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Three Structural Component Linkage Front Suspension and Directly Connected Suspension for Bicycles and Motorcycles

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ABSTRACT

Directly connected suspension is a simple and effective mechanical arrangement where the shock absorber in control of front wheel suspension action bolts directly onto the rear wheel swinging arm/fork, and, the shock absorber in control of rear wheel suspension action bolts directly onto the front wheel suspension control arm. The controlling shock absorber of its respective suspension system is set at an acute angle and at a levered distance from the pivot point of the member to which it attaches, and where it attaches to the opposing suspension system it is set at an obtuse angle and at a reduced levered distance from the pivot point thereof to transfer a limited amount of load weight and motion from one suspension system to the other, front to rear, and, rear to front. This suspension arrangement gives a self-levelling effect of the body of the bicycle/motorcycle in all dynamic conditions, and alters the suspension settings automatically for cornering braking and straight-line travelling to more ideal.

For the design of directly connected suspension to operate a linkage front suspension in conjunction with a rear swinging arm/fork are required. Both of which have at least one controlling member with a pivot point on the body of the bicycle/motorcycle where both shock absorbers are interposed between members of the front and rear suspension systems.

Three structural component linkage front suspension is one of the most basic and effective ever devised. It comprises of only one suspension control arm pivoting with the vehicle body and two steering members which hinge together. An upper ball joint attached with the main frame of the bicycle/motorcycle with further attachment to the upper steering member and a lower ball joint attached at the outer end of the suspension control arm with further attachment to the lower steering member, just above the front tire, together provide the steering axis. The handlebars attach with the upper steering member close to the upper ball joint and move slightly with suspension travel to give increased road feel for the rider.

Keywords: directly connected suspension, linkage front suspension, shock absorber, cornering chatter, active suspension

1 INTRODUCTION

1.1 Background

Directly connected suspension was first devised for the rigors of motocross, in particular, to combat the menace of ‘square edged’ bumps, which react to throw the rider over the handlebars, and, to reduce pitching motion in the chassis to reduce rider fatigue.

What is termed ‘square edged’ bumps are a particular type of bump with an approaching flat vertical face and a level top. Which on contacting with the front tire sends the front wheel airborne, where, on descent the rear wheel comes in contact with the same bump at a moment before the descending front wheel has made contact with the track surface assisting in the forwards rotation of the body of the motocrosser to create a ‘kick’, which reacts to throw the rider over the handlebars. To counteract this dangerous scenario, if on contacting a ‘square edged’ bump with the front wheel, whereon compressing the front suspension, the rear suspension was to extend slightly then the front of the motocrosser would not be projected in such an upwards direction, likewise there would be no compression of the rear suspension as the motocross chassis rotates rearwards on contacting this bump, thereby retaining the front wheel closer to the ground maintaining a more level travel path of the body/rider, and, on the rear wheel contacting the same bump if it was to react to extend the front suspension slightly so to have the front wheel extending closer to or placed back in contact with the track surface this would prevent the ‘kick’. This is exactly what directly connected suspension accomplishes – slight extension of one suspension system upon compression of the other, front to rear, and, rear to front. Further, one suspension system upon compressing acting to extend the other dissipates energy, that would otherwise rotate the frame around its centre of gravity, giving a more stable ride from the body of the motorcycle.

In recent times, motocross races are no longer won or lost with engine power but rider fatigue is now the most dominant factor. Pitching motion of the frame is what is most energy sapping to the rider - not quality of suspension action but simply reducing chassis pitch gives the least tiring ride. Again, with the front shock absorber attaching onto the rear suspension system swinging arm and the rear shock absorber attaching onto a control arm of the front suspension system most of the chassis pitching motion is eradicated by this arrangement.

The mathematical calculations prior to testing this new suspension arrangement gave a 25-30% reduction in chassis pitch, but upon testing this was found to be inaccurate as test riders reported, on average, a 70-80% reduction in chassis pitch where in certain situations the reduction was gauged to be as much as 90%. To give figures to support and further explain these claims…

1.2 Example

All values are estimated and simplified solely to demonstrate the workings of directly connected suspension for a quick understanding of for the reader. Values of 27% (25% - 30%) reduction in chassis pitch [**1.4**] are from original calculations carried out 18/19 years ago, when directly connected suspension was first tried then tested on private land, only to be then afterwards shelved. Unfortunately, equations from this period have since been lost. Values of 70% - 80% reduction in chassis pitch experienced by test riders [**1.5]** with the motocrosser are also from this period of testing. From the resumption of this technology in 2007 until today all testing has been done on mountain bikes only, which have reduced amounts of suspension travel and do not have the additional stabilizing effect of engine mass.

1.3 Conventional unconnected front telescopic forks and rear suspension

Upon contacting a 90mm bump with telescopic forks their travel absorbs 70mm with the handlebars rising up the remaining 20mm. Unknown to the rider the rear suspension has compressed 2mm – as the frame rotates around its centre of gravity upon impact, which is received at a considerable distance from the centre of gravity (i.e. steering head). The value of the pitching motion with the frame is then a total of 22mm.

20mm (upwards) + 2mm (downwards) = 22mm (1) (1)

And, the centre of gravity of the motorcycle body/rider has risen up by 9mm upon contacting the 90mm bump. With the centre of gravity approximately half distance between the handlebars and the rear swinging arm pivot point the equation for which is as follows;

50% of 20mm - 50% of 2mm = 9mm (2) (2)

1.4 Original calculation for directly connected suspension

Upon contacting a 90mm bump the linkage front suspension absorbs 70mm with the handlebars rising up the remaining 20mm, but now the directly connected suspension arrangement has the rear suspension extend 4mm where the pitching motion has a value of 16mm.

20mm (upwards) – 4mm (upwards) = 16mm (3) (3)

A reduction in frame pitching motion of 27%. The centre of gravity rises 12mm upon contacting the 90mm bump. An increase of 33%.

