Front suspension system of motorcycle

CHAPTER 1: INTRODUCTION

1. 1 AIMS

The main aim of this project is to Design and analyse of a front suspension system of motorcycle. The designing and modelling of the fork is done using Pro-Engineer (wildfire-4) and Stress analysis is undertaken by Ansys 11 software's.

1. 2 OBJECTIVES

- To get aware of deformations caused due to application of brakes to the fork of the front suspension system;
- To demonstrate detailed view of functioning of fork ;
- To show existence of various kind of front suspension systems used in motorcycles;
- Evolution of front suspension systems;
- To verify the benefits and the flaws of different front suspension systems, used right from the old age to modern age;
- To illustrate how the motorcycle keeps its balance and analyzing the factors that come into play while riding;
- Application of vibration modes, on suspension system of a motorcycle while riding.

1. 3 INTRODUCTION TO MOTORCYCLE FRONT SUSPENSION SYSTEM

A Motorcycle front fork connects a wheel and axle to its frame, by way of a pair of triple trees. The bike is steered by handle bars which are attached to the triple tree and also brake is provided to retard or stop the acceleration of the bike. There are loads of critical geometric parameters such as ‘ Rake' and ‘ Trail' which are establish by the fork and its attachment points on the frame, which usually play for handling and riding and dives as well during braking.

Telescopic forks

The term ‘ Telescopic forks' is defined because the tubes slide in and out of the body they are ‘ Telescoping'. The upper portion generally called as ‘ Fork tubes' (Male tubes) slides inside the fork bodies (Female tubes), which are lower part of the forks. Over more than century years of motorcycle improvement, different variety of front form arrangements have been attempted but some of them are still remain available nowadays. The most common form of front suspension for motorcycle now days are the ‘ Telescopic fork' Nimbus was the first manufacturer to produce a motorcycle with hydraulically damped telescopic forks in 1934. Early front suspension designs were used frames with springs. Greeves, a British manufacturer used a version of swinging arm for front suspension on their motocross design and also a single sided version suspension system is used in motor scooters such as the Vespa.

Suspension system is equipped with large hydraulic shock absorbers with internal coil springs. The main work of the shock absorbers is to allow the front wheel to react to imperfections in the road while isolating the rest of the motorcycle from that motion. The Upper part (Top yoke) of the forks is connected to the motorcycle's frame in triple tree clamp, which allows the forks to be turned while steering the bike. The Lower part (Bottom yoke) is fixed to the front axle around which front wheel rotates. The fork tubes should be smooth and mirrored finish, so as to seal the fork oil. Some fork tubes found on the off-road motorcycles are covered with plastic protective sleeves called as ‘ Gaiters'. The forks are constructed either of the conventional ‘ right-side-up' or sliding -female configuration, or the ‘ Upside-down' or Sliding -male configuration. In Both the cases, a cylindrical tube or piston sided axially within the cylindrical cylinder.

Trail and Rake:

‘ Trail' is the measurement, on the ground, from a point which is projected through steering axis to the centre of the tyre's contact patch below the axle. Trail determines the self centring stability of the steering as well. The triple clamps provide good lateral offset that the forks clear the sides of the front tyre. Usually Triple clamps are introduced to provide some measure of longitudinal offset as well, to alter the trail. Trail impacts directly on the steering stability of the motorcycle and its ‘ return-to-center' force. The trail is much affected by rake . Rake is defined as the angle between the vertical and steering axis. The steeper rake reduces the trail and trail itself is also affected by the longitudinal fork offset. More offset decreases the trail. The trail is also affected by axle offset. The trail increases in the case if the axle is coupled to the forks in front of their centre.

Ride height:

Sometimes rider desires to increase or decrease trail to change the steering feel so as to improve steering swiftness, or to eliminate high-speed shake, or to reduce a front end push. Ride height is simply defined as the forks extending up through the triple clamp. Decreasing the ride height by raising the forks farther through triple clamps in reality steepens the rake, which results in decreasing the trail. Alter in trail causes the effects to the rider to his ride height adjustments.

