

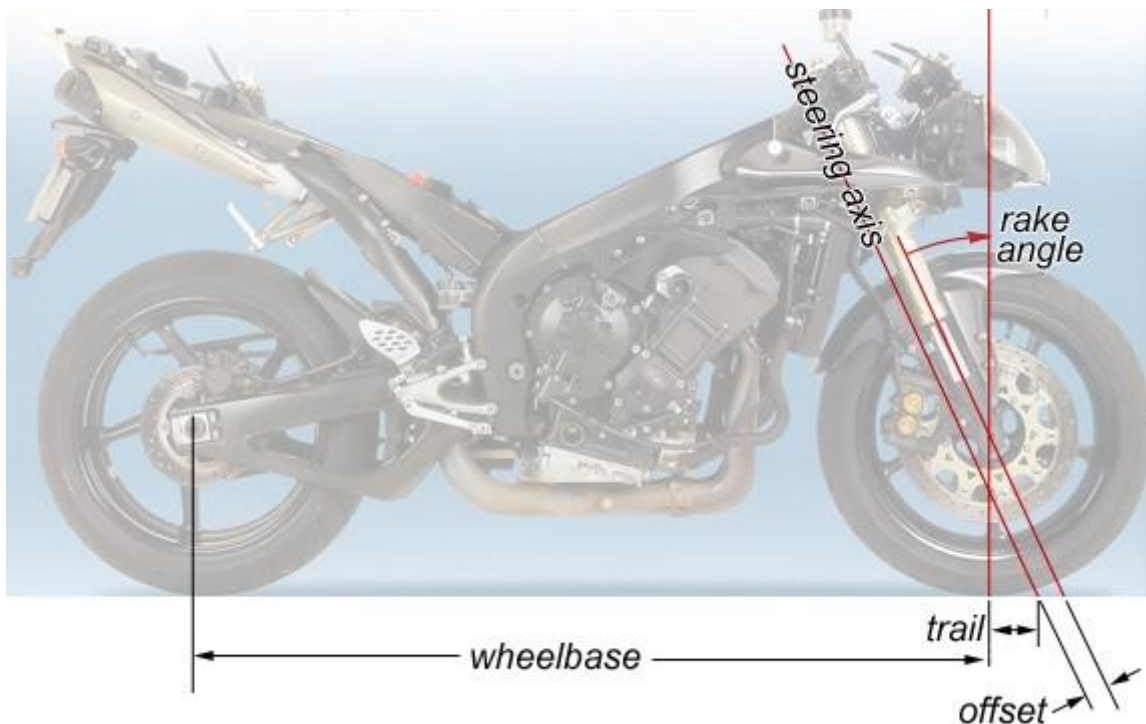
Motorcycle - Suspension

A little background.

Motorbikes, or motorcycles if you're American, have a similarly varied selection of suspension systems as cars. On bikes, of course, you only have two wheels, so bike suspension systems tend to be a little more highly engineered because there is more at stake. By far the most common setup now is the single rear coil-over shock system with either a regular double swing-arm or a single-sided swing-arm. At the front, telescopic forks are still the most prevalent. It's surprising that there's still a large number of cruisers out there, notably Harley Davidsons, that are 'hard-tail' bikes - bikes where there is no suspension at the back. The wheel is simply axled straight on to the frame. This is a throwback to the very first motorbikes which were basically bicycles with an engine strapped to them. (In the 1920s, motorbike suspension consisted of the springs in the saddle and the air in the tyres.)

Motorbike suspension geometry 101.

Before you dive into the murky world of technical terms which litter the rest of this page, it's worth knowing up front what some of them mean in relation to the way motorbike suspension is set up. This little diagram, then, explains the basic terminology you'll come across.

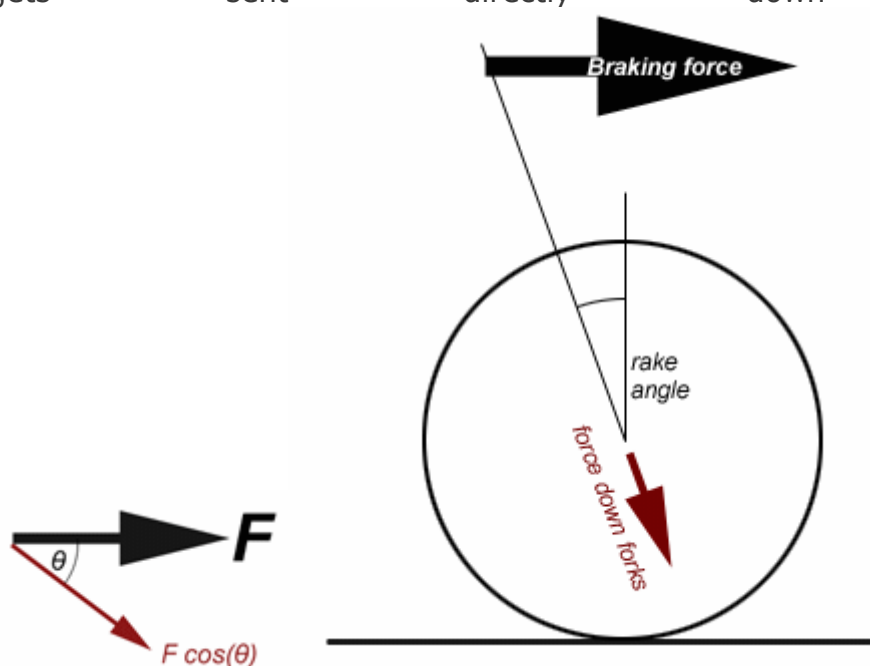


Sports bikes typically have less rake which means less trail. Less trail means less stability, which means a quicker-steering bike. This makes these bikes a lot less stable to ride in a straight line, but a lot more flickable in the corners. Conversely, cruisers, choppers and customs, have much more rake. More rake means more trail, which means more stability, which makes the bike harder to turn. This is why Harley Davidsons are typically a bitch to get around a corner. However, bikes with more rake

work better in a straight line, which is why bikes like the Honda Goldwing and BMW LT series have more rake - they're designed to be long-distance cruisers. It's worth noting that when I talk about more and less rake, it can be within 5°. For example the difference between a flickable Yamaha R1 race bike and a BMW K1200LT cruiser is 24° and 26.8°

Anti-Dive forks.