50% of 20mm + 50% of 4mm = 12mm (4) (4)

1.5 Actual calculation for directly connected suspension

What the latter calculation did not take into account was increased efficiency of the front suspension, due to decreased pitching motion in the chassis combined with increased rising of the centre of gravity, upon contacting the bump. Now 75mm of the 90mm bump is absorbed with the handlebars rising up the remaining 15mm, plus the rear suspension has extended an extra 1mm from 4mm to 5mm, as the front suspension control arm with direct attachment of the rear shock absorber has an extra 5mm of motion from 70mm to 75mm. The pitching motion in the chassis is then 10mm. A decrease of 55% over telescopic forks.

15mm (upwards) – 5mm (upwards) = 10mm (5) (5)

The centre of gravity has risen 10mm.

50% of 15mm + 50% of 5mm = 10mm (6) (6)

An increase of 11%, or, only 1mm higher than telescopic fork designs, which goes unnoticed by the rider anyway.

1.6 Conclusion

The original calculations gave a 25% - 30% reduction in chassis pitch but on testing riders experienced what was surmised to be a 70% - 80% reduction. These original calculations did not take into account the beneficial effects directly connected suspension has on the action of front/rear suspension to further reduce chassis pitch and improve suspension action. N.B. The above theories and values can be repeated for when the rear suspension absorbs a bump, which is most likely the same bump, where again the rider has experienced a duplicated reduction in chassis pitch, in sequence, to further enhance ride quality. Further, a 55% reduction plus a 55% reduction of the remainder will give an 80% reduction in chassis pitch that corresponds with the original claims made by test riders.

Directly connected suspension obviously had the most potential of all recent chassis/suspension developments and from this basis a massive development step was conceived, but, a more functional front suspension system, other than the original one tried and tested on the motocrosser, was required if directly connected suspension was to become a success.

2 MOTORCYCLES

2.1 Description - directly connected suspension

The front shock absorber is set at an acute angle and at a levered distance from the pivot point of the front control arm to which it is attached where the outer end of the front shock absorber is further attached to the swinging arm/fork of the rear suspension system close to its pivot point and set at an obtuse angle to this pivot point. The rear shock absorber attaches at a levered distance from the pivot point of the rear swinging arm and is set at an acute angle from this pivot point with its outward end further attaching to the front suspension control arm at an obtuse angle and at a position close to the pivot point thereof. Both front and rear shock absorbers cross over in this manner. This gives a self-levelling effect in all dynamic conditions and also provides superior suspension action than that achieved by conventional designs of mechanical suspension arrangements that operate independently of each other. When one suspension system encounters a bump or there is a sudden change in velocity with the travelling motorcycle – where such is only partially absorbed as no conventional motorcycle suspension system fully absorbs unsettling forces encountered – the opposing suspension system extends slightly to ensure the body of the motorcycle remains in a parallel plane to the ground.

2.2 Electronic ‘active’ suspension

The differences in ideal requirements for straight-line travelling braking and cornering are so extreme (lowered ride height with standard suspension settings/stiff front and light rear suspension action/preloaded extended very light front and rear action; respectively) that is may be impossible to obtain desired settings until fully active suspension is implemented onto motorcycles. Unfortunately, due to development costs, development complexity, design complexity, vulnerability, available spacing, and substantial additional weight it is doubtful we will see fully active suspension in the foreseeable future. What will materialise, and some designs are already developed at present, are ‘semi-active’ electronic suspension systems to adjust the operation of shock absorbers/telescopic forks on-the-move. These ‘semi-active’ designs alter the internal compression and rebound dampening settings and/or have the ability to increase or decrease spring preload, but fundamental issues are not being addressed by such marginal improvements in performance. Today’s telescopic forks with independently operating rear suspension will have to radically alter or be abolished if suspension technology is to progress. Recent developments in so-called ‘active’ suspension are only a temporary solution to prolong the development life cycle of present suspension designs, in particular, telescopic forks.

Directly connected suspension operating in conjunction with a mechanical linkage front suspension offer an alternative that is close to meeting the above requirements; standard settings but standard ride height for ordinary straight-line travelling; stiffening of the front and lightening of the rear under braking; and, reduced compression of the motorcycle when cornering combined with a lightening of both front and rear suspension action. All of this happens automatically responding to the dynamic conditions imposed upon the motorcycle with no need for external power sources, actuating motors, diagnostic implements, or additional mechanisms that will be required for active suspension systems.

2.3 Directly connected suspension operating

Directly connected suspension acts like a mechanical active suspension automatically altering suspension leverage ratios during braking, acceleration, cornering, up-hills and down-hills from a base setting present when steady-velocity level-ground straight-line travelling to more ideal for differing circumstances. This is achieved by simply displacing the shock absorber/s, set at acute angle/s, to increased or decreased acute angles, by means of its/their attachment to the opposing suspension system upon its/their compression or extension. A shock absorber set perpendicular to an arm will have a compression ratio of 1:1, but once angled over to an acute angle this increases the leverage ratio where it will continue to increase to a certain extent as the shock absorber is leant further from perpendicular. The amount of wheel travel available will also increase with the increased leverage ratio for any given amount of shock absorber travel.

Further, as discussed above, directly connected suspension doesn’t just self-level on absorbing bumps but also reverses its operation and self-levels for depressions or on going over ledges.

Upon extension of the front wheel suspension system into a hollow, with telescopic forks this causes the frame to pitch forward exasperated by an extension of the rear suspension system as weight is removed from it, now with the front suspension extending the rear suspension will react to compress slightly keeping the main frame more level in these conditions. And, with the rear suspension extending into a hollow this will also have the front suspension system compress slightly to maintain greater stability of the body.

For front wheel braking, compression of the front suspension reacts to have rear wheel suspension extend. This displaces the acute angle of the front shock absorber closer to perpendicular by means of its outward attachment to the rear swinging arm where this attachment point has moved upwards (and slightly rearwards), decreasing the leverage ratio thereby stiffening front suspension action. The rear shock absorber has its outer end displaced downwards (and slightly rearwards) by means of its attachment to the now compressed front control arm affecting an increased acuter angle thereby increasing the leverage ratio thus affecting a lightening of rear suspension action. Plus, the in brackets, slight rearwards displacement of the front shock absorber allows the front to dive more – offset by restricting excessive diving geometry utilized by the linkage front suspension – to further decrease its leverage ratio, and, slight rearwards displacement of the rear shock absorber has additional extension and lightening of rear suspension action.

