height adjustment, sometimes incorrectly called pre-load (which is itself generally incorrectly called when used conventionally).

So if you want a better fit to your tastes (not everybody, I said), for $1700 list price or so, riders buy Ohlins shocks. Being different in construction from the stock shocks, they require different sized springs. And so, want it or not, you have the opportunity to change the spring rate. They have all kinds of adjustments for compression and rebound damping, and for spring position (not really a pre-load adjustment but some features of pre-loading). With all these opportunities to customize the suspension, any rider can get the ride they want or can screw things up monumentally. They also are buying a wealth of suspension experience, high quality manufacture, ease of re-building, and one of the classiest and easiest brand-identified pieces of gold-painted bling in the biking world.

With about 20,000 miles on my springs, a racing shop measured spring rates of 53 kg/cm and 121 kg/cm, front and rear[4]. If you heed Ohlins, you will buy springs that are 57 and 160 (or 170). The springs are stiffer and so there is less brake dive and added firmness. However, people describe the Ohlins as being "plusher" which means the shocks are softer. (I go into more detail below.)

Seems to me, you can revalve the stock shocks to have less high-speed compression damping and you are going to be happy and $1200 richer[5].

You can also work on the springs. You can reduce the stock spring rate by grinding down the periphery of the spring. I found a 12% reduction added little to ride softness but introduced more brake dive than I like. There is no simple and safe way, to my

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[3] The designer weighs 85 kg (187 lbs) and rides the Autobahn.

[4] Measuring springs is not all that precise and they vary some in manufacture and the wear a bit. The high-class measurement is in Newton-meters (which considers "mass" not "weight") which is a touch smaller than kg/cm (160 Nm is 163 kg/cm). To get lbs/in, multiply Nm by 5.7 (160 Nm is 914 lbs/in).

[5] Best-known is the revalving work of Lindemann Engineering in California but many shops can do it such as the one I used, John Sharrard. The "non-rebuildable" stock shock has to have a nitrogen valve installed at the first rebuild.

knowledge today, to increase stock spring rate on the front R1100S strut without major surgery. Nor have I been able to locate an off-the-shelf substitute from the local spring winding industry.

Comments on my experience re-valving the “non-rebuildable” Showa shock

Several shock experts can rebuild and even re-valve the "non-rebuildable" stock shocks. I recently paid $175 to have mine done. I asked for less denture shaking on pavement cracks and potholes without otherwise being much different since I like the stockers for their solid feel on the highway. My impression is that this would make them pretty similar to what people say about Ohlins (most frequent descriptor comment on the Ohlins' is: "plush" which means soft) and for $1100 less out of my pocket.

Colour commentary: there's no magic in shocks, only different kinds of adjustment. Some people, like me, like the stock springs and shocks pretty well. Others want something different. You can either buy a highly adjustable shock and choice of springs at great expense or you can ask a shock expert to take a shot at what *you* want and the two of you will be starting from a known starting point... and then try again if that doesn't hit the mark close enough. After all, waving your hands in the air trying to explain what you want in a new Ohlins isn’t as clear as pointing to the old stock Showas saying, “Make these shocks stiffer on the highway...” or whatever.

My expert reduced the oil rating from roughly 7-8 to roughly 5. There is no standard for shock oil, contrary to what you may have though, but my suspension guru tests each oil he uses and keeps a secret notebook. He also removed one springy washer from the high-speed compression stack (there are a number of separate valve-units inside a shock — which is why you need a guru, at least the first time you do it). He also had to install an NPT Schrader valve since the “non-rebuildable” shocks didn’t have one and he re-pressurized the shock. The valve hasn't leaked any oil or gas in a few years of vigorous riding but I can't predict leaking under pressure and longer time. Of course, I’ll just have to pump it up again if it leaks.

For a year or two, I experimented by riding on a spring I lightened by 12%. Got a wee bit of softness and more than a bit of brake dive that way. With Earles forks as my ideal, I hate *any* brake dive. It also made more perceptible the stiffness of the stock shock. So I consider it a step backwards, for my taste, and have returned to the stock spring which seems just fine for my weight and ride tastes.

So now, the re-valved shock seems close to what I'd like (all the credit goes to the John Sharrard, Accelerated Technologies, the Buckhorn, Ontario, shock guru a very patient and talented guy much in demand at the tracks during the summer). Clearly less jarring on potholes and some sense of the wheels sticking better to the pavement. Seems to ease over speed bumps at faster speeds (that's really important in my neighbourhood since Toronto is trying to get into the Guinness book of world records for the most "sleeping policemen")[6]. A small sense of being more bouncy, but that comes with softer shocks and I have to live with that unless I can adjust the rebound control better.

I continue to like the stock stiff springs and the level ride they produce for my 205 lb body. But I am very glad that I was able to soften the shocks some. I guess that is why people wax lyrical about Ohlins, but sadly, without investigating far cheaper alternatives. See colour commentary above.

After a lot of expectation, I am really happy to have made this modest change that I find very valuable. Soon I'll work on my rear shock because that is too stiff too (next time I have the mufflers off since I have dual up-pipes blocking access to the lower mounting bolt).

In summary, it seems sounder to me to have a stock shock and vary it to your taste then just to take very adjustable shock and fool around for a long time (I rather like Elka shocks which are made really nicely). But then with highly adjustable shocks, you can always change the settings for different conditions... assuming you can find your old setting again, eh.

[6] I had a Maserati that took the local speed bumps at normal street speed and the suspension just ate them up. Hate to admit that great speed bump performance is one of my noble performance ideals, but it kind of is.)