One of the drawbacks of telescopic forks on a motorbike is their tendency to compress under braking, making the bike 'dive' forwards. This is due mostly to the steering geometry of the average motorbike. When you brake, you're slowing the forward motion of yourself and the motorbike. That forward force has to go somewhere, and that somewhere is the front suspension. Because the telescopic forks are at an angle to the frame, and consequently at an angle to the braking force, some of that forward force gets sent directly down the forks.



Think back to your school physics. Force transmitted at an angle is equal to the main force multiplied by the cosine of the angle. Remember the rake on a motorbike is calculated from *vertical*. So the angle we want is actually 90° minus the rake - the complement of the angle. Conveniently, because sine and cosine are the inverse of each other, the cosine of one angle is the same as the sine of its complement. So for a bike with a rake angle of 25°, we can either use the cosine of its complement (65°) or the sine of the rake angle itself. Look at the diagram on the right; if the rake angle of our bike is 25°, then the force down the leg of the forks is (braking force) x sin(rake angle). For the sake of getting a number, let's use a ridiculously low braking force of 1 newton. That makes our calculation (1) x sin(25) which is 0.4226, or 42.26%. So 42% of the forward force generated while braking travels down the fork legs into the springs and fork oil. To put a real world number on it, let's say you weigh 100kg, and your bike weighs 165kg. Force = (mass)x(acceleration). Jam on the brakes and you could easily generate a deceleration of just under 1G in an emergency let's say 9m/s². In that case, Force = 265Kg x 9m/s² which is 2385N. If 42% of that zips down the fork legs, your springs and

fork oil are suddenly dealing with around 1000N - about 100Kg of force. In short : you have just transferred your entire body weight into the forks, which is why they dive.



Honda fired the first shot in the anti-dive war in 1969 with the introduction of its TRAC system (Torque Reactive Anti-Dive Control), but it wasn't until the eighties that it became more mainstream. Anti-dive systems were typically linked to the brake hydraulic system, and is remembered best on the Kawasaki GPZ900R where it was introduced under the moniker AVDS - Automatic Variable Damping System. AVDS was a supplemental hydraulic cylinder mounted on the front of the fork legs which was connected to both the brake lines and the hydraulic fluid inside the telescopic forks. The idea was that as you applied the brakes, this unit would use the pressure in the brake line against a plunger to close a control valve. This valve restricted the flow of fork oil and thus stiffened the suspension. Stiffer suspension meant less dive. Anti-dive units mostly featured a dial adjuster on them, normally at the base. This was a way of affecting how much the anti-dive plunger moved, which meant the rider could make the anti-dive more or less severe. It all sounded good in principle but a lot of riders took a dislike to it because of its behaviour on bumpy roads. If you went to brake on a bumpy surface, the front suspension stiffened up and it became less like riding a motorbike and more like falling down stairs as all the road bumps and deformities were transmitted up the now-stiffened suspension into the frame of the bike, and consequently, the rider. The control valve would often stick closed resulting in permanently stiff suspension, which in turn would result in frequently blown-out oil seals. These "features" of anti-dive systems have since been ironed out and they tend to work maintenance-free now.

TRAC

The Honda TRAC system differs somewhat from the ADVS-style units. Honda maintain that hydraulic systems have two basic drawbacks. First, the additional brake-line plumbing and increased brake-lever ratios can produce a spongy feeling at the brake lever. Second, those systems are either on or off - there's no modulation of antidive effect. To get around these problems, TRAC is instead activated through the torque reaction of the brake caliper itself. This makes it completely independent of the hydraulics in the brake system. It works because one of the two front brake calipers is hinged behind the fork leg on a pivoting link, rather than being solidly attached. When you apply the brakes, the pads grip the spinning disc and this tries to drag the brake caliper around with it. The caliper pivots on the link and presses against the anti-dive activating valve which is built directly into the fork leg. From then on it, it works just like the Yamaha and Suzuki systems, restricting the flow of fork oil and stiffening the

suspension. The advantage of the Honda system (they say) is that the harder you brake, the more pressure the pivoting caliper puts on the control valve, and the stiffer the suspension gets. One important difference with TRAC is its ability to deal with the bumpy road surfaces which the other systems had a problem with. The TRAC valve is a floating piston held in place by a spring. This means that if you hit a bump, the sharp and sudden increase in the pressure of the fork oil can override the anti-dive valve and force oil through the valve as if it were not applied. This means that TRAC can respond to bumpy roads whilst braking. Clever eh?

Headshaking, tankslapping and steering dampers.



As mentioned above, if the rake a telescopic fork is set just right, you get a bike which has very quick, precise steering, but becomes fundamentally unstable at low speed. This isn't normally an issue because sharp steering is found mostly on sports bikes, which tend to travel pretty quick. The problem comes when you hit a sufficiently large bump. The front suspension compresses, the wheelbase of the bike gets shorter and suddenly, what was on the cusp of driveability becomes totally unstable. The front wheel will tilt to one side or another and then the suspension returns to its normal length. As it does this, it sets up a standing-wave in the chassis of the bike which, because of the gyroscopic forces generated by the front wheel, forces the steering over the other way. Now the suspension geometry and gyroscopic force of the spinning wheel together try to straighten the front wheel again. At this point, the bike is in a head-shaker - the head of the bike is being shaken back and forth by a rapidly oscillating front wheel. There are ways and means out of this, but if you don't tackle it quickly, things will rapidly go downhill. The head-shaker will get more and more violent because now, the wheel starts to slam back and forth from one side to the other. The handlebars will get ripped out of your hands and the steering will go from lock to lock very quickly, slapping the handlebars against the tank of the bike - hence tank-slapper. The inevitable outcome of this is normally a high-side where the bike will throw you off sideways and upwards. Once you're off, the suspension unloads, the bike settles down, and momentum will take

its course as the bike drives off in a straight line without you. This is the reason for steering dampers, and one of the reasons the Suzuki TL 1000S was recalled within weeks of being put in the showrooms - it went into vicious tankslappers without any provocation.