CHAPTER 2: LITERATURE REVIEW

Motorcycles were first developed out of the bicycle frame, which certainly is rigid. Suspension systems were progressed over the years after critical researchers to filter out ground disturbances in more efficient ways.

CHAPTER 3:

3. 2 FORK FUNCTIONING:

The weights are transmitted from inner tube to the outer tube or vice versa through the slider bushes which are placed between the two tubes. The bushes used for the good fork are critical because it should have a very low coefficient of friction as well as mounting tolerance.

The system smoothness is totally dependent upon the friction forces developed during sliding movements as well as on the amount of stiction. The stiction is at maximum at " Moto incipiente ",, When the initiation of the movement occurs between the surfaces. This stage is called as static friction. In Designing and fabrication of the slider bushes, the problem of sliding friction always stand for a weak point in the front fork of the vehicle.

If we compare it, for example, to the rear suspension in which there is practically no sliding due to the displacements consists of rotations around the bearings. The suspension settings can be achieved by the stiffness of the spring, as well as the damping provided by the hydraulic part, to which is added the resistance given by the sliding friction. It is difficult to predict what the suspension behaviour operates and its proper functioning is taking cared by the availability of friction.

In the design stage, limiting friction forces require that the loads on the bushes be minimized, boosting movement of the unit. When the fork is extended fully, only a small segment of the slider tube enters inside the sleeve. Hence at this stage its overlap is reduced to a minimum. This is also constitutes the least rigid configuration of the whole system. At the end of the travel, as a substitute of the fork tube overlap extreme therefore maintaining the stiffness.

3. 3 FORK STRESSES AND DEFORMATIONS:

Certain forces acts on the fork leg while the vehicle is in motion. Two cases can be considered which helps us to derive fork stresses as well as deformation. They are

(i) Fork flexure due to vertical loads:

The flexure due to vertical loads involves the stresses which act on by weight of the motorcycle plus rider. Also stresses tend to develop due to road surface irregularities such as through potholes, steps ridges, etc. Actually these stresses are considered negligible for example, If we travel in the city at <50 km/h and heading towards a step that rises 4 to 5 cm's from the profile of the road, thus 100 % front overloading can be easily achieved.

The ‘ Moment of flexure' or ‘ Bending moment' is generated when the vertical load is finally applied to the wheel. The moment of flexure or bending moment gradually increases as the fork is inclined. When with the same force applied, the bending moment will reach to the maximum in the case of fork extended fully and vice versa the bending moment will be minimum with the maximum compression. Therefore the values vary as the changes occur in the arm of the force applied. The stresses are less when the slider bushes are closer to the wheel spindle and are expected to function better.

When the rider passing over dip holes in the ground in the road surface, the vertical loads can attempt very high values, hence the frame structure has to be stiff enough to avoid excessive deformation and simultaneously it should have the capability to absorb all the immediate bumps whenever the suspension bottoms out. At the front end the area, steering head tube receives the heavy stress . whereas, at the rear end connecting rods as well as the shock mounting come under the greater stress.

When the motorcycle is stationary, the load values that appear during normal use are two to three times as big as static loads which are normally acting on the wheels.

If we consider a medium powered street bike which is kindly moving on a bumpy road with a high speed and if the wheel bounce on hole then the stress exerted on the structure may be hundred of kilos or more. Maximum load values can take place when the off-street bikes jumps and cross over the obstacles.

(ii) Fork flexure due to braking force:

As it is the known fact that when braking force is applied to the wheel, then it is obvious to the wheel, experiencing the deformations upon different circumstances of road. In this case, Bending will greater as the length of the fork is high. The highly noticeable point of interest is that the deformation due to vertical forces is opposite to the deformation due to the braking force.

In the previous case we observed that, during braking, because of the weight transfer effect, the front load increases; i. e. there can't be a braking force without an increase in vertical load.

