Dynamic Suspension System

Simanta Ghosh and Vivek Joshi
Department of Mechanical Engineering
Indian Institute of Technology Kharagpur

Abstract

The prevention of roll and bump simultaneously is something that Engineers have been trying to achieve for a long time. This requires two opposite behavior of suspension to be incorporated in the same design and to switch between them as and when required. Here we present two different approaches to achieve the same. The basic concept in these versions is to use an air spring and vary its pressure to achieve different pressures and hence different spring constants. In the first approach this is achieved without the use of any electronic components or pump while in the second approach a pump, electro-valves and sensors are used to achieve the same. The two approaches differ in terms of their complexity, cost, handling, comfort level etc.

1 Aim

The main design aims of the Suspension System here were

- To achieve different spring constant as per road conditions and the behavior of the vehicle.
- To achieve proper fluid flow as per the requirement of the situation and design valves to control this flow.
- To achieve proper damping whatever the behavior of the car.
- To achieve dynamic ride height control.

2 Passive Suspension System

The main aim here is to improve the handling and comfort level without use of any electrical or electronic components.

2.1 Cases Considered

Table 1 Different Cases to be considered in designing

CASES	FLUID FLOW	SPRING STIFFNESS REQUIRED	DETERMINING FACTOR
Evasive Maneuvering	Fast	Very High	Handling
Normal Cornering	Slow	High	Comfort and Handling
Bumps/Droops	Very Fast	Low	Comfort

2.2 Design

The design consists of two piston cylinder assemblies attached to each tire at the lower wishbone. One of these is a slightly modified strut (Cylinder 1) while the other is a cylinder with a piston and a floating piston. The compressed air in Cylinder 2 acts as a spring. The two cylinders are hydraulically joined by a pipe with a Pressure controlled valve. Each of the four chambers in the two cylinders contains a separate small reservoir. This reservoir stores extra fluid to be used by the chamber or here fluid is discarded. This extra fluid is maintained at some pressure by pressurized air. The pipeline from a chamber to its reservoir acts as the damping element. For the lower chamber of cylinder 1 and the upper chamber of cylinder 2 ,this pipeline contains a High Pressure Valve which opens only at a high pressure provided by bumps.The initial pressure of the fluid in all the chambers except the upper chamber in cylinder 1 is same as that of the air in air spring. The pressure in the upper chamber of cylinder 1 is quite low compared to other chambers.

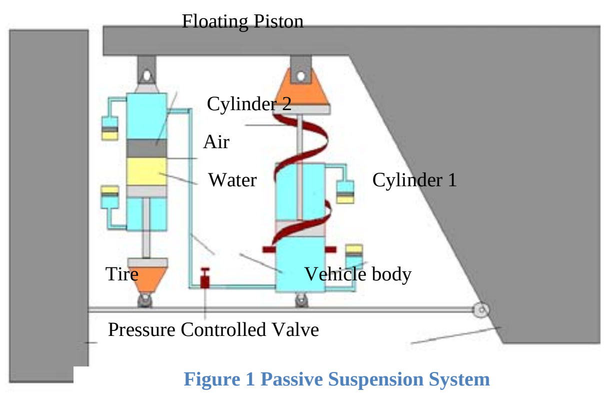

Figure 1 Passive Suspension System

2.3 Pressure Controlled Valve

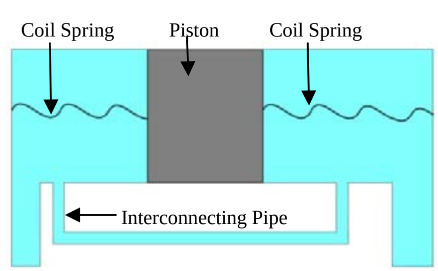

Figure 2 Pressure Control Valve

The above figure shows a pressure controlled valve. It consists of an inlet on right to cylinder1, an outlet on left to cylinder 2, a piston and two coil springs. The piston divides the valve into two parts interconnected by a pipe. The springs are so chosen that in case of evasive or normal maneuvering the piston remains between the two ends of the interconnecting pipe while in case of bump, the pressure on right side(cylinder 1) is sufficiently high to move the piston to the left end, hence covering the left end of interconnecting pipe, which results in parallel combination of the two springs.

2.4 Working

2.4.1 Bump

In case of bump, the wheel encounters a sudden upward movement. This would create high Pressure on the fluid in the lower chamber of Cylinder 1. Since the pressure here would be higher due to greater wheel travel, this would keep the Pressure Controlled Valve closed. Hence the cylinders would now be disconnected hydraulically, thus placing the two cylinders, and hence the two springs, in parallel. This would lower down the net spring constant. Thus we get a soft suspension as per the requirement.