Steering dampers, therefore, are A Good Thing if you are going to be racing or owning a bike with suspect handling. They come in two basic forms - linear and rotary. Linear dampers are literally a long cylinder with a clamp on it and a hydraulic ram with another clamp. One end gets attached to the front forks of the bike, the other to the frame. They look like mini shock absorbers and are designed to be virtually un-noticable under normal circumstances (in terms of steering stiffness) but if you get into a headshaker, the rapid vibration can quickly be cancelled out by the damper. On the right here, the top image shows a linear damper attached lower down the forks, and to the frame. The second image shows one mounted across the steering head, attached to the tank and the top yoke. The third image, at the bottom, shows a rotary damper. These are still pretty new at the time of writing, and are normally not available as aftermarket items. (There *are* some around but what I'm saying is that they typically are designed into the bike from the factory). Rotary dampers sit at the top of the head bearing, either above or below the top yoke, and use either a rubber friction bearing or a hydraulic system. The outer part of the damper is attached to the frame, and the inner part has a splined hole through which the steering head shaft passes. The rubber or hydraulic system sits between the inner and outer sections so that if the bike gets into a headshaker, the rapid oscillation of the steering head shaft causes the splined internal part of the damper to try to spin from side to side. The outer part is solidly attached to the frame and the friction medium in between the two damps down the oscillation. Or to put it more simply, stick your left forefinger out and grasp it with your right hand so as to make a fist. Now twist your left hand and voila - rotary steering damper 101.

Motorbike suspension - front end.

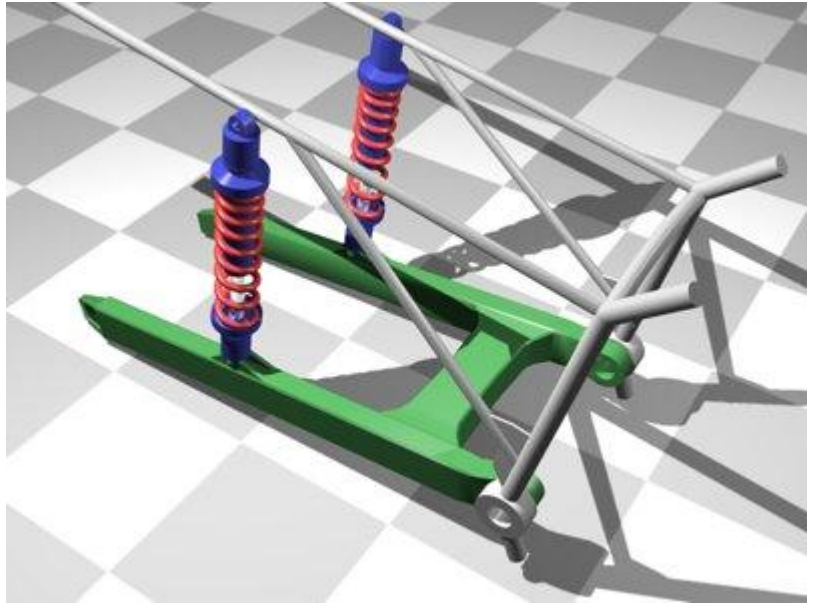
Today's modern telescopic fork front suspension systems are basically the current evolution of something called a 'girder fork'. This was one of the earliest attempts to control the front wheel of a motorcycle but it has one serious disadvantage : as it works through its limits of movement, the effective wheelbase of the motorbike continually changes. Hit a bump, the front wheel moves up and back relative to the frame, and the wheelbase is shortened. Shorter wheelbase means less stability at speed, which is one of the reasons that if you're unlucky enough, you can get into a tank-slapper on almost any modern motorbike.

Check back shortly for a breakdown of the different types of front-end suspension. In the meantime, feast your eyes on :

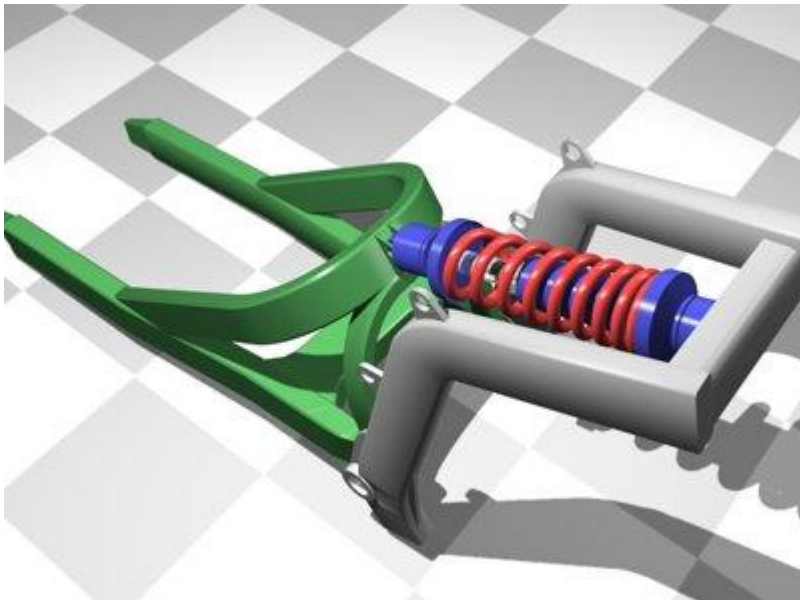
Motorbike suspension - back end.

