WHAT'S THE BIG IDEA?

One of the biggest leaps in technology we'll see this year is the introduction of Showa's big piston forks on Kawasaki's ZX-6R and Suzuki's GSX-R1000. But already there are a lot of different theories about what they're designed to do, how they do it and even what they feel like. We've enlisted the help of K-Tech suspension guru Ken Summerton to explain everything you need to know

Words: Bob Gray **Pics:** Howard Boylan (Monster Pictures)

First, a fact. While the idea of big piston forks on the ZX-6R and GSX-R1000 is exciting and new, the concept itself is not. In 1981 Mr Wim Peters of WP fame (or White Power as it was known then), developed a 40mm fork called 4045 that used exactly the same idea as the Showa BPF forks. It featured a large diameter piston sliding against the inner wall of the fork stanchion. Granted, it was an off-road fork, but the idea was the same and it was developed for over four years until the firm reverted back to conventional cartridge based forks.

Twenty-eight years later, Showa's new road fork is still worth getting excited about. In fact early reports from the ZX-6R launch suggest it might be the most significant advance in fork technology since someone had the bright idea of turning them upside down*. But how do they work? More to the point, what do they do differently to conventional cartridge forks and what are they going to feel like when you ride them down your favourite road? To answer these questions we really need to understand how a conventional fork works in the first place—and understandably this is something we all struggle to do.

While this feature may look heavy at first glance, what you've got here is everything you need in order to understand how forks work. What it won't tell you is how to set your suspension up. In fact you should really be able to understand all this before you even touch an adjuster... so here goes.

**Simons (USA) first introduced USD forks [Simons UDX] in 1982. They were used by Brad Lackey on his factory Suzuki RN500 to become FIM 500cc World Motocross Champion that year.*

Ken Summerton. He's got a big one and he knows how to use it

CARTRIDGE FORKS

Explanations are virtually useless when it comes to understanding how forks work—you have to see how they work, so we'll try to keep the pictures big and words small. What you can see on this page is a conventional cartridge fork gradually being stripped down. Read everything about it. Then read it again. There are some tricky bits, but if you can get your head around them, you'll truly understand what's going on inside your forks. Then we can look at big piston forks.

CONSTRUCTION

1 The first illustration shows the fork separated into its outer tube, stanchion and internal cartridge components. The outer tube (also called the slider on right way up [RWU] forks), would be clamped by the yokes. You can see the top cap screws into the outer tube. As well as keeping in the oil, this makes the fork airtight. When the fork compresses, air trapped inside is compressed and helps support the load—just like another spring.

2 The spring inside the fork is trapped between the top cap and spring spacer. The spring spacer sits on top of the cartridge, which is firmly attached to the fork bottom. If we unscrewed the top cap, the spring would actually 'ping' it off as it's already compressed (preloaded) a little even when the fork is fully extended and preload adjustment is wound off.

3 When you hit a bump, the cartridge (which is attached to the fork bottom) moves up. This forces the spring spacer to move up, which presses on the bottom of the spring and squashes it in between the top cap.

DAMPING INTERNALS

4 Removing the top cap, outer tube, stanchion, spring and spacer leaves us with the damping internals. Up top you can see the threads that the top cap screws onto. The black plastic section (the spring guide) does nothing, but the orange rubber bit at its base is the bump stop. Imagine pushing the black section down like you're compressing the fork (the damper rod slides into the cartridge) and you can see how it'll eventually hit the top of the cartridge—trying to squash the bump stop

CARTRIDGE INTERNALS

5 Remember the cartridge screws firmly into the fork bottom and is normally full of oil. The piston is fixed firmly to the end of the damper rod. Move the rod and you move the piston. As the piston fits snugly inside the cartridge, it must move through the oil when either part moves.

6 You can also see the top-out spring. Imagine pulling the spritzng guide upwards and the cartridge downwards. At some point, the top-out spring will hit the rod guide. When it does, you'll be compressing the top-out spring between the piston and the cartridge cap. In other words, the top-out spring doesn't want the parts to extend beyond a certain point (the opposite of the main spring, which wants to extend the fork as much as possible).

You can download extra images showing how the fork fits together from our website (where we're not limited by page size) at www.superbike.co.uk

PISTONS

7 Now let's look at the pistons. It's important to understand that these pistons are nothing more than adjustable one-way valves. However, they're built in such a way that there are two one-way valves in each piston.