2.4.2 Evasive Maneuvering/Normal Cornering

In case of evasive maneuvering or normal maneuvering, the most important requirement is handling as there should not be any skidding (over-steering or under-steering). Thus we need the suspension to have maximum stiffness on outer wheels i.e. the springs should be in series and minimum stiffness on inner wheels i.e. the springs need to be in parallel. In this case the pressure acting on the valve is not sufficient to open it. Thus the two springs are in series and the net force is higher than in the parallel combination. Hence we get the stiffer suspension as required.

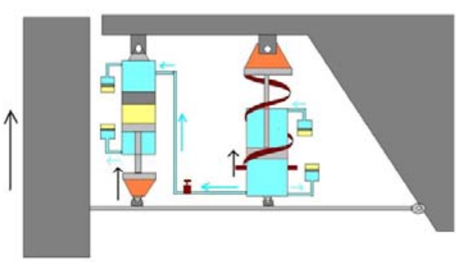

Figure 3 Fluid Flow in Roll/Cornering

2.5 Is Force greater in Series Connection?

The assumption here is that the effect of fluid pressure in the upper chamber of cylinder1 and that in lower chamber of cylinder 2 has been neglected. The other assumption is that we assume the vertical displacement of bottom points of the two cylinders on the lower wishbone to be the change in the length of cylinder.

Let X = wheel bump
X1 = change in length of cylinder 1
X2 = change in length of cylinder 2
K1 = spring constant of coil spring
K2 = spring constant of air spring
K0 = initial spring constant of air spring
L0 = initial length of air spring column
L1 = distance of base of cylinder 1 from ball joint at the chassis end of the lower wishbone
L2 = distance of base of cylinder 2 from ball joint at the chassis end of the lower wishbone

By simple mathematics, it can be shown that

In Parallel: Here the displacements are governed by geometry, fluid pressures in the two cylinders may be different.

$$F_{net} = \frac{K1 \times L1 \times X}{L} + K0 \times \left(\frac{L^2}{L0 - \frac{X \times L2}{L}} \right)$$

In Series: Here the fluid pressure in the two cylinders is the same.

$$F = \frac{K1 \times L1 \times X}{L} + K0 \times \left(\frac{L^2}{L0 \quad \frac{X \times L2}{L}} \right) \left(1 + \frac{L1}{L2} \right)$$

Thus we can clearly see that for a given wheel bump, the net force is greater in series combination of springs.

2.6 Advantages

1. Much cheaper, compact and light weight than the existing systems.
2. Very easy to manufacture and can easily be added to any car without much changes.
3. No use of Pumps. This reduces unnecessary oil consumption in engine.
4. Significant improvement in ride quality.

2.7 Disadvantages

1. Lesser ride comfort and handling than active suspension.
2. A precise control of the spring stiffness and damping is not possible.

2.8 Innovations Possible

Here we have used a simple system where each wheel acts independently. A better bump control can be obtained by interconnecting the dampers amogst themselves. Similarly here an entirely another aspect of suspension adjustability, ride height adjustment has not been achieved. If it could be achieved then we get a new dimension of handling control. However with these additions, the analysis of the car becomes more and more difficult.

3 The Active Version

3.1 Design

The second design of the suspesnion system is basically an improvement over the first one, implementing electronics and computics thereby making it possible to delegatemany functions previously solved by mechanical-hydraulical components to electronic units.Although the basic functioning is practically the same, the actual layout has undergone quite a few changes.

Most importantly, the previously mechanically operated height correctors are replaced with electronically controlled hydraulic units.They are now built into a Eclectro-hydraulic Interface Unit which mainly has the following parts:

•A pump which would maintain a high pressure in the fluid used in the hydraulic lines,as required.The pump can be driven by an electric motor running independently of the engine and only when necessary.

•The hydraulic units,including an accumulator with a pressure regulator basically to even out the pressure pulsations of the pump therefore maintaining a working range of pressure in the hydraulic lines.

•Electrovalves and their hydraulic counterparts would be employed to achieve the desired fluid flow within the control circuit.

•A suspension ECU(Electronic Control Unit) communicating with with other computer devices across the multiplex network(the engine and the ABS ECU's) in order to readthe inputs of various sensors and control the fluid pump and the electrovalves to achieved a specific pattern of fluid flow.

In contrast to the height correctors of the previous systems, operated mechanicaaly via linkage coupled devices, the new system would make use of electronic sensors to learn the actual height of the suspension system and its tendency to roll and would employ electonic actuators to modify the ground clearance whn needed and as required. The main advantage of using them is that the ECU can implement very sophisticated algorithms to derive and the height and roll corrections, what were impossible with mechanically linked feedback with simple thresholds.