The above scenario can be repeated for down-hills where weight transfer has loaded the front suspension.

And, this scenario is reversed for up-hills and under hard acceleration where weight transfer has loaded the rear suspension affecting a decreasing of leverage ratios stiffening rear suspension action plus enacting a lightening of the front suspension.

The dynamics involved concerning cornering present difficulties achieving ideal suspension settings spring rates and leverage ratios. Once the motorcycle is leaned over from vertical centrifugal and related forces compress and stiffen both suspensions when, ideally, they should become lighter in action to absorb bumps that are incoming at angles other than that which suspension travel is orientated to accept. Further, the recent practice of designing in lateral flex into frame/suspension components to provide an amount of cornering suspension travel for the leant over chassis is not without its problems. At full extension of the suspensions lateral flex is at a premium and at full compression lateral flex is held to a minimum, which is the opposite of what is required. At maximum speed fully extended laterally flexing suspension is to the detriment of straight-line travelling stability, and, during cornering compressed suspension is restricting lateral flex that was designed in. In addition to these conflicting syndromes is excessive diving during front wheel braking resulting in stiffer rate front springs, than would be ideal, to counteract this compression. Linkage front suspension can be designed to dive less during front wheel braking than with telescopic forks taking one awkward predicament out of the equation – this being excessively stiff front suspension spring/s. Directly connected suspension, on reacting to extend the opposing suspension system during compression of the other suspension system, gives reduced overall compression of the motorcycle during cornering benefiting any lateral flex in the chassis. And finally, both front and rear shock absorbers, when both suspension systems are compressed during cornering, are displaced to more acute angles thereby increasing leverage ratios and lightening suspension action to potentially offer increased travel for cornering bumps. Lateral flex and stiff suspension action with increased lean angles of the motorcycle achieved from superior tire grip led to the syndrome known as cornering ‘chatter’. Linkage front suspension and directly connected suspension give many advantages to reduce the risk of cornering ‘chatter’ yet provide superior suspension action (of reduced leverage ratios) when cornering, plus chassis component dimensions and designs can now be redesigned to avoid harmonic frequencies associated with and responsible for cornering ‘chatter’.

Directly connected suspension has been found to be too efficient as it has a natural ‘anti-wheelie’ aspect to it. This is because the shock absorber/frame/swinging arm relationship no longer has such a defined ‘locking’ point to it when rearwards pitching motion of the frame is experienced under acceleration, which instantly stabilizes into an equilibrium of forces resulting in a lifting of the front wheel off of the road surface. Now such a ‘locking’ point is difficult to determine as the outward attachment point of the rear shock absorber is no longer fixed in these circumstances but retreating from the line of force, which acts to defy establishing a ‘locking’ point. With this ‘anti-wheelie’ measure superior drive can be obtained and a shorter wheelbase utilized to the benefit of cornering performance and weight reduction, in particular, (unsprung) weights of suspension components.

2.4 Three structural component linkage front suspension

In recent times, motorcycle telescopic forks have been found to be nearing the end of their development cycle where an alternative front suspension design will have to be found soon. This conclusion is occurring due to increased tire grip giving increased lean angles during cornering resulting in cornering ‘chatter’ – a dynamic phenomenon that results from displacement of chassis components in a lateral plane, utilized as suspension travel for the leaned over motorcycle, where as chassis components rebound back to its/their original form/s from its/their lateral displacement, should this happen in harmonic sequence, this creates an amplified vibration referred to as ‘chatter’. To counteract this unsettling phenomenon, if lighter suspension action could be made available for cornering in comparison to straight-line travelling, even with the motorcycle leaned over at angles of up to 60 degrees less lateral flex would be required from chassis components as increased suspension travel would occur in the motorcycle’s vertical plane to absorb cornering bumps. This would present the possibility of stiffer chassis components, designed to laterally flex less but at higher natural frequencies out with that associated with and responsible for cornering ‘chatter’.

To make the above possible a linkage front suspension was required, one with a pivot point on the main frame of the motorcycle, so directly connected suspension could be utilized and provide altering suspension settings required for cornering. Even with this requirement fulfilled there was still an important issue needing addressed. Telescopic forks have one major advantage over nearly every other front suspension design; this is superior feeling at the handlebars. A situation that is now exasperated by directly connected suspension as it provides superior suspension action plus reduced chassis pitch further reducing rider ‘feel’ – there has always been a conflict of interests where as suspension action improves rider feeling is lost. Taking this into consideration a simple linkage front suspension was required that would provide additional ‘feel’ at the handlebars. One with the possibility of having the handlebars move slightly with suspension travel to provide magnified feeling from the front tire; to have structural steering members extend considerably outwards of the line of the steering axis to prevent any steering ‘feel’ being lost to flex and/or play in the system (this extension out from the steering axis is at the expense of increased steering inertia but it is a necessity; a situation that can be mitigated by using lighter stiffer materials such as aluminium to replace steel, etc); and, to provide the most direct connection from the front wheel axle to the handlebars. Three structural component linkage front suspension met these requirements. The first design of [**Figure 1.]** had a lower ball joint positioned inside the front wheel hub, which was at the end of a suspension control arm. This control arm pivots with the main frame and has the front shock absorber attach at a levered distance plus the rear shock absorber attach close to its pivot point. A steering member kingpin attached with the lower ball joint, further receiving the front wheel axle nearby, extends outwards from this position to a hinged pivot point with a second steering member in front of the front tire. This second steering member extended upwards and rearwards of this position to an upper ball joint, which had further attachment to the main frame, and near this position the handlebars fixed rigidly to this upper steering member.