Twin-shock, regular swingarm

The classic motorcycle suspension system. An H-shaped swingarm is pivoted at the front to the motorbike frame. On either side there are basic coilover units which provide the suspension. The shocks are inside the coilover units. This is about as basic as you can get on a motorbike and has been around for as long as the motorbike itself. This style of suspension began to fall out of favour in the 80's due to weight considerations and the availability of newer, stronger materials. It was also not a particularly robust design by modern considerations. It all got a bit bendy and flexible under extreme riding conditions, and the only way to make it stronger was to add more metal, which added more unsprung weight, which reduced the efficiency of the suspension.



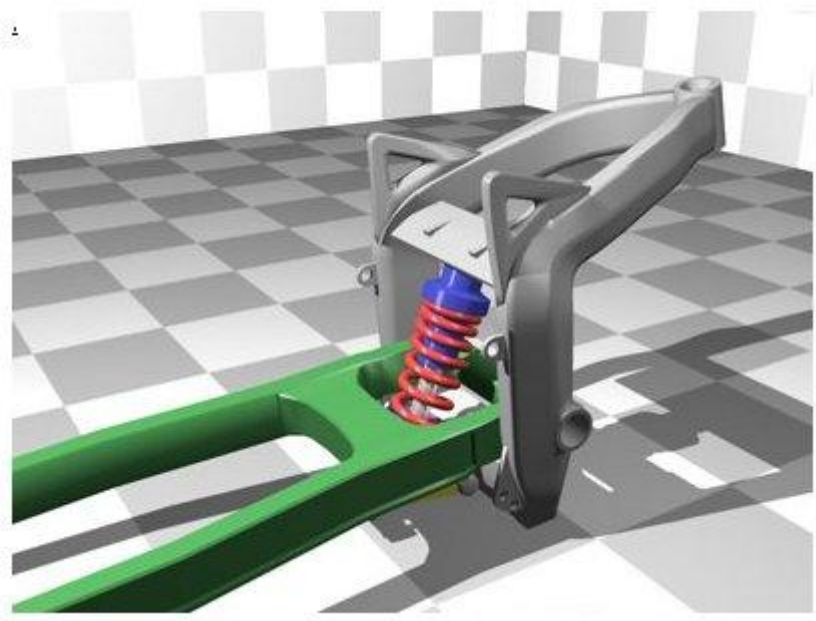
Monoshock, older style, regular swingarm

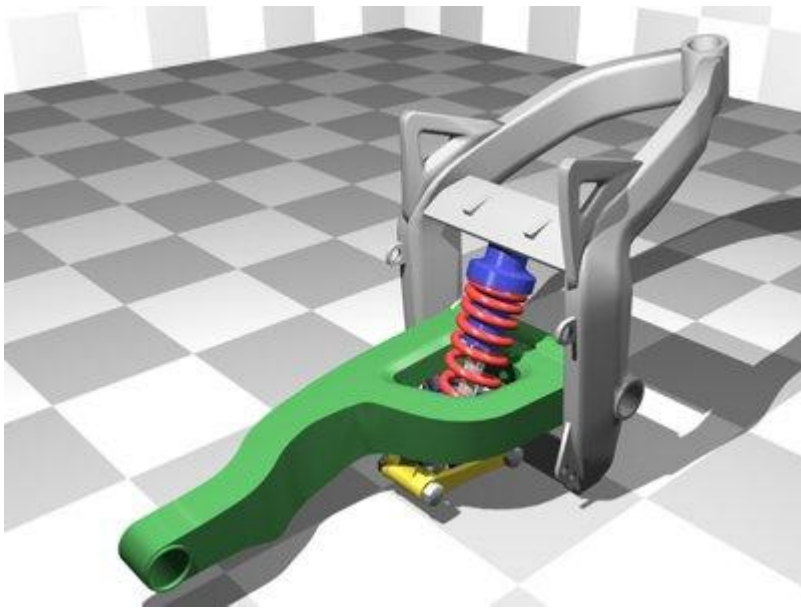


In 1977, the first monoshock system appeared to niche markets and racers. It has actually been around in one form or another since the 1930's, but it was only in the early 80's that monoshocks started to appear on production bikes. Monoshock is actually a Yamaha trademark, but it has become synonymous with the design in the same way as people in the UK refer to vacuum cleaners as hoovers. (The Honda version is called Pro-Link). The premise was that manufacturers could save some weight by redesigning the rear suspension and removing one of the coilover units. Monoshocks are still coilovers, but there's only one and it's mounted centrally to the swingarm. On earlier models, the rear swingarm was a sort of basket with a linkage at the top-front. The monoshock sat nearly horizontal in the bike.

Monoshock, newer style, regular swingarm

On the current monoshock designs, there is now a complex linkage at the bottom end which joins the coilover to the swingarm itself, and its important to lube the joints in these linkages regularly. They are very exposed to the elements when riding. The linkage adds leverage to the suspension plus it allows the coilover to be mounted more vertically. Ever in need of less weight (and hence more speed), those clever engineers who devised this variation were able to remove the 'basket' part of the swingarm, and revert to the traditional "H" shaped arm, only with a bit more welding here and there and stronger materials. Hover your mouse over the image to show a closeup detail of the linkage.