The inputs to the suspension ECU comprise of rear and front body height, brake pedal, vehicle speed, acceleration, steering angle sensor , steering wheel rate sensor and the yaw rate sensor fot the vehicle.Most of them are generally used for the ABS and the TCS for modern day vehicles.

One of the innovations of the system could include a height setting parameter for the vehicle with the selected seeting being displayed in the multi-functional screen of the vehicle dashboard [the levels being **high,normal and low**].The system would adjust the ground clearance automatically. Approximately speaking, below 110 kmph on well surfaced roads the ride height remains standard but as soon as this speed is exceeded, the vehicle will be lowered by 15 mm at the front and 11 mm at the rear.This change lowers the centre of gravity, improving stability and lesser roll to take care of and also lowering fuel consumption by reducing drag and reducing the sensibility to crosswinds.The car resumes its normal height setting when its speed drops below 90 kmph.On poorly surfaced roads or off-terrain vehicles (the computer learns the data about the road quality by monitoring the inputs from the vehicle speed, height and the suspension movement sensors) the ride height will be lowered by around 13mm but this setting is used on very poor roads and with the vehicle speeds being less than 70 kmph.

[Note: All the threshold values indicated in the above paragraph have to be developed through tests on the vehicle suspension system and would be different for different vehicles depending upon their suspension design and weight factors.The given values have been chosen emperically just to provide an idea of how the system would actually work.]

3.2 Working

The system's starting point can be assumed to be the high pressure supply subsystem consisting of a volumetric pressure pump drawing the mineral suspension fluid from the reservoir. The fluid under pressure is stored in the main accumulator which also houses a system of spring loaded pistons that will regualte the pump line pressure to a certain range say, 140 bar(the lower limit) and 175 bar (the upper limit). The spring below the first piston is calibrated so that it will collapse only when pushed down with a pressure exceeding the cut-in threshold.While the pressure in the main accumulator remains inferior , the piston stays in the upper position, allowing the pump to deliver the fluid into the accumulator.The other spring's cut-in threshold pressure would be the upper limit of the range required.When the pressure exceeds 175 bar both the springs and their respective pistons are in their lower position and the excess pressure is released via the return(to the reservoir) fluid line.The line coming out of the accumulator is reffered to as the feed line with a specific range of working pressure.

Another important part of the whole system is the type of damper employed.In this case, the damper used here consists of two different layers of fluid with a small portion of gas (included between two floating pistons), thus dividing the whole damper into three distinct parts as shown in the figure below. The distinct feature and by far the most innovative piece of information in this damper is that there can be two diffrent types of control that can be achieved through the system.The first one being the ride height of the quarter model of a car by introducing or taking away quantities of fluid from the lower fluid chamber.The second one being the stiffness of the suspesnion model ;which in this case is mainly provided by the entrapped gas between the pistons(a highly non-linear spring) which can be controlled by regulating the pressures of the upper and lower fluid chambers.

Now there will be different cases according to which the fluid lines coming out of the damper would be controlled via the electrovalves.For example when the car is taking a left turn or say is in an evasive manuever situtaion, the

