International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
Index Copernicus Value (2015): 62.86 | Impact Factor (2015): 3.791

Variable Spring Rate Adaptive Suspension System

S. Hariharen[1]

UG Student, Automobile Engineering, Sri Venkateswara College of Engineering, Sriperumbudur, Ch-602105, India

E-mail: hariharen24[at]gmail.com

Abstract: ***A vehicle's suspension is a system intervening the interface between the vehicle and the road. The basic function of the suspension system is to isolate the passengers and chassis from the excitation due to road unevenness to provide better ride comfort, road holding and stability. It is also seen that a good suspension should be soft for good ride comfort and be stiff to have insensitivity to applied load variations and should have a setting between soft and stiff suspension for good handling. The existing conventional passive suspension systems are unable to satisfy the conflicting criteria of a balance between the ride comfort and road handling. It was observed that, a good ride is obtained with relatively modest damping around 20% critical damping and to minimize suspension displacement and dynamic tyre force. These objectives are not fulfilled by a conventional passive suspension system because of its limited scope of variation in spring stiffness and damping coefficient. By identification of the scope to provide the better means to improve the conventional suspension principle, the theme of implementation of a variable-Hydraulic Suspension is proposed. The major objective of my paper is to vary the stiffness of the spring according to the driver's decision. The stiffness of the spring can be changed by varying the travel in the suspension system. There are 3 modes in the driver's cockpit so that the driver can select any one of the three he wanted. The 3 modes are race mode, normal mode and luxury mode. In race mode, the travel of the spring is reduced so that the handling characteristic of the vehicle is increased. In luxury mode, the travel of the spring is increased so that the passenger's comfort is increased. In normal mode the travel is moderate so that it balances both handling and comfort characteristic. Thus our system allows the driver to vary the characteristics of the system as required. Thus this system can replace the conventional passive system in passenger car in a cost effective way.***

Keywords: Semi-active, variable spring rate, Adaptive suspension, Dampers

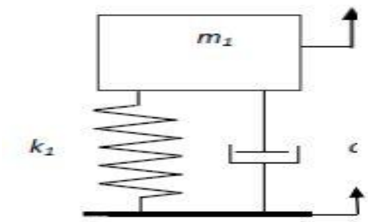
1. Introduction

The main task of the suspension system is to provide a comfortable and safe ride. Usually the suspension consists of passive force elements which are designed to optimize the trade-off between ride comfort, suspension travel and wheel load variation. A good suspension design protects the human body against uncomfortable bumps in the road. By selecting the right spring and damper characteristics, the suspension functions as a filter and passes only those frequencies which are less uncomfortable for the human body. However, the characteristics should also guarantee a safe ride. Therefore, the wheel- load variation should be small in order to prevent the wheels from losing contact with the road. All this should be achieved in the available suspension travel. The only contacts between car and road are the four contact patches of the tires and it is very important to exploit these areas optimally. Therefore, usually a system of links connects the unsprung mass (wheel, brake, steering hub) to the sprung mass (car body). The geometry of these links is a trade-off between optimal orientation of the wheels with respect to the road in case of suspension travel caused by bumps in the road and suspension 4 travel caused by cornering. Another trade off comes to light when the car is cornering. The spring should be stiff enough to avoid exaggerate rolling of the car's body, because otherwise the suspension geometry should be able to extremely compensate for this situation. Often, an anti-roll bar is used in order to prevent exaggerate rolling. Then, the spring stiffness can decrease in order to improve comfort. However, the stiffness of anti-roll bars is limited because it is undesirable to transmit vibrations due to road irregularities from one wheel to the other. Also, one of the suspension functions is to support the vehicle sprung mass and to maintain the vehicle attitude angle. Another one is to decrease body vibration motion transmitted from the road and, therefore to improve handling stability in various driving conditions. There are 2 major types of suspension system;

- Passive suspension system
- Active suspension system

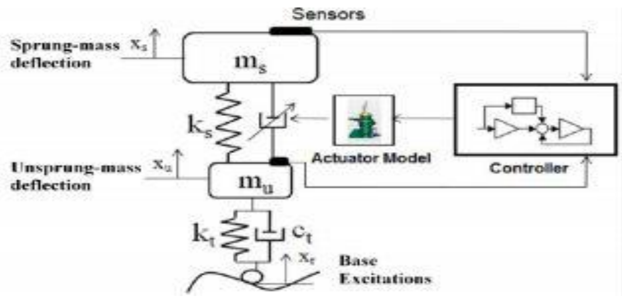
Passive suspension system:

The commercial vehicles today use passive suspension system to control the dynamics of a vehicle's vertical motion as well as pitch and roll. Passive indicates that the suspension elements cannot supply energy to the suspension system. The passive suspension system controls the motion of the body and wheel by limiting their relative velocities to a rate that gives the desired ride characteristics. This is achieved by using some type of damping element placed between the body and the wheels of the vehicle, such as hydraulic shock absorber. Properties of the conventional shock absorber establish the tradeoff between minimizing the body vertical acceleration and maintaining good tire-road contact force. These parameters are coupled. That is, for a comfortable ride, it is desirable to limit the body acceleration by using a soft absorber, but this allows more variation in the tire-road contact force that in turn reduces the handling performance. Also, the suspension travel, commonly called the suspension displacement, limits allowable deflection, which in turn limits the amount of relative velocity of the absorber that can be permitted. By comparison, it is desirable to reduce the relative velocity to 6 improve handling by designing a stiffer or higher rate shock absorber. This stiffness decreases the ride quality performance at the same time increases the body acceleration, detract what is considered being good ride characteristics. An early design for automobile suspension systems focused on unconstrained optimizations for passive suspension system which indicate the desirability of low suspension stiffness, reduced unsprung mass, and an optimum damping ratio for the best controllability [57]. Thus the passive suspension systems, which approach optimal characteristics, had offered an attractive choice for a vehicle suspension system and had been widely used for car. However, the suspension spring and damper do not provide energy to the suspension system and control only the motion of the car body and wheel by limiting the suspension velocity according to the rate determined by the designer. Hence, the performance of a passive suspension system is variable subject to the road profiles.



Active suspension system:

In early active suspension system, the regulating of the damping force can be achieved by utilizing the controlled dampers under closed loop control, and such is only capable of dissipating energy (Williams, 1994). Two types of dampers are used in the active suspension namely the two state dampers and the continuous variable dampers. A 2 DOF Active Suspension System Model The two state dampers switched rapidly between states under closed-loop control. In order to damp the body motion, it is necessary to apply a force that is proportional to the body velocity. Therefore, when the body velocity is in the same direction as the damper velocity, the damper is switched to the high state. When the body velocity is in the opposite direction to the damper velocity, it is switched to the low state as the damper is transmitting the input force rather than dissipating energy. The disadvantage of this system is that while it controls the body frequencies effectively, 8 the rapid switching, particularly when there are high velocities across the dampers, generates high-frequency harmonics which makes the suspension feel harsh, and leads to the generation of unacceptable noise. The continuous variable dampers have a characteristic that can be rapidly varied over a wide range. When the body velocity and damper velocity are in the same direction, the damper force is controlled to emulate the skyhook damper. When they are in the opposite directions, the damper is switched to its lower rate, this being the closest it can get to the ideal skyhook force. The disadvantage of the continuous variable damper is that it is difficult to find devices that are capable in generating a high force at low velocities and a low force at high velocities, and be able to move rapidly between the two. The control strategy utilized a fictitious damper that is inserted between the sprung mass and the stationary sky as a way to suppress the vibration motion of the spring mass and as a tool to compute the desired skyhook force. The skyhook damper can reduce the resonant peak of the sprung mass quite significantly and thus achieves a good ride quality. But, in order to improve both the ride quality and handling performance of a vehicle, both resonant peaks of the sprung mass and the unsprung mass need to be reduced. More recently, the possible applications of electrorheological (ER) and magnetorheological (MR) fluids in the controllable dampers were investigated by Yao et al. However, since MR damper cannot be treated as a viscous damper under high electric current, a suitable mathematical model is needed to describe the MR damper.



2. Principle

As the tire strikes a bump in the road, so a vertical force is applied to the spring' which is compressed or deflected. Therefore the wheel moves vertically relative to the body, and the tire maintains contact with the road surface. However, some of this force is transmitted through the spring to the body, which also tends to rise. If the springs are very 'soft' (i.e. have relatively low spring rates) the body rises little, but if the springs are very stiff the body rises quite a bit, depending on the severity of the bump. For a good ride, therefore, the springs should be soft. Although soft springs give a good ride in most circumstances, they allow the body to roll a lot during cornering. In practice, spring rates are a compromise between the requirements of ride and handling.

This system is based on the principle that "liquid are incompressible". There is a small modification done to the inner tube of the dampers. The inner tube is divided into two chambers. The lower chamber is filled with a fluid. Since the diameter of the inner tube is constant, The height of the chamber can be varied by changing the volume of the lower chamber, As more liquid accumulate the length of the liquid chamber increases and hence the effective stroke length can be increased. If there is more liquid, excess liquid will flow back to the reservoir and hence the height of the chamber is decreased. Thus by altering the effective stroke length, the stiffness of the spring can be altered.