This design of three structural component linkage front suspension **[Figure 1.]** was very successful providing superior suspension action compared to telescopic forks but it was beset with six minor issues. (i) It was found difficult to obtain reasonable strength and stiffness but retain light weight for the suspension/steering members due to their designs, in particular, this was apparent with the long upper steering member. (ii) Due to the lower ball joint being positioned inside the front hub, to have it in the bike’s centreline, this restricted steering lock, and, the suspension control arm had to be of an ‘U’ shape to provide ample steering clearance for the front wheel. (iii) With the control arm being one-sided to access the front hub this made equal amounts of lateral flex difficult to regulate. (iv) As the suspension control arm extends rearwards and slightly downwards from the lower ball joint this positioned its pivot point very low on the main frame, which, upon front wheel braking reacted to push this pivot point downwards whereon this projected the bike's centre of gravity forwards (from a forwards downwards rotation of the main frame) taking load off of the rear wheel to the detriment of road-holding and braking performance. (v) Increased steering inertia, with the forward pivot point of the two steering members, could be detected, where it was considered a more inboard pivot point position was more appropriate to reduce this polar moment of inertia. (vi) With the long upper steering member having 2 degrees of motion complying with the range of front suspension travel this slight handlebars' motion was lost in the suspension system as the upper steering member flexed combined with ergonomics of the rider upon compression of the front suspension leaving the impression that the handlebars were more rigidly fixed than that of telescopic forks!

By repositioning the lower ball joint from inside the front hub to above the front tire yet retaining the same basic architecture of the original design all six issues were addressed [**Figure 2.].** A straight centrally positioned control arm could now be utilized; the lower steering member now became the largest member but of a strong triangulated design with its outward pivot point positioned closer to the line of the steering axis; and, a shorter upper steering member with greater degrees of pivotal motion corresponding with suspension travel. Further, the control arm pivot point is now higher on the frame, with the possibility of positioning it directly above the rear swinging arm pivot point, where front wheel braking reaction now places load onto the rear wheel (and rear wheel braking places more load onto the front wheel than previously experienced) to benefit road-holding and braking performance.

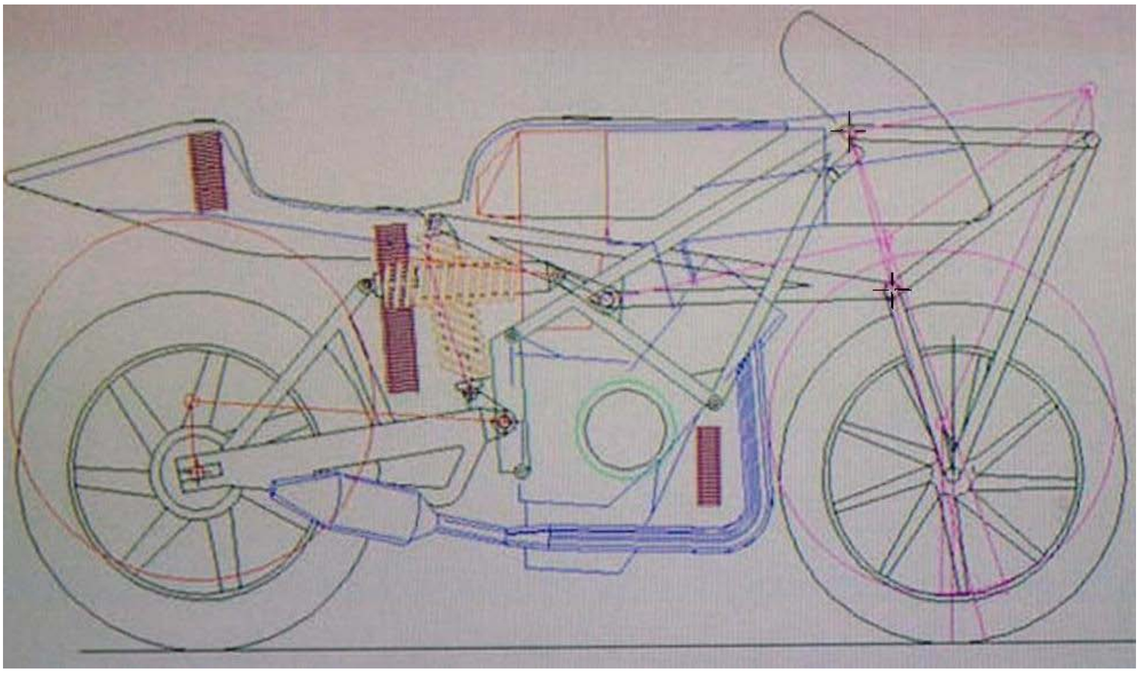
2.5 Braking

Initial braking force reacts to have the brake calliper subject rotational force onto the steering/suspension member it is attached to, in the same direction of the rotating front wheel. For telescopic forks this, in most instances, should be a force perpendicular to the line of the fork therefore be of a neutral reaction, but this is not desirable as on initial braking load needs to be instantly applied to the front tire to ensure grip is present to prevent the front wheel from locking up. With the calliper fixed onto a leading link of a linkage front suspension system initial braking reaction is to extend the front suspension (thereby pushing the bike's centre of gravity upwards), which places load onto the front tire minutely before braking force is subjected to it (due to tire flex), which is perfect for braking performance, whereas with a trailing link of a linkage front suspension this reaction is to compress the front suspension, which is undesirable, initially taking load off of the front tire. Then after this initial reaction the next instantaneous reaction is for the slowing front wheel to compress the telescopic forks (this is also apparent with trailing link linkage front suspension), which is desired, but due to excessive rearwards travel of telescopic forks this compels the forks to compress too much and not have available travel at acceptable compression rates for adequate suspension action under hard braking. Leading link linkage front suspension reacts to have the slowing front wheel extend the suspension, which is taking load off of the front wheel to the detriment of braking performance and road-holding. From the above scenarios with the three common front suspension systems, there is no perfect design for front wheel braking.

This final design of three structural component linkage front suspension [**Figure 2.]** has the required reactions for front wheel braking. With the disc brake calliper fixed to the lower upright triangulated steering member initial braking force reacts to rotate it forward. Given that the lower ball joint, with load upon it from spring pressure of the front shock absorber, is positioned behind and above the front wheel axle as a fixed bearing point this reaction is to force the front tire into the road surface and simultaneously initiate compression of the front suspension to further fluidly apply load onto the front tire. The slowing process of the front tire will then continue to load up the front suspension where a desired amount of load/dive can be achieved from the steering/suspension geometry utilized.

Figure 1.

Figure 2.