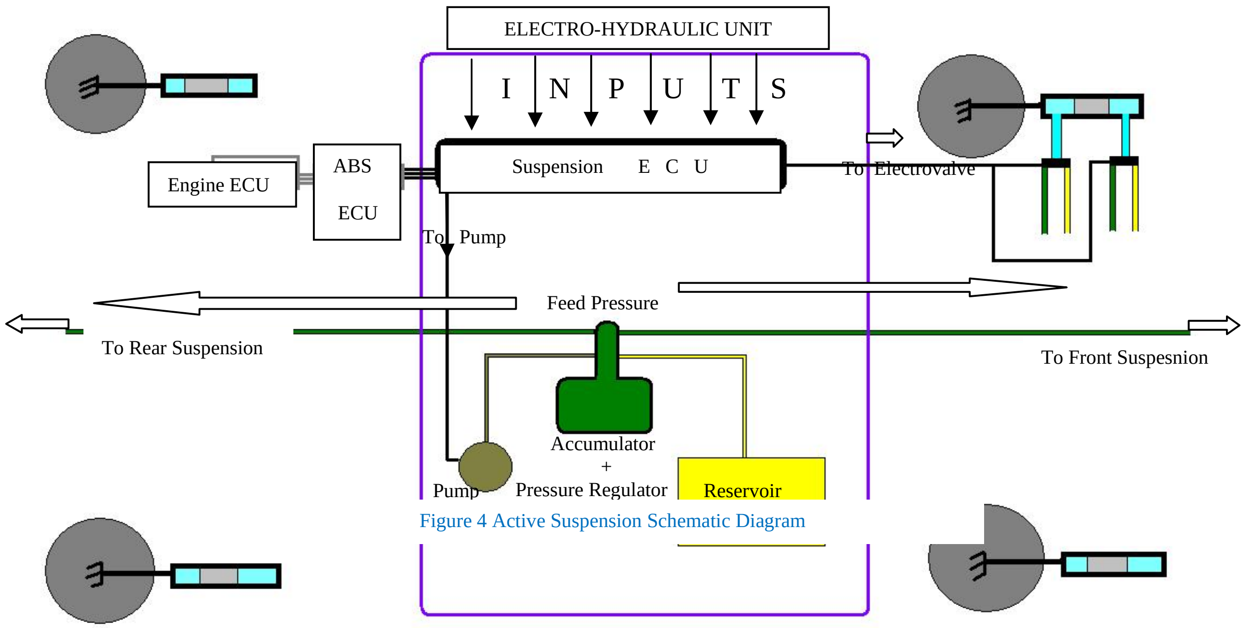

Figure 4 Active Suspension Schematic Diagram

inner wheels have the tendency of taking off from the road surface while the outer wheels would push into the road.Thus, the most suitable condition of controlling such a situation would be to decrease the stiffness of the inner wheel suspension along with increasing the ride height so that there is no way left for the wheel to leave the road surface.Just opposite would be the case of the outer wheels in which one would have to harden the spring (.i.e. increase the stiffness) and increase the ride height.Now how can such parametric variations be achieved acn be answered by the hydraulic fluid lines that have been setup previously.In case of the inner wheels, both the upper and the lower chambers are connected to the return(to the reservoir) line. What this helps the system to achieve is that the fluid in the lower and the upper chambers being at a higher pressure flow away in to the reservoir line; the pressures in both the chambers decrease thereby increasing the length of the air column and hence decraesing its stiffness.Similarly in the outer wheels the upper chamber is connected to the feed line while the lower chamber is connected to the return line by actuating the electrovalves.In this way the control system induces an appreciable amount of anti-roll behaviour. The case of the ground clearance problem i.e. in case of irregular road conditions like potholes,bumps etc. would be similar to the case of inner wheels. The stiffness of the air column has to be as minimum as possible and soa s to allow maximum amount of fluid flow from the dampers to other hydraulic components within the system. The effect would be a drastic change in the road holding capabilities of the vehicle and would prove to be crucial in cases of evasive manuevering conditions thereby decreasing the chances of a road accident to a great extent.

The major difference between this system and its predecessor is the supervision of the Electrical Control Unit in determining the height correcting and roll- controlling capabilities of the suspension system.Although the system is costlier than the previous one but the control in this case is better.

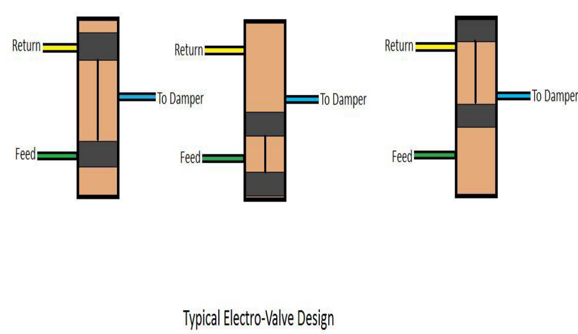

Figure 5 Electro valve Design

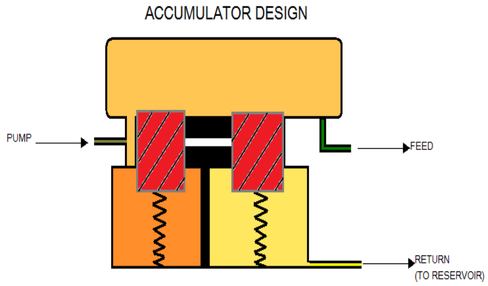

Figure 6 Possible design for accumulator

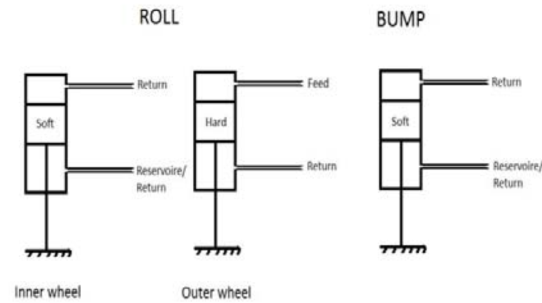

Figure 7 Fluid connections in different conditions

Acknowledgment

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References

[1] Race Car Vehicle Dynamics, W.F. Milliken and D.L. Milliken

[1] Fundamentals of Vehicle Dynamics, Jason D. Gillespie

[1] Prepare to Win, Carroll Smith

[1] Tune to Win, Carroll Smith