3. Components Required

- Liquid reservoir- A reservoir is a storage space for liquids.
- Pump- It is a device that moves fluids by mechanical action.
- Uni-directional valve- A uni-directional flow control valve allows the control of liquid flow in one direction only.
- Level sensor- level sensor is used to monitor the level of a particular free flowing substance within a contained space.

4. System Setup

The space under the piston of the damper is divided into two chambers. The upper chamber contains the usual working fluid as in normal dampers. The piston slides in the upper chamber. The upper chamber is connected to the bottom of the inner tube through a rubber tube. The lower chamber is a separate chamber that contains a separate liquid. There is a liquid reservoir which is connected to lower chamber. The liquid is almost present to 3/4th of the reservoir. The centrifugal pump is different in working than a positive displacement pump. All centrifugal pumps include a shaft-driven impeller that rotates inside a casing. Centrifugal pumps are unique because they can provide high or very high flowrates and because their flowrate varies considerably with changes in the Total Dynamic Head of the particular piping system. This allows the flowrate from centrifugal pumps to be "throttled" considerably with a simple valve placed into the discharge piping, without causing excessive pressure buildup in the piping or requiring a pressure relief valve. It is used supply the liquid to the chamber through a Uni-directional valve. The excess liquid in the chamber flows back to the reservoir through another Uni-directional in the return pipe. . The valve restricts liquid flow by the use of screw adjuster which when driven into the valve begins to block the way reducing the liquid flow rate. This restriction is active in only one direction. The level sensor is placed inside the inner tube. It is used to identify the level of the lower chamber.

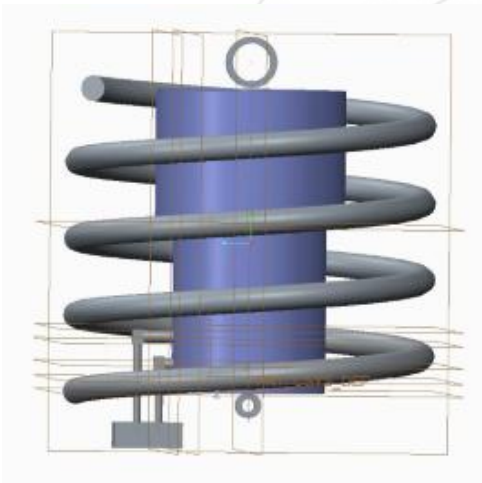


Figure 1: System setup of spring and damper

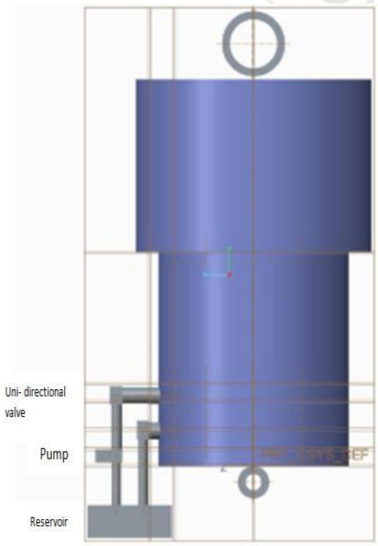


Figure 2: Front view of damper with pump and reservoir

5. Working

The working of this system is based on the fact that “liquids are incompressible”. This system works effectively by varying the length of the liquid chamber. The driver can able to select three modes.

- Race mode
- Normal mode
- Luxury mode

In race mode, the stiffness of the spring should be more so the travel of the spring should be less. Hence the volume of the liquid chamber should be more. Since the radius of the damper is constant, we can vary the length of the liquid chamber. A volume sensor is used to determine the required volume. In case of less volume, this sensor sends signal to ECU and it drives a pump which suck the liquid from the reservoir and deliver it to the chamber through the uni-directional valve. Once the optimum volume is reached the valve closes and the pump stops working. Thus the length and volume of the chamber is increased and the spring travel can be effectively reduced. In luxury mode, the stiffness of the spring should be less so the travel of the spring should be more. Hence the volume of the liquid chamber should be less. Since the radius of the damper is constant, we can vary the length of the liquid chamber. A volume sensor is used to determine the required volume. In case of more volume, this sensor sends signal to ECU and the valve in the return pipe is opened so that the excess liquid flows back to the reservoir. Once the optimum volume is reached the valve closes. Thus the length and volume of the chamber is increased and the spring travel can be effectively reduced. . In normal mode, the stiffness of the spring should be medium so the travel of the spring will be moderate. Hence the volume of the liquid chamber will be medium. Since the radius of the damper is constant, we can vary the length of the liquid chamber. A volume sensor is used to determine the required volume. In case of more volume, this sensor sends signal to ECU and the valve in the return pipe is opened so that the excess liquid flows back to the reservoir. . In case of less volume, this sensor sends signal to ECU and it drives a pump which suck the liquid from the reservoir and deliver it to the chamber through the uni-directional valve. Once the optimum volume is reached the valve closes. Thus the length and volume of the chamber is increased or decreased and the spring travel can altered accordingly.