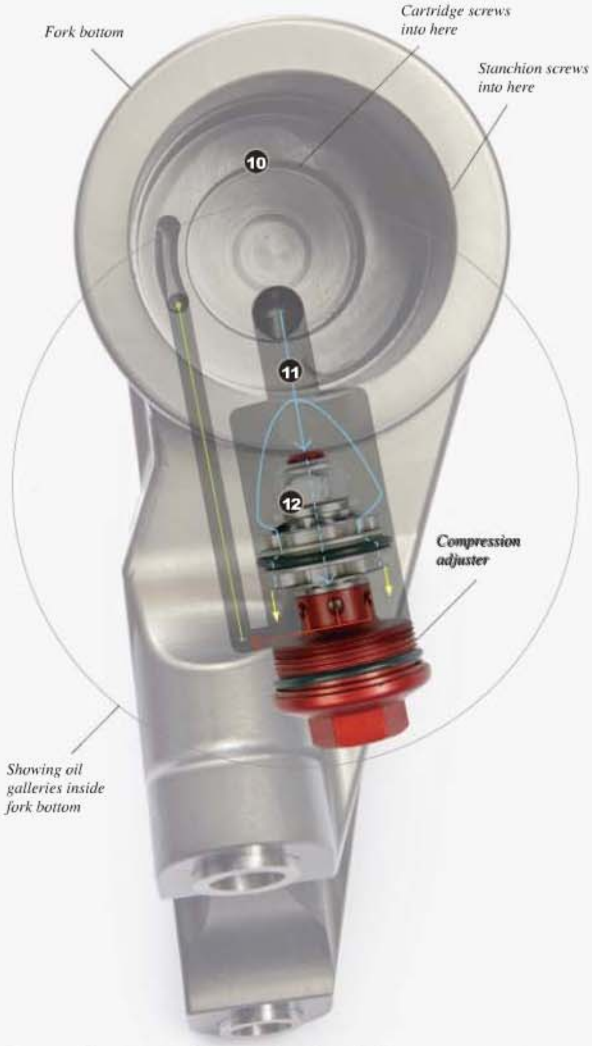
8 Look at the overhead shot and you can see there are a number of holes around the perimeter of the piston. This is where the oil passes through. You can see there are two different sizes (six bigger and six smaller holes). From the side on picture, you can see how the holes are set at different levels—and that there is a raised lip around the outside. When a shim presses down on this lip it effectively blocks those holes off. Of course metal bends. So if oil tries to come up underneath the shim, it can bend it out the way and sneak through (shown by the red arrow). But it can only do that in one direction (hence our one-way valve).

9 Because only half the holes are raised up, the shim only blocks off half of them. When rebounding, rather than try to get through the one-way valve the hard way, oil goes around the top set of shims and down the other set of holes (shown by the green arrow). Of course we've fitted shims to the opposite side too, but because the oil is trying to lift them up, it can escape easily. In other words, pushing the piston in one direction will lift one set of shims, and pulling it in the other lifts the opposite set.

The shims form a seal against this raised lip. Pressure from underneath can lift the washers, but pressure from above simply seats them harder

Rebound oil flow

Compression oil flow



Fork bottom

Cartridge screws into here

Stanchion screws into here

Compression adjuster

Showing oil galleries inside fork bottom

COMPRESSION ADJUSTER

10 Here you can see where the cartridge screws into the fork bottom creating two separate chambers (one inside and one outside). The two holes in the fork bottom link the two chambers giving the oil somewhere to go when the piston moves up and down in the cartridge. Let's look at a very slow compression movement.

11 As the piston moves down the cartridge it squeezes oil out of the hole in the fork bottom. This flows into a chamber where it meets the compression adjuster. Because the piston on the compression adjuster fits snugly, oil is forced through the centre of the compression adjuster. The straight dotted blue line shows its path. At this point, it has to push its way past a tapered needle (the bit you adjust), before it can escape as indicated by the red arrows. It then flows up towards the other hole and is now outside the cartridge.

12 Because these are only small holes in the compression adjuster, and the piston in the cartridge is moving a fairly large amount of oil, it doesn't take long for the port to choke (see next page). Once this happens, pressure builds in the cartridge until there's enough to open the shims on the compression adjuster's piston (as shown by the yellow arrows) where it again flows up towards the outside of the cartridge.

What happens when I adjust the compression adjuster?