When the brakes are applied to the bike then some strong longitudinal forces are created, giving rise to bending moment that gets stronger as it rises from the ground to the steering head tube, finally transmitted to the whole frame. The steering head tube experiences the strongest moment. The steering head tube is the point with the least depth of section, which is the major plane of stress. Due to this considerations observed, detailed research and study has undergone to give the actual design dimensions of the whole steering tube. On this part of flexure happens during the big thrust of acceleration would definitely cause trail variation. When the braking stress dies out for example; when entering a corner, there would be an annoying elastic rebound action in response. Meanwhile the rear fork doesn't experience much stress during braking as front fork does.

The above two effects (i) Flexure due to vertical load as well as (ii) Flexure due to braking force will certainly oppose each other and within the deceleration range of characteristics of motorcycle, depending upon Cg height, wheel base and fork inclination. In general fork flexing during braking is not as severe as one might think.

Deformation due to torsional forces:

The twisting forces which derived are as follows

- The alignment is poor between the fork axis and equilibrium forces;
- The components of equilibrium forces perpendicular to the fork axis and out of alignment with it;
- The couple which applied by the rider to the steering head.

The resultant deformation is said to be very harmful for handling because the wheel does not respond properly according to the direction of control set by the rider of the vehicle.

Effect of deformation on functionality:

It is clear straight away that the presence of fork deformation makes the proper sliding inside one another more complex to the point of potentially impeding it. When the bike is in motion, the deformation is at highest at most critical circumstances such as brake application and corner entry.

3. 4 DIFFERENT DESIGN TYPES OF FRONT SUSPENSION SYSTEM

Telescopic forks are mainly classified into two kinds which are used in practical applications in daily routine life. They are

- Traditional or standard which is equipped with an internal tube, the one with smaller diameter in the upper postion, fixed to the frame.
- Upside Down or Inverted which is equipped with internal tube in the lower position, which is fixed to the frame.

The hydraulic as well as elastic fundamentals of these kinds can be simply comparable in order to know the different responses of the same motorcycle equipped with two distinct types of forks. There are some manufacturers whom have created a ‘ Cartridge' containing the hydraulic part which can be easily mounted onto each of the applications being tested.

The first telescopic fork prototypes was designed right after the Second World War, were laid out with little attention as to whether they were in traditional or upside down form. In the sixties, the majority of the forks produced was traditional type whereas Upside down design came into the existence at the beginning of the eighties. The upside down design was popularised back into circulation of sport bike applications.

Contrast between Traditional and Upside Down form of telescopic forks:

Benefits of Tradional form:

- Less number of components, given that the wheel attachments and axle lug derive directly out of lower stanchion which also keeps weight down;
- Unsprung mass weight is slightly reduced;
- Tubes slides in areas that are more protected from bumps and dirt.
- Benefits of Upside down form:
- It has superior torsional stiffness with the same weight, where the tube has larger diameter and is positioned in upper area, which deals with greater stress from the bending moment;
- Strong attachment between the tubes and the triple clamps which have large tube diameters.

The above comparison between the two applications says that one is absolutely better than other. So, in this case upside down layout presents more advantages in the terms of stiffness which makes ideal for some sport-oriented applications.

Both the applications Traditional as well as Upside down forks are characterized by

- Different stiffness's;
- Different weight distribution;
- Different values of unsprung weight;
- Different center of gravity heights between the steering and the ground;
- Different values of inertia around the steering head axis.

There are some other types of unconventional fork types and can be classified into the groups. They are

- Swinging front fork or Pivoted;
- Parallelogram linkage or Girders;
- Straight line slider guides;
- Paralever linkage.

a) Swinging front fork :

This type of fork was especially used on the earliest bike models and it is a very simple construction solution. In practical, it reproduces the geometry of the rear fork, along with a n arm that usually rests on a fulcrum which is placed on the steering column, making the fork rotate in one piece along with the steering head. Depending upon whether the arm is compressed or extended during braking, leading link or trailing link front forks are discovered. In both the cases of the forks, the layout may be seen to be symmetrical to the head angle with two arms or it may consist of only one arm. For scooter models, Pivoted front fork suspension is adopted, but they are almost rare when coming to high performance vehicles.