3 BICYCLES

The above motorcycles dynamics associated with three structural component linkage front suspension and directly connected suspension apply for bicycles, plus…

3.1 No loss of energy when pedalling

In recent times, bicycle design has progressed from having no suspension to the ‘Y’ framed bicycle with dual suspension, then, in general, digressed to commonly having the ‘hard-tail’ (telescopic fork front suspension only with no rear suspension) as the most popular design of bicycle. Dual suspension is essential for not just rider comfort but safety. Road-holding and braking performance are greatly improved when a bicycle has both front and rear suspension systems. What influenced this apparent u-turn in cycling technology was dual suspended bicycles (‘Y’ framed and alternative designs) were too inefficient when pedalling where excessive bouncing motion is experienced, which is a loss of energy. Even today’s more common ‘hard-tail’ suffers from too much energy loss due to excessive bouncing motion of the front suspension when the spring rate is ideal for rider weight.

Now development is ongoing to create an ‘intelligent’ rear shock absorber that will absorb road shocks but resist bouncing motion when pedalling - a costly intricate and potentially vulnerable enterprise.

Directly connected suspension on bicycles is the most (possibly only) successful suspension means of eradicating bouncing motion, both front and rear, when pedalling when ideal spring rates are utilized. Not only is this a massive breakthrough in cycling technology but it is achieved with low cost standard shock absorbers. How this is achieved is by the previously detailed operation where compression of one suspension system reacts to extend the other. Where, with both shock absorbers crossing over, this reaction is front to rear and rear to front, basically cancelling out any compression or extension of either or both suspension systems when pedalling thrust is apparent.

The following may be additional factors in this breakthrough: - self-levelling effect of directly connected suspension has the frame of the bicycle remain more parallel to the ground when suspension motion is experienced where if there was any bouncing motion it would impact equally on both suspension systems/springs; the high rear swinging arm pivot point would, if there was compression caused by the downward thrust of pedalling, react to project the bicycle’s centre of gravity downwards and, crucially, forwards where there is natural resistance against accelerating the centre of gravity forwards; with linkage front suspension geometry having front wheel travel in a more directly upwards manner (compared to telescopic forks) in the initial part of suspension travel this has more resistance to compression of the front suspension when accelerating; and, more preloading of both suspension springs, which is beneficial to directly connected suspension operating, stiffens up the lightest (initial) part of suspension travel to resist bouncing motion when pedalling.

Three different types of linkage front suspension have been tested on four different mountain bike prototypes where no bouncing motion when pedalling was recorded every time. It is most definitely directly connected suspension that is responsible for this breakthrough in cycling technology. N.B. This breakthrough was discovered by a reigning national downhill mountain bike champion **[Reference 2.]** when testing these prototype designs.

4 LIST OF ADVANTAGES

4.1 Reduced frame pitch

Pitching motion in the frame is reduced in all dynamic conditions with up to 90% improvements reported by test riders in certain circumstances **[1.1]**.

4.2 Suspension action on 'square-edged' bumps

This is one of the primary reasons directly connected suspension was devised, to counteract this menace, where this could be considered the design's forte **[1.1]**. Of particular importance is the advantages this gives for motocross enduro supermoto and mountain bike racing, plus it is a general safety feature for all types of bikes and riding disciplines.

4.3 Reduced spring resonance

With two springs operating against each other at different harmonic frequencies this counteracts spring resonance where there is reduced bouncing motion from disruption of the suspension benefiting overall suspension performance.

4.4 Fluid suspension action

Motocross racing is the most demanding of all on bike suspension where the best production rear suspension system to date is the original *Suzuki Full Floater* (1981-1985), which had the top of the shock absorber attach onto a rocker arm and the bottom attach onto the rear swinging arm. There was no direct connection with the shock absorber onto the frame unlike designs utilized by the competition. Directly connected suspension takes this principle a stage further where the outward ends of both shock absorbers attach onto members of the opposing suspension system, which are not fixed but move independently and beneficially with the other suspension system. Further, because there is a linked arrangement to the opposing suspension system the respective shock absorber is pushing against a position, which in most circumstances, is retreating from the incoming force. This is the most fluid way of subjecting sudden forces to a static mass - i.e. body of the bike.

4.5 Greater stability

As sudden jolts are being transformed into a slight lifting motion of the frame and not acting to rotate it around its centre of gravity, and, some of the energy from motion of one suspension system is being dissipated as it is transferred to the other suspension system an overall improvement in bike stability is obtained.

4.6 Reduced impact on two wheel landings

When there is a two-wheeled landing, or travelling over a compression dip, both ends of both shock absorbers are compressed simultaneously automatically stiffening the suspension action. Less front and rear suspension travel is available when this occurs but what is is at a higher compression rate to the benefit of resisting bottoming out of both suspensions.

4.7 Mass centralization

With telescopic forks, their mass and that of a substantial steering head are far removed from the centre of the bike, which is where its centre of gravity is positioned. Now with this new arrangement the heaviest suspension components – two shock absorbers – are positioned close to the centre of the bike to give a concentration of mass around its centre of gravity to benefit handling and manoeuvrability.

4.8 Low centre of gravity

Again, as described above [**4.7]**, the heaviest suspension components are positioned lower in the frame lowering the centre of gravity, thereby giving the impression of the bike being lighter than it is for any given weight.

4.9 Steering and chassis geometry

Telescopic forks operating with a parallel steering axis to them detrimentally restricts bike geometry. For telescopic forks to function adequately they had to have excessive rake angles beyond that which is ideal for steering considerations. Now front wheel travel and steering head angles are not intertwined where both can now be set for optimum performance to benefit steering, handling and, in particular, suspension action when front wheel braking. Further, the geometry can now be designed to beneficially alter upon compression of the suspension systems.

4.10 Lighter steering

A steeper steering head angle can be utilized **[4.9]**, without design constraints of telescopic forks, to affect lighter steering action.

4.11 Safer Cornering

Any rocking motion caused by bumps or changes in velocity during cornering can influence a break in traction when the bike is leant over, which is dangerous. With directly connected suspension reducing pitching motion in the chassis plus shock absorbers utilizing lighter suspension settings **[4.37],** and with lateral flex better regulated **[4.47]** in the frame/suspension components, bumps and changes of velocity have reduced unsettling action when cornering.