As mentioned in paragraph 11, moving the compression adjuster has the effect of moving a tapered needle in and out of the low-speed adjuster port. Moving it in restricts the flow more and vice versa. Or to think of it another way, screwing the adjuster in causes it to choke sooner and winding it out makes it choke later. Following that logic, screwing the adjuster causes you to feel the effects of the main shims lifting sooner rather than later because the pressure builds quicker for a given flow rate.

Two other very important points

Remember the cartridge is sealed (it's not airtight, but it's still fully enclosed), it's important to consider what happens behind the piston as it slides down the cartridge. It's easy to imagine it forcing the oil out of the bottom, but what about the "vacuum" created above?

First, there are several small diameter bleed holes on the piston which permanently link both sides to help balance the pressure and there's the fact that the cartridge is enclosed, but not sealed. This means oil can enter around the rod guide although this is limited. Also, because the damping force is generated by the pressure difference on both sides of the piston, the shims would bleed to keep this as balanced as possible once a certain threshold is reached anyway.

That's the first important point. The second one, which is sort of connected, is that of the differential volumes on either side of the piston, or rod displacement. This is caused by the fact that one side of the piston will always have a bloody great rod in it.

Think of it like this. Imagine the piston half way down the cartridge. If we push the piston down until it squirts out an egg-cup full of oil, it makes sense to assume we could pour the same amount in the other end of the cartridge. But that isn't the case. The reason is because the rod has a volume too.

Say, we had to push the piston 3mm in order to fill our egg-cup; it means we've dragged another 3mm of rod into the cartridge. If the rod has a diameter of 10mm giving an area of 78.54mm^2 ($\pi \times 5^2$), and we multiply it by our 3mm we get a rod volume of 236mm^3. So if we used oil from the egg cup to balance the volume of oil either side of the piston, we'd have 0.236cc of oil leftover. ›

CARTRIDGE FORKS (CONT)

13 Things work the same for rebound. The main piston moves upwards in the cartridge. Now oil above the piston needs somewhere to escape too, and passes into the holes (low velocity rebound) and comes out of the nut below the piston (shown by the grren arrow). This passage is partly blocked by a tapered needle. It's attached to a long tube that you can see poking out the top of the fork in diagram four. Adding rebound damping presses down on this tube and drives the needle deeper into the port (making it harder for the oil to flow).

14 In the same way as the compression adjuster choked, The low speed rebound adjuster also chokes. When it does, pressure builds until it lifts the shims on the bottom of the piston and oil flows as shown by the blue arrow.

Choking

Did you ever squirt water from a washing up bottle as a kid? If not, it's important to go and do it now. What inquisitiveness should have taught you is that the harder you squeeze the bottle the further the water shoots. But that only happens up to a point. Squeeze too hard and the top pops off the bottle and it all goes wrong. The nozzle has choked.

First of all memorise this because it's important; pressure is simply resistance to flow. When you squeeze the bottle gently you're forcing the water to flow out through the nozzle. Keep squeezing gently and there's no problem. Squeeze harder and the water goes further (but the bottle also feels firmer in your hand—the water can't escape as fast as you want it too, so you feel the pressure build in the bottle. Squeeze even harder and at some point the pressure gets so great (water will still be flowing from the smaller hole) that the pressure fires the main cap off or the bottle explodes.

The same thing happens with these valves. As long as the flow rate is within a certain range, they work as normal. But increase the flow rate too much and you create a back pressure—the port chokes.

CARTRIDGE SHIMS

Even though we've generated enough pressure to open the shims on the compression adjuster as shown in Fig12, it's important to remember that the piston in the cartridge (the one doing all the pushing), also has shims to let it bleed oil. Assuming the pressure is still rising, there comes a point when its own shims will open and, rather than pushing the oil like a solid piston, it will also let oil flow through it. And here's the BIG BUT. Even though the piston is effectively leaking (by letting oil pass through it), it's moving so fast there's still enough pressure in the cartridge to keep the compression adjuster shims (Fig12) open as well as choking the low speed port.

If the oil wants to move any faster now, the only option is to bend the washers out of the way more so they cause less restriction. And this happens, although if you try to move a fork quickly enough there comes a point when all the ports choke and the fork feels like it's locked up.

BIG PISTON FORKS

So how are big piston forks different? In one sense they're not. They still use springs to support load and a piston moving through oil to provide damping. The difference is that they've done away with the separate cartridge—instead choosing to make the piston bigger so it touches the inside of the fork stanchion itself.