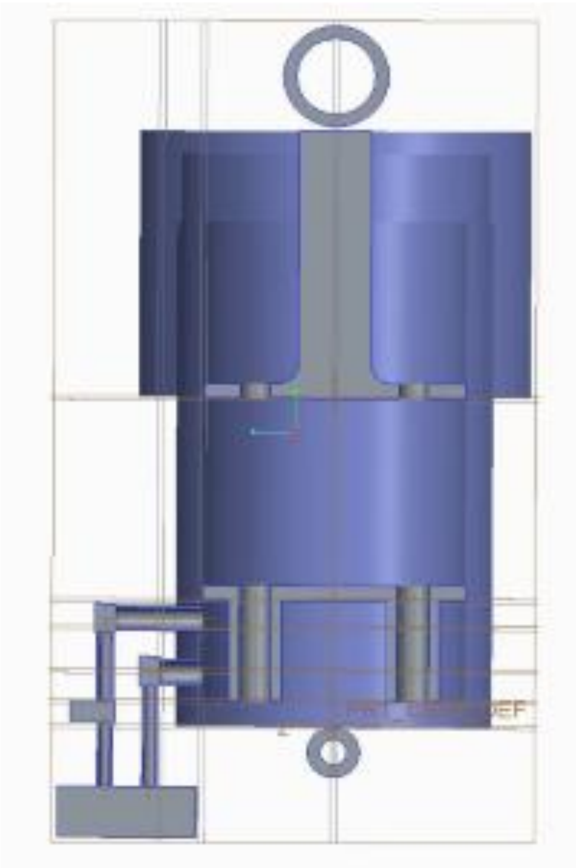


Figure 3: sectional view of damper with pump and reservoir

6. Calculation

RACE MODE:

Length of fluid chamber = .2 m

Front:

Volume of fluid in the chamber = $\pi * r^2 * h - 2(\pi * r_1^2 * h)$

$= 3.14*30^2*200 - 2(3.14*2^2*200)$

$= 560176\ mm^3$

Stiffness of spring = load on one wheel/compression of spring

= (400*9.81)/100

= 39.24 N/mm

$\omega_n = \sqrt{(s/m)}$

$= \sqrt{(39.24/400)}$

=.313 cyc/sec

Rear:

ω_n (rear) = 1.3* ω_n (front)

= 1.3*313

= .407 cyc/se

Stiffness of spring = $\omega_n{}^2 * m$

$= .407^2 * 200$

= 33.15 N/mm

LUXURY MODE:

Length of fluid chamber = .1 m

Front:

Volume of fluid in the chamber = $\pi * r^2 * h - 2(\pi * r_1^2 * h)$

$= 3.14*30^2*100 - 2(3.14*2^2*100)$

$= 280088\ mm^3$

Stiffness of spring = load on one wheel/compression of spring

= (400*9.81)/200

= 19.62 N/mm

$\omega_n = \sqrt{(s/m)}$

$= \sqrt{(19.62/400)}$

= .22 cyc/sec

Rear:

ω_n (rear) = 1.3* ω_n (front)

= 1.3* .22

= .287 cyc/sec

Stiffness of spring = $\omega_n{}^2 * m$

$= .287^2 * 200$

= 16.57 N/mm

NORMAL MODE:

Length of fluid chamber = .15 m

Front:

Volume of fluid in the chamber = $\pi * r^2 * h - 2(\pi * r_1^2 * h)$

$= 3.14*30^2*150 - 2(3.14*2^2*150)$

$= 420132mm^3$

Stiffness of spring = load on one wheel/compression of spring

= (400*9.81)/150

= 26.16 N/mm

$\omega_n = \sqrt{(s/m)}$

$= \sqrt{(26.16/400)}$

= .255 cyc/sec

Rear:

ω_n (rear) = 1.3* ω_n (front)