The main characteristics of swinging front fork suspension system are as follows.

- In Smoothness , They are very smooth when the rotations are assured by rolling bearings eliminating stiction;
- When the matter comes to design construction, the stiffness may be better or sometimes worst.
- The connecting rod linkage systems have never been used to gain progressive rates; it is easy enough to obtain progressive spring rather.
- The inertia is high around the steering axis and the unsprung masses have moderate weights which are totally dependent upon the type of construction used for the forks

If we compare both leading link as well as trailing link, it will be the great point of interest.

Leading link:

In mid 1950s, the world champion Moto Guzzis which are the best handling racing machines of their period, were installed with leading link. The leading link consist of a tubular or pressed steel structure which connects the steering column in the link pivots and slot in for the suspension struts. The links appear to be independent or formed by a single U-shaped loop around the back of the wheel. In the case of the links separation, their resistance to independent movement as in the type of telescopic fork, depends upon the rigidity if their attachment to the wheel. If the wheel has large- diameter spindle then it also haves large wheel bearing and the most convenient and efficient method is a loop behind the wheel and a smaller -diameter spindle.

Benefits of leading fork are as follows

- Quality of detail design
- Possibility of greater rigidity.
- Greater stability on the fork
- Precise control over the steering.

The lack of stiction enhances the sensitivity to the small undulations and also any degree of anti -dive under heavy braking. The wheel has precise path which usually depends on the relative heights of the wheel spindle and link pivots. Because of the curve shaped, these forks are highly unsuited for the large movements which are usually used on modern off road machines.

In the leading link during braking the anti-dive behaviour can be seen. The anti dive behaviour tries to extend the suspension, in the case of application of braking force that is applied to the fork . The Anti -dive behaviour can be prevented by fixing brake calliper to a torque arm which is connected to the steering. In this case, spontaneous center of rotation may be positioned so as to create anti-dive behaviour.

Trailing link:

The trailing link differs from that of leading link in many ways like the link pivots of the wheel spindle are ahead, not behind. The demerit of this kind of fork is higher steering inertia, since the bulk of the mass is relatively far from the steering axis, which has an effect that partially offset by the smaller amount of material required to reach the pivots.

In the trailing link during braking, the pro-dive effect occurs which is quite similar to the traditional fork . In this case as well brake torque arm will be introduced along with fixing brake callipers in order to get the proper effect when braking.

b) Parallelogram linkage or Girders:

Girder forks are widely used now a day's which is also considered for their excellent steering. Due to friction dampers, the performance was generally limited and very crude by current hydraulic standards. The links which operates the suspension system were short and due to this kind of forks are very much suitable for small amount of suspension movement.

One of the forks namely Vincent " Girdaulic" was most sophisticated. It consists of light -alloy blades and one-piece upper as well as lower link assemblies. The trail for this fork was readily adjustable. Springs were adjusted in the long telescopic tubes, behind the uprights, but the hydraulic damper was separate, mounted in front of the head stock. The lateral stiffness was boosted by a plate which will bridge the front of the blades. Hydraulic damping is employed against suspension movement and also to damp out steering excursions, a damper was used.

The most recently released linkage designs comes under this category. The main characteristics of the parallelogram linkage are as follows

- The smoothness of the fork is outstanding, since sliding friction is substituted by rolling friction i. e. Sliding movements are kindly replaced by rotations around the roller bearings;
- It has got adequate amount of stiffness enhanced by the design construction;
- The progressive rate of the suspension can be incorporated;

- The trajectory control is excellent which is highly dependent on type of fork used. It is possible to have different types of wheel trajectories with the help of parallelogram linkage system. The trajectory can be considered perpendicular to the ground, maintaining the same wheel base, or to obtain certain degree of anti-dive it may be inclined forward, in the beginning phrase.
- The trail control is good. In this case, it is highly possible to create constant trail geometry with varying travel . It can be increased or decreased according to riding behaviour of the vehicle.
- Depending upon the fork design, the unsprung weigh could be less but the net weight of the suspension remains constant.
- The most popular design solutions used in automotive industry are as follows

Solution (a):

In this type of solution, the fork legs are allowed longer along with mounting brake callipers. Like single sided rear fork, the links that hold the wheel can also be asymmetrical. The steering is controlled by positioned links.