There are several possible benefits to this system. First, the fork is cheaper to manufacture as there are fewer parts. Second, it's lighter for the same reason and what weight there is, is distributed in a more favourable way for motorcycles (lower down and less unsprung weight). Other benefits are harder to fathom unless you understand the damping itself.

The piston is larger of course. But unlike the reports I've already read about these forks it's not just the piston size that's important—instead the bigger piston allows bigger shims to be used. Incidentally Öhlins TTX concept sits half way between these ideas. It uses a large diameter piston but small shims.

The reason shim size is important is down to control, but we're getting ahead of ourselves. First we need to look inside the big piston fork and see how it works...

HOW DO BIG PISTON FORKS WORK?

Look across to FigB and imagine the stanchion is full of oil below the piston. There's also oil above the piston. Now you hit a bump. It's important to realise the piston itself doesn't move. It's attached to the damper rod, which is attached to the top cap, which in turn is fixed to the outer tube. These are of course clamped in the yokes. So what actually happens is that the stanchion slides over the piston.

Either way, as the fork begins to compress there is a body of oil underneath it that's in the way. For the merest fraction of a second, oil simply bleeds through the bypass hole drilled in the piston (FigC overleaf), however, this quickly chokes and so pressure begins to build. At this point some oil will be flowing up the centre of the rod and through the rebound adjuster (in the wrong direction), however, this too chokes relatively quickly (depending on the rebound setting), and pressure will again continue to rise. Almost simultaneously, pressure acting on the compression shims will begin to lift them off their seat.

Spot the difference

And here's where things differ to small piston forks. Because the piston is larger, we displace more oil per millimetre of suspension travel. In turn, the shims controlling the damping are wider too, giving the oil a bigger mechanical advantage when it comes to deflecting them. This means the oil can start to bleed past at lower pressure than with smaller cartridge system because it doesn't have to push so hard. Also, because the shims are yielding at a lower pressure, and because they have a greater surface area, the deflection needed for a given volume is reduced. So with less movement, the shims can control a greater volume of oil, and because of their fine control, this happens before smaller shims would react.

Under pressure

To simplify it another way, the pressure in a smaller piston fork has to increase more before there's enough pressure to bleed past the shims (which are smaller in diameter and therefore behave more stiffly). In other words, there has to be x amount of pressure in the system before the shims start to bleed. It's the same story with a big piston fork, but the value of x is lower.

Of course you could fit thinner, more flexible shims to the cartridge fork piston to achieve the same effect. But the damping characteristics of the piston are determined by the entire shim pack. Making some weaker affects the performance at high velocities, meaning you'd need to make others stiffer and would lose some control at higher speeds. The same would be true of a big piston fork, but the increased diameter of the shims gives the suspension tuner greater control over the ❯

STRUCTURE

1 Here's the fork with the outer tube removed and it's clear there appears to be less going on inside. The top cap still screws in and forms an air-tight seal to give us an air-gap effect. It also houses the compression and rebound adjuster screws, unlike the cartridge fork which had preload and rebound damping.

2 Immediately below the cap we find the bump stop. Ironically, the thing which stops the forks bottoming is now located at the top. As the damper rod slides into the rod guide, you can see how the bump stop will eventually collide with the rod guide and squash the bump stop.

3 Next we see one of the bushes mounted on the stanchion. This slides up and down with the stanchion as it's housed in a groove. A little below that we see some holes which we'll explain later as these are important to making the fork work. Next we come to the end of the outer tube.

4 As with the other fork, the stanchion is screwed into the fork bottom (you can see the threads), but unlike the cartridge fork the only adjuster we find in the fork bottom is the preload adjuster. There are also no oil passages in the fork bottom, simplifying its construction and reducing cost.

INTERNALS

5 We've removed the outer tube here which allows us to look inside the stanchion. Starting at the top, you can see where the rod guide screws into the top of the stanchion—just like it screws into the top of the cartridge on the other fork. Apart from being bigger obviously, you should notice that this guide also has a seal around it (the cream coloured bit).

6 When the outer tube is fitted, this seal touches its inner wall and stops oil rising above this point. This isn't to create pressure, simply to control where the oil can and can't go. Although it's sealed on the outer edge, there are no seals where the damper rod passes through the rod guide, so oil air can pass from inside the stanchion to the area above the rod guide.