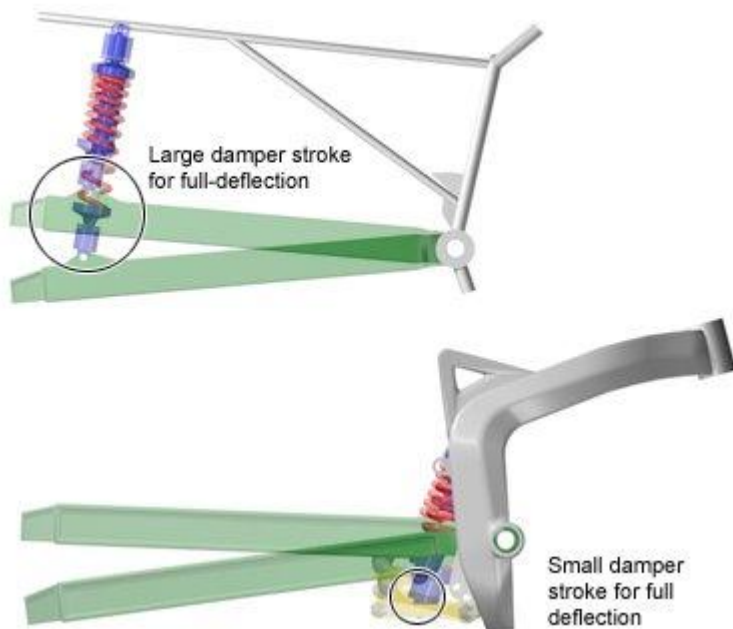




Monoshock, single-sided swingarm

The ultimate evolution of the monoshock design is the single-sided swingarm. These are super-strong, super-lightweight swingarms like you might find on a VFR800. The advantage of a single-sided system is that the wheel can quickly be taken out and replaced. Not really a huge advantage for you or I fiddling with our bikes at the weekend, but for Moto-GP style racing, it does make a huge difference for the pit crew. Single-sided swingarms need to be pretty heavily engineered because they bear the all the stresses from the rear axle offset to one side. With the traditional double-beam swingarm, the design needs to have longitudinal stiffness to stop it from bending. With the single-sided design, it needs to also have torsional stiffness to stop it from twisting under the offset load. As a result, single-sided swingarms are typically a lot larger and have a huge amount of cross-bracing inside them.

One shock or two? The frothy subject of frappuccino damper oil.



In the good old days, motorbikes had two shock absorbers on the rear of the bike, as shown at the top of this section. As suspension evolved, the dual rear shocks were replaced with a single unit, but the question is why? The answer, it turns out, is pretty simple. In a dual-shock system, the suspension units are typically attached very close to the rear axle. This means that as the suspension compresses and expands, the shock absorber pistons are travelling in a stroke which is nearly the same as the full deflection of the swingarm. Hitting a large bump might deflect the rear axle upwards by 10cm and back, resulting in the same 10cm stroke in the shocks. Do this a lot and the shock absorber piston begins to behave like the plunger in one of those natty little cafetières or milk-frothers - it agitates the damper oil so much and so frequently that the oil begins to heat up and foam or froth. At this point it not only looks like frappuccino foam but it has about the same damping properties too, and thus loses its ability to perform as it should. This is known as fading shock absorbers. Enter the single shock absorber system mounted towards the front of the rear swingarm. The swingarm might still have a lot of travel at the axle, but basic geometry shows you that closer to the pivot, the deflection is much less. This translates into shorter shock absorber movements which in turn means less opportunity for the damper oil to froth. The ultimate evolution of this is the complex link monoshock system (also shown above), where a complex series of levers reduce the shock absorber travel even further. Typically multi-link setups like this also have some amount of variance in them so that they have a different amount of deflection in the first part of the stroke to the that in the second. This means a single shock absorber unit can respond better to changing road surfaces, soaking up the smaller bumps and shocks with ease and comfort without sacrificing the ability to respond to the occasional mountain or pothole. As a side note, you'll notice as you read the section on BMW rear suspension below that the monolever and first-generation paralever had a single shock but it was mounted

close to the rear axle. This had all the disadvantages of a dual-shock system without any of the advantages of a single-shock system. For the second-generation paralever, the shock was moved closer to the swingarm pivot, thus bringing the design in-line with the small-deflection idea.

BMW and their contribution to the world of motorbike suspension.



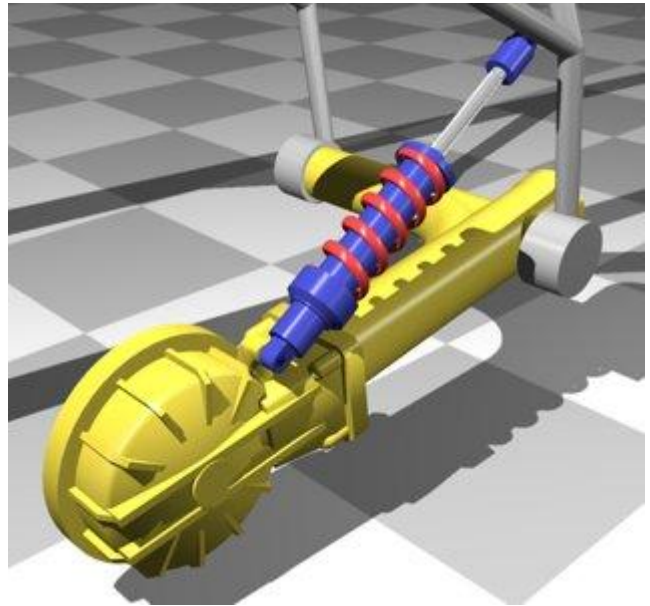
Bayerische Motoren Werke: BMW are responsible for a lot of developments in motorbike suspension - not just the quirky ones. The first hydraulically dampened telescopic fork on a production motorcycle (1937), the longitudinal swinging arm ('50s and '60s), and the long-stroke high-comfort telescopic fork (1970). Because of this, I've given them an entire section to try to explain some of their innovations for which we should all be thankful.

Well perhaps not all, but those riders who have chosen BMW as their steed of choice will know that their bikes have what could best be described as some pretty funky and unconventional suspension systems. BMW, it seems, are never quite happy with the status quo. Why use an existing design when it could be bettered? Why settle for DVD when you can have Blu-Ray? Just because a particular type of suspension system is favoured by the Japanese, and sold on hundreds of thousands of motorbikes every year doesn't necessarily mean that it's the best option. At least not in the eyes of the Germans.