Solution (b):

It is rarely employed and characterized by high steering masses and substantial inertia, less bulk and steering control is high.

Section (c):

This type is rarely employed. The leg length is reduced to make large wheel travel. Kinematic loads will be large with such a short fork legs.

Solution (d):

This kind of solution is generally employed for light motorcycles and has been introduced right after the Second World War. The steering control is good but it imposes limits on the steering mass size and on trajectories available to the wheel. Because the links are located at certain altitude, the stresses on the links due ot the forces are very tough.

Solution (e):

This kind of solution has been introduced in most advanced applications. In general, it unites all the advantages offered by girder solutions. When it comes to design of the fork, it experiences some drawbacks in the terms of the looks. The horizontal arms have to be long enough to allow the wheel to be steered. Due to this factor, it could be a strong limit the maximum steering angle value, which usually restricting the use of this solution to the street bikes.

The links controls the steering; offering the possibility to position the shock absorber in areas that make the mountings powerful and fabrication is easy. Through connecting rod system, the steering control may be easily constructed.

Solution (f):

This solution is quite similar to the solution (e), but it does not allow offset of the wheel with respect to the steering head axis or zero offset. Due to the large diameter bearings in order to house the steering kingpin, the wheel hub center becomes complicated.

(c) Straight -line slider guides:

Straight-line slider guides are especially regarded by the same geometry as the rear fork when speaking about the controlling the trajectory of the point O point and trail are concerned. Practically, the cylindrical slider is replaced by a straight line slider but of rolling type. The classic shock absorber is represented as the damping element in this case, while rolling guide bearings are similar to ones used for highly developed mechanical machining work.

The Advantages of Straight-line slider guides are as follows

- ü It enhances better smoothness;
- ü It hails limited play as well as has got good stiffness;

The limitations of straight-line slide guides are as follows

- The main problem is difficulty in positioning the two disc brakes
- Asymmetry-it gives rise to bothersome moment around the steering axis.

(d) Paralever linkage

This type of solution is generally considered as a corrupted parallelogram linkage system because, the upper linking bar is missing and also the suspension function is done by a slider derived from intermediary part that becomes a sort of fork.

Advantages of paralever linkage system are as follows:

- The sliding motion in this case is simpler when compare it to standard fork

- The transmission ratio is 1: 1 in this case as the steering is directly connected to the tubes.

Limitations of Paralever linkage are as follows:

It is more mechanically complex than a traditional fork and generally bulky due to the presence of horizontal arm.

(e) Mechanical anti-dive system:

In the field of racing, mechanical anti-dive type fork systems have been introduced to limit their tendency to front end dive. In this case, By means of a series of links, the braking force sustained by the brake calliper is transferred to the chasis, opposing its tendency to dive.

The mechanical anti-dive system has been not recognised universally because of the following problems incurred.

- Making of brake callipers is difficult in this case which mounts rigid enough, with possible braking power loss and aswell as formation of micro-vibrations.
- The system's weight is high
- Moment of inertia is increased over the steering masses
- Less amount of effort have made in vehicle's handling.

(f) Hydraulic anti-dive system:

Mechanical anti dive system has been replaced by hydraulic-anti system. Hence they are increasingly rare. The hydraulic anti-system is totally based on the hydraulic braking usually when the brakes are applied, by blocking the passages.

When the hydraulic brakes are made too strong thus it becomes difficult to absorb small irregularities in the road surface, especially during the complex way of entering the corner of the road.