7 Next we see the top-out spring. This works the same as before. Pull the top cap upwards and eventually the spring will be squashed between the piston and the underside of the rod guide—this spring wants to stop the fork extending too far. Immediately below that is the piston which we'll look at on the next page.

8 Next comes the spring spacer, which is does its job while causing the least resistance to oil flow. The spring then is found at the opposite end of the fork to normal. This doesn't affect the way it works at all or its proportion of unsprung weight. But, because the spring is physically lower down it in turn lowers the fork's centre of gravity, moving it closer to the bike's roll centre.

9 The white plastic parts you can see at the bottom do two jobs. As well as fitting inside the spring and acting as a guide, they also help space the spring correctly. In fact it's made of two parts. The bit touching the spring actually sits on top of the preload adjuster allowing it to align its self properly.

Preload adjuster
This nut is threaded onto the bolt in the adjuster. When you add click, the nut moves closer to the adjuster. One full turn moves the nut 1mm. There are four clicks per turn. So four ***clicks equals 1mm of preload. There are 63 clicks in total***

The dotted red line indicates the ramp. The two parts ride *up each other as the nut pulls the bottom one closer to the gold adjuster.*

entire range of adjustment. It's like having a quick action throttle and a normal one—you have finer control with the conventional one.

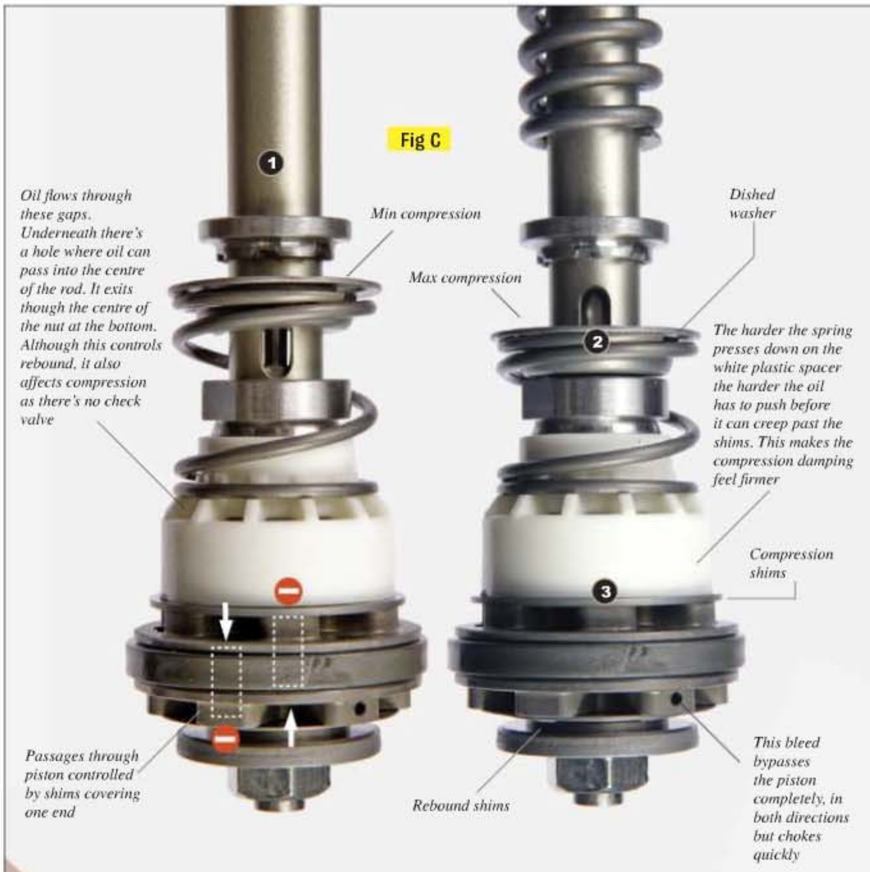
So the oil has passed through the piston. The next problem is rod displacement. Unlike the conventional fork where oil could flow in and out of the cartridge, there's nowhere for it to go in the big piston fork, so four 8mm holes are drilled in the stanchion. It's perhaps easier to look at these in FigA. You can see the holes are in between the rod guide seal and the outer tube's seal. That means there's a very thin space between the outer tube and the stanchion where the oil displaced by the rod can escape into (the oil level is always above these holes). Problem solved.