4.12 Improved cornering speed

With the potential for a shorter wheelbase [**4.14/4.15]**, greater mass centralization [**4.7]**, and the advantages of directly connected suspension **[2.3]** cornering speed can be safely increased.

4.13 Reduced front suspension diving when front wheel braking

With front wheel travel no longer travelling upwards and displacing considerably rearwards (to have telescopic forks operate adequately), now with only a slightly rearwards displacement upon compression this will now not overly cause the front suspension to dive dramatically upon front wheel braking leaving ample suspension travel to absorb road shocks present.

4.14 'Anti-wheelie' dynamics

Directly connected suspension has a natural anti-wheelie aspect to it **[2.3]**, which can manifest itself in superior drive and road-holding when excessive power is applied to drive the rear wheel. Such can also allow for a shorter wheelbase to be utilized **[4.15]**.

4.15 Shorter wheelbase

Cornering performance **[4.12]** can benefit from this [**4.14]**. It is also beneficial for weight savings and strength and stiffness of chassis components, in particular, suspension components, reducing unsprung mass **[4.16]**.

4.16 Reduced unsprung mass

Sprung mass being the frame engine or pedals etc, which, ideally, should be unaffected by suspension motion, and, unsprung mass is the components that move with suspension motion (wheels control arms springs etc). These components should be as light as possible to have least effect on sprung mass. A shorter rear swinging arm/fork **[4.15]** and front suspension components of lighter design can be utilized reducing unsprung mass **[2.4]**.

4.17 More predictability over bumps

Not only does directly connected suspension give a more stable ride over rough surface **[4.2]** it also projects the front wheel upwards when in loses contact with the ground, more so on leaving a depression, or similar circumstances, when weight is present on the rear suspension system. This is the safest way of negotiating bumps and other obstacles of this nature as it acts to avoid a nose-dive landing should the bike become airborne.

4.18 Suspension which beneficially alters for up-hills and down-hills

On up-hills compression of the rear suspension and extension of the front suspension, due to rearwards weight transfer, has the rear automatically stiffen and the front lighten by means of displacement of the outer ends of respective shock absorbers. This scenario is repeated for down-hills, again, beneficially so **[2.3]**.

4.19 Automatic altering of suspension leverage ratios under front wheel braking

The scenario, as described above [**4.18**], applies under front wheel braking. Compression of the front suspension enacts a stiffening of its action and a lightening of rear suspension action to the benefit of road-holding handling and braking performance.

4.20 Superior braking performance

Nearly all linkage front suspension systems tested on motorcycles have been found to give shorter stopping distances than that achieved with telescopic forks **[Reference 3.]**. With the added advantages of retaining weight on both wheels **[2.4]** and beneficially altering suspension settings as braking force is applied [**2.5/4.19]**, this new design of bike will possibly give the shortest stopping distances available.

4.21 Safer braking

On applying the front brake, initial braking force reacts to slightly compress the front suspension **[2.5]**, applying weight to it (which is a necessity for braking performance), which in turn (the compressing front suspension) reacts to place load onto the rear suspension. And, applying rear braking force reacts to place more load onto the front suspension system than would be achieved with a telescopic fork designed bike **[2.4]**. Both scenarios benefit overall braking performance road-holding and handling.

4.22 Increased front braking feedback

Now that the front brake calliper travels in an arc with the front wheel during compression and extension of the front suspension **[2.5]**, any upsetting circumstances from the front wheel/road surface can be easier to detect providing a more responsive reaction for the rider thereby giving increased braking feedback.

4.23 Strength and stiffness

The only areas of the main frame now requiring substantial strength and stiffness are framework between the pivot points of the front control arm and the rear swinging arm plus their surroundings, instead of substantial strength and stiffness required from the swinging arm pivot point up to the steering head. Further, suspension components now have designs which favour strength and stiffness from reduced mass. Furthermore, the large distance between upper and lower ball joints (acting as a steering head) aid strength and stiffness for given frame weight.

4.24 Lightness

With the bulk of the steering head removed plus no longer having telescopic forks, which required substantial structural mass due to accepting forces that would react to bend them rearwards, considerable weight savings can now be made.

4.25 Reduced complication

With only three structural front suspension components, a main frame and a rear swinging arm, this is what the entire bike chassis consists of. Two shock absorbers, two ball joints, which provide the steering axis, and three sets of rotational bearing is what the bike requires to function.

4.26 Suspension which alters beneficially under acceleration

As weight transfer places load onto the rear suspension system during acceleration it enacts a stiffening of the rear suspension and lightening of the front.

4.27 Superior rear suspension action

The advantages of directly connected suspension improves rear wheel suspension action without the need for a mechanical linkage to actuate the rear shock absorber [**4.2/4.3/4.4**]. Plus, other advantages such as a shorter rear swinging arm [**4.15**], with reduced un-sprung mass **[4.16]**, also assist in providing superior rear suspension action.

4.28 Superior front suspension

Telescopic forks, by their nature, operate a 1:1 spring/suspension travel ratio. Now with linkage front suspension the leverage ratio can be beneficially above 1:1; have a rising rate [**4.29**]; and, benefit from the advantages of directly connected suspension **[2.3]**, where front suspension action is greatly improved.

4.29 Rising rate front suspension

Telescopic forks, in general, have a linear spring rate [**4.28**], where more advanced versions have progressive rate springs. Now the suspension system provides a rising rate where linear or progressing rate springs can be utilized opening up many possibilities.

4.30 Increased rider feel

The handlebars now move very slightly with suspension travel amplifying rider feel from road surface **[2.4]**. Further, with two front steering members extending at a considerable distance outwards (on the longitudinal plane of the bike) of the steering axis [**5.1**], any flex or play in the system will give reduced losses of feel. Furthermore, the connection from the front wheel to the handlebars is the most direct available comprising of only two rigid steering members and one pivot point with the steering now operating without interference from suspension action.

4.31 Familiar feeling

The designs of three component linkage front suspension and directly connected suspension have so many variables, where, for example, dive can be designed in for front wheel braking similar to the performance of telescopic forks, solely to give familiar feedback.