BMW have long been known for their ability to cast scorn the accepted way of things, and pursue other, better methods of achieving the same result. Whether their suspension systems for their bikes actually are better or not I suppose is open to debate. Having ridden and owned a BMW with telelever suspension, I can't understand why it's not used on all bikes. Conversely, bullet bike riders will look at a BMW and see nothing but excess weight. You can be certain of one thing with BMW suspension systems: they're different. Very different. So let's start at the back and work forwards.

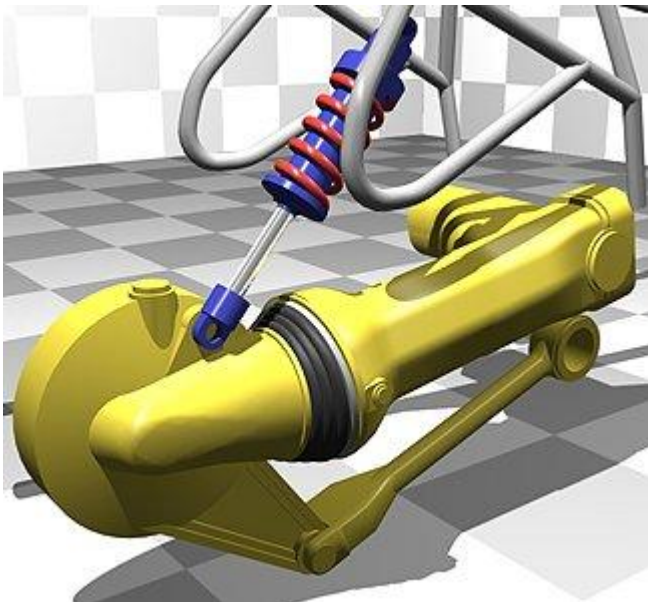
Rear monolever.

In 1980, BMW introduced the world to the monolever suspension system on the back end of their R80GS big dirt bike. Little did anyone know at the time that it was a sign of the radical design changes to come. Most BMW bikes, modern ones anyway, have shaft drive, so its a given on a beemer that one side of the rear suspension is going to be pretty beefy because it has to house the driveshaft and ultimately the rear drive. BMW capitalised on this and with the monolever, they created a single-sided suspension system, much like the Yamaha monoshock, but the shock / strut unit was mounted to one side of the bike, rather than in the centre. The driveshaft ran down the inside of the single-sided swingarm and into the rear drive. This design helped eliminate the need for beefier engineering at the front of the swingarm which would have been needed to resist the torsional load of having the wheel mounted to a single-sided swingarm.



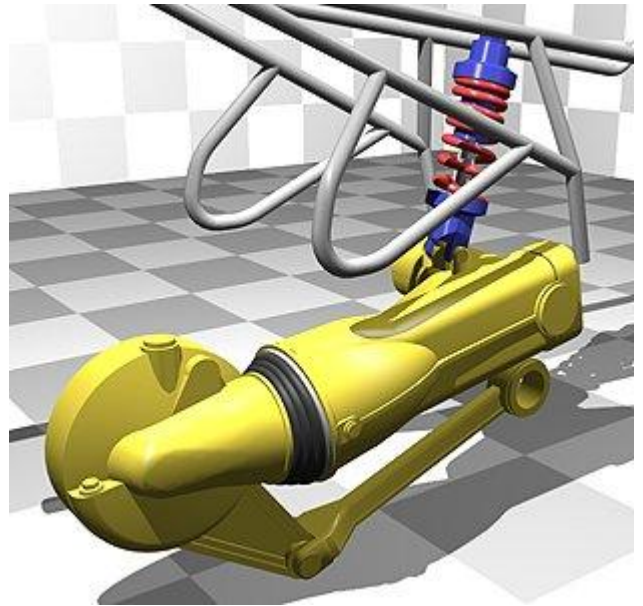
Rear paralever, first generation.

In 1987, BMW improved on their design and introduced the paralever suspension system on the back end of the new R100GS, a system which found its way on to their K1 sports bike too. (Note : This is an improvement of a suspension system originally fitted to the Magni Sfida called *Parallelogramo*. It was also available as a kit for Moto Guzzis in the 80s. *Parallelogramo* itself is a derivative of a prototype suspension of the same type shown on the MV Agusta 500 in 1950) Paralever uses the same basic principle as monolever but adds a lower control arm to the mix and an extra pivot point between the main swingarm and the rear drive. The effect is that the old pivoting swingarm now becomes part of a skewing parallelogram system - in fact a geometric double wishbone system just like in a car. This added lateral stiffness to the suspension, but it also kept the rear drive at the same orientation relative to the rest of the bike. Because of the extra link at the rear drive, the strut / shock unit was turned over so that it was "the right way up", and it was still mounted to one side of the bike. Because the whole system now acts as a *double* swingarm, it substantially reduces the change of load response of the driveshaft. Using this type of suspension was also the impetus for BMW to change to using the engine as an integral stressed member of the frame, which allowed the swingarm and suspension components to be bolted directly to it.



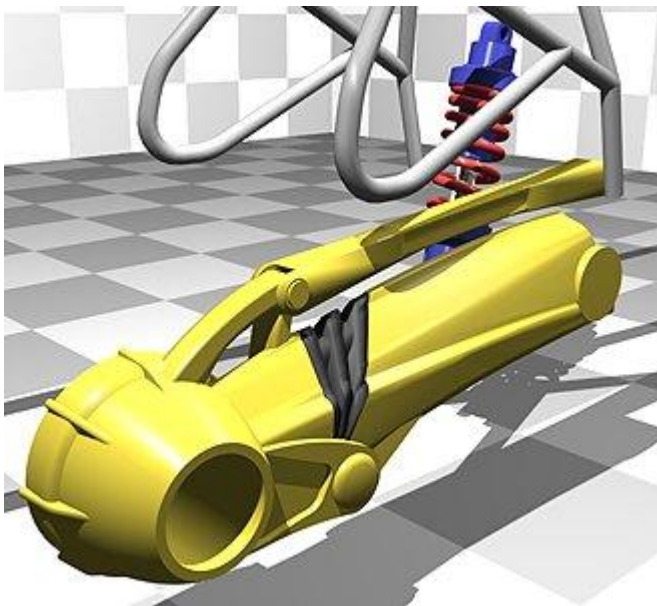
Rear paralever, second generation.