On the other hand

The next bit can be tricky to get your head around. What happens when it rebounds? Common sense suggests that something with holes drilled in it won't build any pressure. Surely, there's nothing there for the oil to push against and therefore no reason for it to try and flow through the piston? In fact there are several reasons.

No matter where it is in its rebound stroke, as soon as the fork begins to extend two things happen. Pressure on the underside of the piston tries to fall and pressure on the upper side tries to rise. Assuming there's no cavitation the oil simply won't allow the piston to rise until it gets some more oil (in the same way that fluids don't compress, they don't like tension either). And in the same way that pressure builds in compression, the faster the fork tries to extend, the more pressure there is sucking the oil through the piston.

In the reverse of the compression stroke, oil first bleeds though the bypass hole in the piston, but this quickly chokes. Next, it flows past the rebound needle located inside the piston and vents through the nut at the bottom of the damper rod. However once this port has choked the only option left is to open the rebound shims, which have the same advantage over smaller pistons that the compression shims do. And that's how the forks work.



DAMPING CONTROL

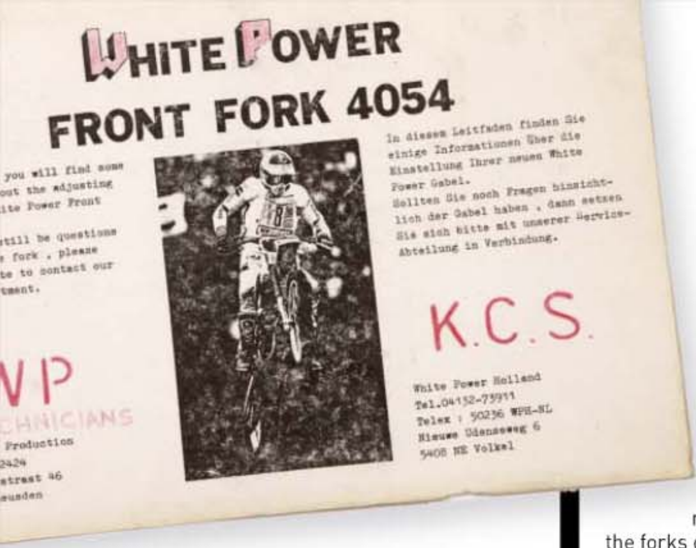
1 Unlike the conventional fork, all damping control on the big piston fork is located around the piston itself. Starting from the top, you can see the damper rod. The smaller metal collar fixed to the shaft is what the top-out spring sits on, but it's not fitted here.

2 Below that you see a dished washer sat on top of a spring. The two pictures show it can move up and down. This is the low-speed compression damping (it's what you do when you twiddle the screw in the top cap). I won't explain that mechanism, but it's important to understand that when you add compression damping at the clicker, what you're really doing is moving this washer downwards.

3 The washer logically presses on the spring which presses down on top of the white plastic part. The white plastic part sits on top of the outer edge of the compression shims (you can see them just below it although they look like one thick shim). So, adding compressing damping makes the spring press down harder on the shims. In other words, the oil has to push harder to lift the shims and so the fork feels stiffer to you.

4 The rebound damping works a little differently as shown in the detail shot. We've removed the nut that holds the piston assembly on as well as the white plastic part. Now you can see inside it. So on the rebound stroke when oil wants to pass from the top to the bottom of the piston, it passes into the hole and has to squeeze past the needle. The more rebound clicks you add, the deeper the needle is forced into the passage (restricting flow). Once the oil gets past the needle, it continues through the hollow centre exiting near the nut (dotted yellow line). At this point someone should say 'hang on a minute'. If the oil can flow though this valve on the rebound stroke, what stops it taking this path on the compression stroke—after all, it's not a one-way valve, just a restriction? The answer is nothing at all. Changing the rebound setting on these forks will absolutely affect the low speed compression damping at the same time. Equally, removing a load of rebound damping would also make the compression stroke feel softer too. It's not an ideal scenario and shows up very clearly when measured—worse than a conventional fork. We'll look at the implications of this later.

LOW SPEED REBOUND DAMPING CONTROL



SO WHAT WILL BPF FEEL LIKE?

Loads of theory is all well and good, but what happens when you stick it on a bike?

It was interesting reading all the initial reports on Kawasaki's new ZX-6R. Everyone seemed to like the forks, stating that they offered finer control both in terms of pitching and also under braking.