4.32 Aesthetically pleasing

A direct connection can be seen from the handlebars to the front wheel where such can be emphasised solely for design and style considerations. Psychologically, it is important for rider confidence that they can make such a connection **[Figure 2.]**.

4.33 Greater longitudinal stiffness

Telescopic fork designed bikes made it difficult to achieve reasonable longitudinal stiffness due to the load path of the forks/frame combination – similar to a large ‘A’ frame. Now the design of the main frame and suspension members are more adapted towards longitudinal stiffness (the main structural members are all in a more direct sequence from the front wheel axle to the rear wheel axle), which benefits high speed stability and braking performance.

4.34 Greater design freedom

Without the bulk of a substantial steering head this area can be utilized for other cycle components.

4.35 Increased rider confidence

With so many advantages plus weight reductions **[4.16/4.24]** the rider has greater control over the bike boosting their confidence.

4.36 Less rider fatigue

With reduced pitching motion in the frame [**4.1**] and superior quality suspension action **[4.2/4.3/4.4/4.27/4.28]** riders will be less tired riding this new design of bike and have higher levels of concentration as a result of which.

4.37 Reduced compression and rebound dampening

With suspension forces being transferred from one suspension system to the other, a reduction in internal dampening is required due to this means of dissipating energy otherwise suspension systems would become over-damped. With lighter suspension settings **[4.39]**, this gives a more receptive suspension response, where, for example, the suspension can rebound quicker to accept the next incoming obstacle without upsetting the balance of the bike.

4.38 Efficiency

As directly connected suspension operates with reduced compression and rebound dampening [**4.37**] less heat is generated by the workings of shock absorbers. Further, as the body of the bike rises slightly upon wheel/s contacting bumps, which is maintained at a more parallel plane to the ground than that of other bike designs, this transforms back into forward motion as the bike settles down again. An aerodynamic advantage is also possible **[4.46]** from restyling of the bike.

4.39 Lighter suspension settings

Reduced compression and rebound dampening [**4.37**] and lighter spring rates can be utilized to benefit superior road-holding traction and reduced tire wear.

4.40 Increased spring preload

As directly connected suspension transfers load from one suspension to the other, increased spring preload is beneficial to keep the suspension taught assisting in transference of loads, thereby providing superior action from the initial stages of suspension travel, which, in most circumstances, had been previously too light to be purposely utilized. As one suspension system acts to extend the other, when it does so, the extended suspension is at its lightest providing light but taught (better controlled) suspension travel.

4.41 Increased scope for the requirements of differing rider weights

With increased preloading of the springs [**4.40**] where both springs/shock absorbers operate on each suspension system, spring rates are therefore less critical to gauge for rider weights within operating tolerances.

4.42 Automatic altering of suspension leverage ratios for cornering and straight-line travelling

When cornering, centrifugal and related forces react to compress suspension systems, which enacts a stiffening of suspension action that enhances circumstances leading to cornering ‘chatter’. With directly connected suspension such compression of the shock absorbers displaces their outward ends further away from perpendicular to affect a desired lightening of their action by means of increased leverage ratios **[2.3],** to reduce the potential for cornering ‘chatter’ to develop, and enhance cornering suspension action.

4.43 Reduced compression of the bike during cornering

With one suspension system, upon compression, reacting to extend the other this gives reduced overall compression of the bike when cornering. This can manifest itself into increased ground clearance and possible aerodynamic advantages [**4.46**].

4.44 Reduced unsettling of the suspension when loading and unloading of the bike in quick succession

As cornering forces react upon suspension systems to compress them less [**4.43**] with directly connected suspension, there is reduced ride height to unload to. In circumstances such as chicanes where there is loading unloading loading then unloading in quick succession this is a distinct advantage.

4.45 Future developments

‘Active’ and ‘semi-active’ shock absorbers and telescopic forks [**2.2**] or ‘intelligent’ shock absorbers [**3.1**] cannot compare with the advantages offered by directly connected suspension operating with three structural component linkage front suspension. Only a fully active suspension system will do this but such a prospect is beset with so many problems and additional facets it is doubtful this prospective development will materialize in the foreseeable future.

(The following advantages are for motorcycles only.)

4.46 Aerodynamics

With reduced compression of the motorcycle during cornering [**4.43**] to the benefit of ground-clearance, the overall design of the motorcycle can then be produced lower to the ground, which can give reduced frontal area to effect a reduction of aerodynamic drag.

4.47 Lateral flex easier to design in

Telescopic forks made it extremely difficult to achieve a desired amount of lateral flex, especially so in equal quantity over a substantial distance (lateral flex is designed into the yokes not the telescopic forks), yet retain longitudinal chassis stiffness. Now longitudinal stiffness [**4.33**] can be retained yet lateral flex easily achieved and regulated.

4.48 Shorter chassis and suspension members of higher natural frequencies

Structural members of shorter lengths [**4.15/4.16**], in general, resonate at higher natural frequencies, which can be out with that associated with and responsible for cornering 'chatter'.

4.49 Suspension and chassis members of designs which resist harmonic resonance

The current design of motorcycle with telescopic forks, extended main frame, and extended rear swinging fork (commonly referred to as a swinging arm) are of designs similar to that of giant tuning forks. This new design of motorcycle reconstructs and shortens these members [**4.15/4.16/4.48**] into designs that reduce the potential for harmonic resonance. Further, with the motorcycle comprising of five main structural members at different harmonic frequencies, interacting with each other, this disrupts potential for harmonic resonance to develop.

4.50 Settled suspension

The relationship between the pull of the drive-chain from the engine onto the rear wheel sprocket, positioning of the swinging arm/fork pivot point on the frame, angle and length of the swinging arm/fork, spring/s and shock absorber/s utilized, and, drive from the rear wheel can result in an unsettled suspension where a rocking motion develops as forces react and overreact until they settle into an equilibrium. The self-levelling nature of directly connected suspension gives less potential for a rocking motion to materialize where a balance of forces is easier to obtain and then be maintained.

(The following advantages are solely for bicycles.)