In 1993, the second generation paralever system appeared on the R1100GS. The basic design was the same as the original paralever except that the strut/shock unit was moved away from the side of the bike and on to the centreline, bringing it more in line with the monoshock type system. It also gained a remote preload adjuster and spring plate height adjuster. This new paralever was made of aluminium instead of steel so it was lighter than the original whilst maintaining the strength needed for the single-sided shaft drive system.



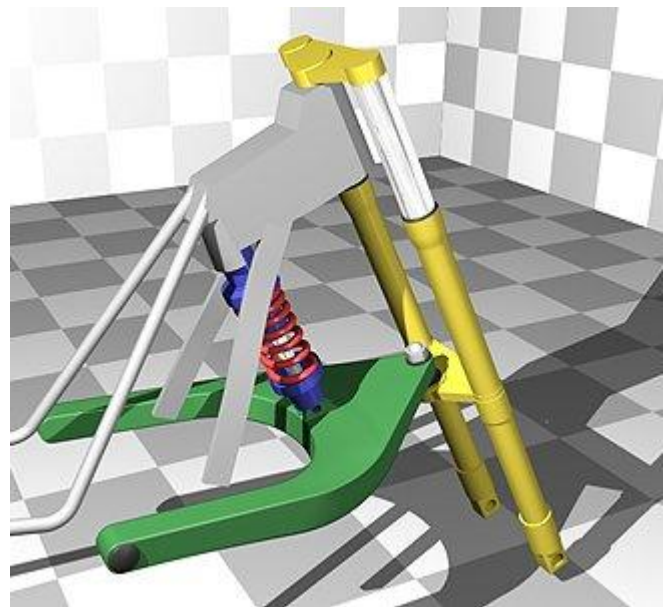
Rear paralever, third generation.

Skip forward ten years to 2004 - which tells you how good the paralever II was that its design didn't change in nearly a decade. The third generation paralever appeared in the new R1200GS. This design is similar but at the same time noticeably different to its predecessor, and at the time of writing is now the current BMW rear suspension of choice. The control arm was moved above the shaft drive from underneath, and the rear drive was changed to have a hole through the middle of it to save weight. The unsprung weight of the latest generation paralever is considerably lighter than its predecessors. That's not to say that it couldn't still be used as a substantial bludgeoning weapon if you got it off the bike, but in engineering terms, it has slimmed down considerably.

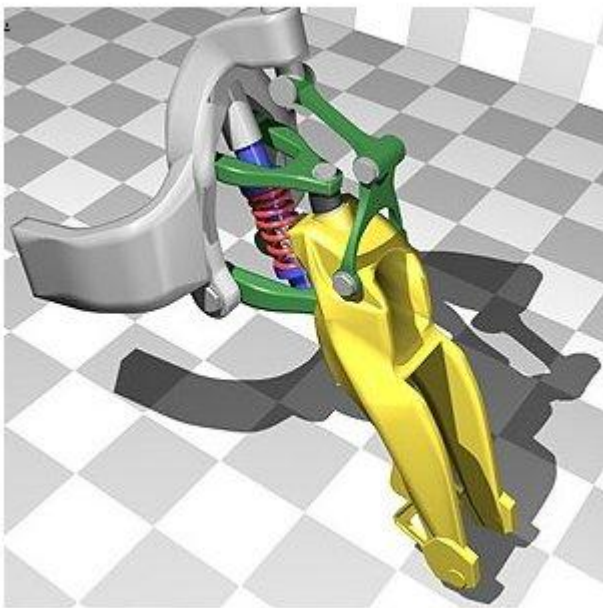


Front telelever.

In 1993, when paralever II appeared on the R1100GS, BMW also introduced their new telelever front end suspension system. The problem with traditional telescopic fork suspension is that all the forces acting on the front of the bike are transmitted to the handlebars, and thus the rider. Some people think this is A Good Thing - it keeps the rider "informed" as to what is going on. Others argue that it is a necessary evil and that telescopic forks are an unfortunate accident of history (see the section on forks above - it's the same reason we got VHS when Betamax was the better system). BMW fell squarely into the second camp, and developed telelever as a method of separating the braking and suspension forces from the steering force. With telelever, there is now a single strut/shock unit in place of the combined spring/shock functions of telescopic forks. Telelever still has front forks, but their primary function now is to make a stiff frame for the front wheel to sit in, and to allow the rider to steer the bike (which is always useful). The strut/shock unit is connected to a wishbone which itself is connected to the frame of the bike at the back via a yoke, and to the crossmember of the forks at the front using a ball joint. When you hit a bump with telelever, the suspension forces are transmitted through the ball joint, across the wishbone and up through the strut / shock unit into the frame of the bike. One of the biggest advantages of this system is that you don't need to engineer an anti-dive system into the forks. The design of the Telelever effectively reduces fork flex under braking to near zero which in turn reduces dive under braking. Another benefit is that the forces acting on the steering head bearings are dramatically reduced. In fact with telelever, as a rider you have to get used to the concept of braking without the bike diving at the front. It's really quite unique.