CHAPTER 4: STRAIGHT LINE MOTION

The topic straight line motions deals with How the motorcycle keeps its balance analyzing the factors that come into play which can simply help the rider to maintain the motorcycle in a vertical and stable position while travelling. The factors that are responsible for maintaining the straight line motion path are

- Inertia effects
- Gyroscopic effects
- Righting effects.

4. 1 INERTIA EFFECTS

The product if mass multiplied by the velocity of a body gives the quantity of motion of the body. Due to greater value of this is, the less influence external forces will have on trajectory.

For example, let's assume that a motorcycle is travelling at high speed such as 100km/h then the vehicle also attains a velocity of 10 km/h perpendicular to the original trajectory as shown in fig a. If the motorcycle moves at slower speed of 10km/h, then the same component velocity influenced by the gust of wind brings variation in the direction of travel as shown in fig b. Hence as the velocity increases, small directional variations orthogonal to original direction will bring smaller angular variation. Therefore, now we can state that the greater the forward velocity, the more difficult is to move the vehicle from its initial straight-line trajectory. The same concept can be applied to mass like heavier a body is; the more it resists changes to its speed and direction.

In the figure, Vint = initial velocity

Vres = resultant velocity

dV = variation in velocity

α = angular variation in velocity.

4. 2 GYROSCOPIC EFFECTS:

When every time a body spins rapidly on its axis and simultaneously is to set into rapid spin around a second axis is referred as gyroscopic effects or a moment that eventually acts around a third axis perpendicular to the other two. In routine life, gyroscopic effects can be seen for example, a spinning of bicycle wheel in between one's hands illustrates gyroscopic effect. If the wheel is set to keep axially parallel to it and raise and lower the wheel straight up and down then we can notice no opposing action on our hands. Hence it can be said that the opposing vertical force is needed to perform the action will never be more than the weight of the wheel itself.

Now in the next trial if the axis of the wheel is turned in clockwise motion around vertical axis, as if we were holding the steering handlebars. In this case, we will notice that our arms are affected by a couple that tends to rotate them around the longitudinal axis. From the following experiment, certain conclusions can be drawn

Gyroscopic effects will be more when the wheel rotates faster

The intensity of the reaction will differ obviously, if the axis is tilted faster or slower.

4. 3 RIGHTING EFFECTS:

The parameter righting effects is profoundly influenced by the geometrical characteristics of the steering unit of the motorcycle. The correct combination of these factors gives positive results for the awareness of stability. Righting effects can be depend upon the following phenomenon's

- Steering axis
- Rake angle (Castor)
- Trail

4. 3. 1 Steering axis:

Regardless of structure of motorcycle suspension they are characterized by a front wheel suspension by a front wheel steering, because front wheel is free to rotate around the axis which is called as steering axis. In general, the steering axis in the bicycles is referred as Head angle and is measured clockwise from the horizontal when viewed from right hand side. A 90° head angle would be vertical. For example a 2007 Filmore, which was designed for the track with a head angle, varies right from 72. 5 ° to 74 °, depending upon frame structure and size.

4. 3. 2 Rake angle:

In the case of front suspension, it is very easy to identify steering axis especially in the telescopic fork because the steering axis coincides with the axis of the guide bearings inside the slider around which the fork rotates.

This steering axis is present in all automotive type suspensions is inclined with respect to the vertical angle known as Rake angle. Rake angle is measured usually in degrees from zero.

Inclination of rake angle (ε):

If we increase the angle of the steering axis then we should also increase the value of trail. Usually the steeper the inclination of the rake angle, the motorcycle tends to be more stable directionally. Some grand prix bikes meant for competitive or sports oriented uses smaller rake angles such as little as 21° rake angle. custom made bikes have modified a steeper rake angle beginning from 28° and reaching 40°.

4. 3. 3 Trail:

The Trail of the front suspension system is defined as the distance between the point of intersection of the axis with the ground and the contact point of the front wheel w