I did read one report that said the forks didn't dive under braking—which as far as I'm aware is impratical. No dive generally means no-grip and no-turn-in. I'm pleased to say JP found the nail with the head of the hammer when he said they have, "less tendency to instantly dive."

If I can be so bold as to put words into his mouth... it's the way they dive that's important. Think of it this way. If you were sat in an F1 car and accelerated as hard as possible up to 70mph, you'd probably shit your pants. But being accelerated up to 70mph in the back of a Rolls Royce driven by the best chauffeur in the world would feel very different. Both cars reached the same speed, but they did it in different ways.

Control issues

It's the same with these forks. Both dive under braking and both extend under acceleration. The difference is in how they get there. It'll be interesting to datalog, but in theory, the big piston fork should begin to move sooner, but in a more controlled manner. It'll build up to that movement more slowly. The conventional fork almost has to wait until there's enough pressure inside it to move, then once it does, it's off like a shot—and the difference here is rider perception.

In the same way that most riders (myself included), feel that the rear suspension squats coming out of corners (it doesn't really), most riders can't really notice small changes in suspension position. They can't for instance tell if a fork is compressed 100mm or 120mm because there are so many other things clouding their senses. What they can perceive, is acceleration (positive and negative), and so a fork that moves the same amount, but in a more controlled manner, will feel like it moves less. This is what big piston forks should feel like.

So riding big piston'd forks down your favourite road should feel very different to normal forks. It won't necessarily guarantee you'll go faster, but it should feel like a smoother ride—which is normally enough of a confidence booster to make you rider faster anyway.

It's a set-up

Depending on the setting employed, big piston forks are likely to be more finicky to set-up than even a conventional fork. This is because of the cross-over between the low speed compression and rebound circuits. The key here is going to be balance—almost moving the adjusters as a pair rather than individually. What you wouldn't want to do is have the rebound adjuster wound most of the way in and the compression adjuster most of the way out. This is a disadvantage of this system.

There is a solution though, and one that's being addressed. By splitting the legs so one does all the compression damping and the other takes care of rebound you eliminate the problem. You also cut down on the lack of control as the fork moves between compression and rebound (and vice-versa), caused by the short time it takes one set of shims to seat and the others to open.

The future?

So overall it should be a good thing to have these on your bike. I'm led to believe several manufactures have tried them on their development bikes over the last 18 months including Triumph. And as Showa, who supply an awful lot of OE units, have clearly decided this the way they're going to go, I wouldn't be surprised if they become as popular as radial brakes over the next three years. The good thing is by reading this, you now know what they do.

Unique today, common tomorrow. Expect big piston forks to become the norm soon

HISTORY MAN

Wim Peters, co-founder and owner of WP suspension, came up with the idea of using a big piston fork nearly 30 years ago, so we asked him what he thought about the idea now

"When we started with the idea of a big piston fork in 1981 we were using a 36mm piston—I think the Showa will be something like 38mm because the outside diameter is 43mm. At the time when we started, we chose the big piston because it was the simplest system (using fewer parts), and was lighter too—although I don't remember how much.

The problem we had was always to keep the oil around the piston. On the very fast compression stroke this was OK, but you have to have oil around the piston when it goes in the other direction otherwise there will be no control. At that time we could not find a good solution to make it work reliably all the time. In motocross it is much harder to make a good fork because the speeds are so much higher, reaching maybe 10m/s where in road racing it is maybe just 1m/s.

"IT WAS HARD TO BE BETTER WHEN YOU WERE BEING PIONEERING AS WELL."

Friction

Between starting development and production it was 11 months. As well as keeping oil around the piston we had problems with friction with the bearing bushes. Now they are very good, but we are talking about over 20-years ago and back then the standard of everything you could buy was much lower so there were more problems.

We did serious testing during several season's racing with very good riders. None of them really said they found the fork any better, but you have to understand that at that time we were one of the first to be working with upside down forks and so it was hard to be better when you were being pioneering as well. We were also one of the first companies to take USD forks into production at that time. Our big piston USD fork was used on KTM's 495 which was one of the last big 500cc two-strokes.

Little damping

Because we could never fix it reliably, we made a decision and went testing with a normal cartridge system and decided to develop that instead (which was also quite new at that time) in the upside down fork. I am open-minded about the system, but I don't see big advantages theoretically. For a shock absorber at the rear you can say the bigger the piston the better up to a point, but in the front fork you have nearly no damping anyway, so why do you want that big piston? One thing is for sure, the initial movement is very, very important."