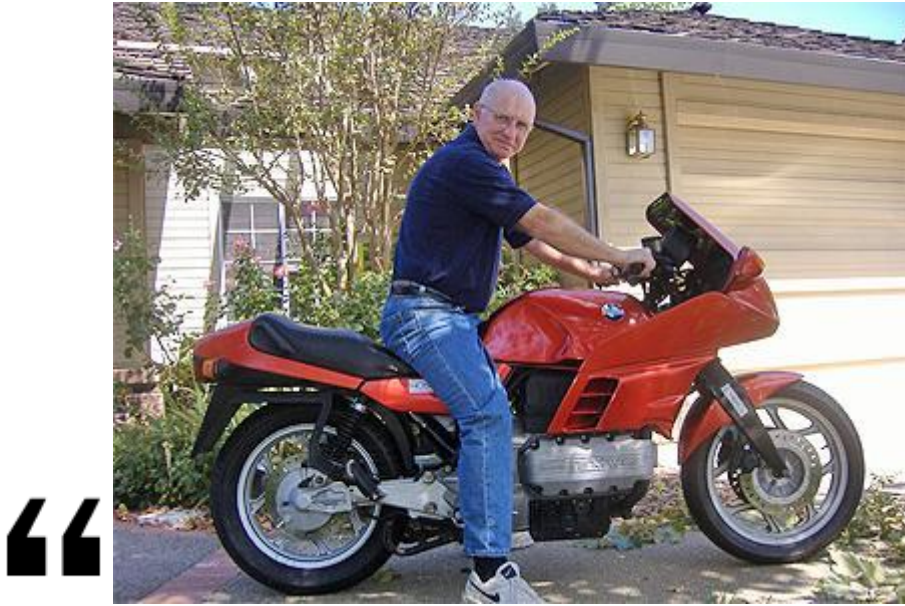


Front duolever.



Never being satisfied with resting on their laurels, by 2004 BMW decided that telelever was yesterday's news, and introduced duolever on the front of their first inline-four sports tourer - the K1200S. I'm not sure, but I think some of the BMW engineers might have discovered suspension nirvana with this system as they now finally have double-wishbone type suspension both front and rear. Duolever is an evolution of Norman Hossack's double wishbone / parallelogram suspension, which is why it's sometimes referred to as Hossack Suspension (see below). The idea itself has been around since Hossack modified a Honda XL500 in 1979. In the early 90's he modified a BMW K100RS, and whilst it never really caught on in England, German engineers understood the idea instantly. Like the rear paralever, it's geometrically a double wishbone system. As with telelever, in duolever the pivoting links and springs are not steered. But with duolever, the physical link from the handlebars to the suspension is radically different, involving a hinged link. If you look at the image here, you'll see the front suspension is completely independent of the steering, with the two only being connected by the hinged link up top. (That link is simply used for *turning* the fork assembly and provides no structural support or strength). Hover your mouse over the image for a close-up of the system. With the combination of paralever III on the rear, and duolever at the front, sitting on and riding a K1200S is unlike riding any other type of motorcycle. Whilst it may technically be the current pinnacle of motorbike suspension design, BMW have created a system which has divided riders into the love/hate camps.

A word from Norman Hossack himself



I set out to bring some new thinking to motorcycle design. I had left McLaren with a wealth of experience seeing how racing cars developed and how Formula 1 addressed their technical problems. I was only a spectator in the motorcycle industry and had no connections with it and still don't; I don't even ride a bike. I do own the first Hossack BMW (see the picture on the right) but can't ride it where I live because the EPA think German carbon monoxide is worse than American carbon monoxide. Back in the mid 70's, from where I stood, motorcycle design problems were obvious and easily solved. Just improve the rigidity, lower the weight, lower the polar moment, and kill 'stiction'. So I did that and it worked, and it won races and then it won again and again. Job done! No! I didn't count on the inertia and negativism in that industry. Seems perceptions are more difficult to change than the engineering. What has become known as the Hossack suspension system, I chose from a list of about 5 designs options that I had invented. I assessed this one was the one that my meagre resources could do justice to. The other would have required expensive tooling and structures and didn't take things that much further forward. I am not talking here about simple material changes; making the same thing from aluminium or carbon fibre does not constitute a new invention. To look at the fundamentals of my design there are some first principal elements to study.

1. Lower weight. A bar bending between fulcrums suffers a pure bending load. However if the load wasn't strictly bending, but straight push and pull, it could carry a load thousands of times higher. This higher value can be exploited with triangulation. Race car wishbones are an excellent example. These little devices can carry thousands of times their own weight and have near total rigidity. Everything on my design is triangulated and with that added strength you have a chance to save weight.
2. If you were able to look down the axis of the steering on my design you would see that the weight was quite close to the pivot axis. This means low polar moment and this is important because most forms of weave are sustained by this mass. The further it is from the axis the greater the chance it can add to weave.

3. Low stiction allows the tyre to ride bumps in with out being bullied by the suspension this is where grip come from. You will commonly hear commentators say 'mechanical grip' in F1 events and that's what I am talking about here.
4. Tellies (telescopic forks) turn brake loads into dive, and dive limits free wheel movement. My system doesn't do that and allows full and free movement even while braking. But more when a tyre is stopped too hard and it loses traction, the energy stored in the front spring of a telescopic system is suddenly released and it punches the tyre further making the chance of regaining traction nearly impossible. Vernon Glasier on HOSSACK1, my first bike, could readily slide the front wheel and still regain traction.

So the fundamentals are there for discussion and challenge. But whether I managed to get it right first time with only my meager resources is in question. Though as a comment on my design it is worth noting that Hossack1 won its last championship in 1988 at which point it was 10 years old. Could I have done better? You betcha! I never built a bike with a real race engine and never found funding to do it the way it should have been done.

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So my attempt to revolutionize motorcycle design was a nonstarter in the environment it was born in and I had to wait nearly quarter a century to see the idea reach production (the K1200S) leaving me out in the cold as patents don't last that long. I wonder when the next manufacturer will take it up and exploit the areas that BMW didn't.

Norman Hossack.

Illustrations of some of Norman's 1974 / 1975 thinking on the subject of front suspension. These support the triangulation part of his essay above; he never set out to build these items and didn't see them as new thinking in any way:



For further reading on Norman Hossack and his suspension designs, pop over to Hossack-Design.co.uk. All images & Text taken from: www.carbible.com