4.51 No bouncing motion when pedalling with rear suspension

This is probably the biggest breakthrough in cycling technology in recent years as this predicament has held bicycle design back until now [**3.1**]. All four prototype mountain bikes shared this advantage where three different designs of linkage front suspension were tried and tested on such, thereby it can be deduced directly connected suspension is solely responsible for this breakthrough in cycling technology. Even conventional 'hard-tail' bicycles with only telescopic fork front suspension suffer from loss of energy as bouncing motion is experienced with the front suspension when the rider pedals. Again, this new design of bicycle with three structural component linkage front suspension and directly connected suspension is superior as there is no detectable bouncing motion (energy loss) when pedalling.

4.52 Sprung/unsprung weight ratio

With bicycles there is so little frame weight (sprung weight) in ratio to unsprung weight (suspension arms wheels spring etc) making it extremely difficult to achieve good suspension action with little pitching motion in the frame, but with directly connected suspension having suspension forces transfer from one wheel to the other, the frame is less effected by this sprung/unsprung ratio, thereby providing superior suspension action.

4.53 Production costs

With a required reduction in dampening **[4.37]**, it is now possible to utilize only springs on the shock absorbers without any compression and rebound dampening yet provide excellent suspension action. This can give weight savings, reduced complexity, reduced maintenance and lower production costs.

4.54 Duplicity of components

Structural suspension/steering component designs now lend themselves to dual usage such as the upper steering member being transformed into a carriage rack, and, a front mudguard as an integral part of the lower steering member.

4.55 Travelling efficiency

The workings of directly connected suspension, where suspension motion has less interference upon the frame leaving it more parallel to the ground surface, but has it rise slightly with suspension action provides additional forwards energy as it settles down again **[4.38].** For the rider, this may be a psychological advantage as the bicycle feels ‘energized’, other than an actual performance advantage.

5 DISADVANTAGES

The following are a list of disadvantages associated with three structural component linkage front suspension and directly connected suspension.

5.1 Increased steering inertia

The forward pivot point, where the two steering members hinge together, at a considerable distance outwards of the steering axis can be detected as increased steering inertia, more so as a distraction than as a handling disadvantage. On bicycles, at low speed, this is profound and also on motocrossers where excessive steering lock is required it is also an issue, but for general bikes, once underway, very little steering lock is utilized, wherewith it is not detected.

5.2 Fitment on motorcycles

The two shock absorbers now occupy the position that was reserved for tank and/or air-box placement with one behind the engine and the other above and rearwards of the engine position **[Figure 2.]**. Fortunately both these components are of no fixed shape or dimensions therefore can be easily re-fabricated into accommodating positions for both shock absorbers.

5.3 Lower ball joint

This ball joint is subjected to a majority of front suspension forces. A similar design, that of *telelever*, has a lower ball joint that accepts suspension forces when *telelever* is of a flawed design as it promotes binding between telescopic members due to a focal point being produced by the lower ball joint, yet this ball joint, in these circumstances, operates without issue. Whereas this new suspension design relies upon pivoted joints where there is no possibility of binding action between associated members therefore less stress is subjected upon the critical lower ball joint.

6 POINT OF INTEREST

The following is neither an advantage nor a disadvantage, but solely a design consideration.

6.1 Handlebar rotation

With the handlebars moving in an arc **[2.4]** with rigid attachment to the upper steering member, upon suspension travel, a small amount of motion is desirable to amplify road feel. With the first single-sided three structural component linkage front suspension system **[Figure 1.]** only 2 degrees of handlebar motion was available, but this was not noticed by the rider due to flex in the system (in particular, long upper steering member) combined with a natural rotation of the rider’s wrists in conjunction with handlebar rotation where the handlebars gave the impression of being more rigid in the rider’s hands than with telescopic fork designs. Above 12 degrees of handlebar rotation the rider starts to become aware of it as more than just a means of amplifying feeling from road surface. With large degrees of handlebar rotation the relationship with the rider and ergonomics involved have to be considered. For these circumstances the upper ball joint can be repositioned above and rearwards of the handlebars where the rider’s wrists will naturally fold inline with rotational motion of the handlebars so the rider will not have additional stress placed upon their wrists. In such an arrangement, it can be even more natural feeling for the rider than static positioning utilized with telescopic forks.

7 CONCLUSIONS

7.1 Motorcycles

The telescopic fork is now at the end of its development cycle due to issues concerning cornering ‘chatter’, confounded by the requirement for extremes in settings to counteract excessive dive during front wheel braking. A realistic alternative has to be devised for chassis/suspension development to progress. Current designs of electronic active suspension only offer marginal improvements in suspension and handling performance at large development costs, vulnerability, complexity, increased maintenance and additional weight, and will only prolong the usage of present suspension designs for a limited period of time. Directly connected suspension and three structural component linkage front suspension offer the simplest most effective and possibly best answer to date **[Reference 1.]**.

7.2 Bicycles

Development of the bicycle has been held back in recent times by rear suspension where bouncing motion is experienced when pedalling, which is a loss of energy. Directly connected suspension gives the breakthrough of no bouncing motion when pedalling with rear suspension allowing bicycle design to become more efficient safer lighter and more comfortable for the rider. Plus, with only three structural components, two ball joints, and two sets of rotational bearings for the linkage front suspension, this can be one of the simplest designs of dual suspended bicycles ever devised.

REFERENCES

[1] A letter of praise from Massimo Tamburini (designer of *Ducati 916* and *MV Agusta F4*) dated 10/06/2008. Quotation from: *‘I have thoroughly evaluated the information and the pictures you sent me, and I clearly recognize the innovation and the advantages that your project could bring in a motorcycle application.’*

[2] The mountain bike prototypes were successfully tested by reigning Irish National Veteran Downhill Mountain Bike Champion Carl Young.

[3] *Motorcycle News* (U.K.) Wednesday 29 April 2009.

Comparison of stopping distances from 70mph – 0

(Linkage front suspension) *BMW K1200S* 46.0meters

(Telescopic forks) Typical ABS bike (*Honda CB1300 ABS*) 52.6meters

(Telescopic forks) Typical conventional superbike (*Suzuki Hayabusa*) 52.9meters