= 1.3* .255

= .287 cyc/sec

Stiffness of spring = $\omega_n{}^2 * m$

$= .332^2 * 200$

= 22.10 N/mm

Table 1: Stiffness of the spring, N/mm

	Race mode	Normal mode	Luxury mode
Front	39.24	26.16	19.62
Rear	33.15	22.10	16.57

Table 2: Volume of liquid chamber, mm^3

	Race mode	Normal mode	Luxury mode
Volume of liquid chamber	560176	420132	280088

The mat lab design for all the three modes are given below:

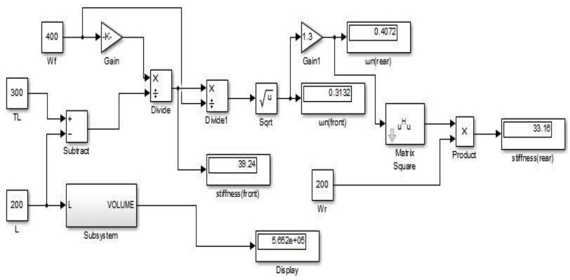


Figure 4: Matlab for race mode

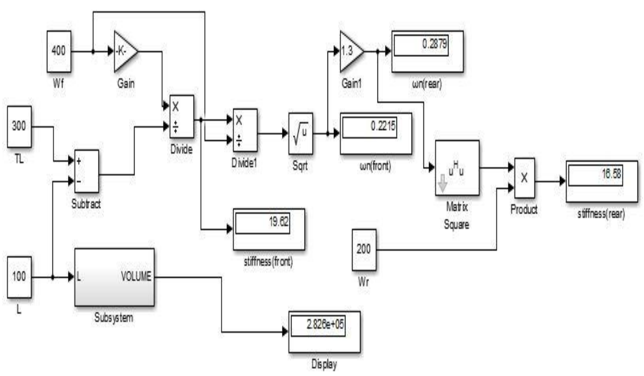


Figure 5: Matlab for luxury mode

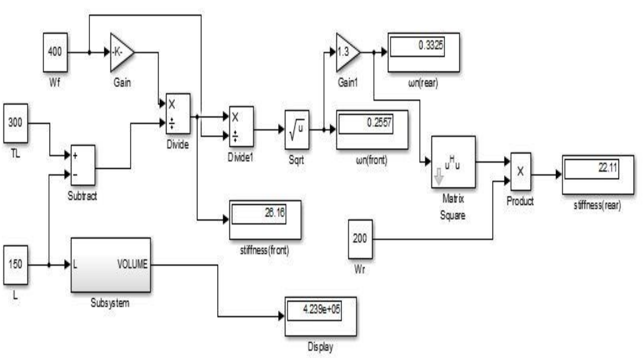
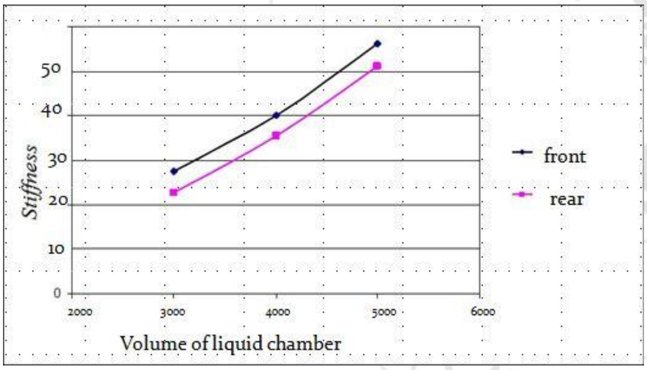


Figure 6: Matlab for normal mode



ERROR! REFERENCE SOURCE NOT FOUND.

7. Conclusion

Thus this system is a type of semi-active suspension system as we can change the stiffness of the spring. In this system small changes are done to the existing suspension system so that the driver can be able to use 3 modes of suspension. This system can be used in normal passenger car as it is cost effective and simple in design. In this method the stiffness of the spring has been varied by varying the travel of piston inside the inner tube of dampers. Thus the handling characteristics of the vehicle can be increased.

References

[1] M. Nagai, ―Recent Researches in Active Suspensions for Ground vehicles‖, Series C , Vol. 36 , No.2 , 1996 , pp 161-170
[2] R.A. Williams, ―Electronically Controlled Automotive Suspensions‖, Computing & Control Engineering Journal, June 1994 , pp 143-148
[3] R. S. Sharp and D. A. Crolla, ―Road Vehicle Suspension Design – A Review‖, Vehicle System Dynamics, 16 (1987), pp 167-192
[4] C. Kim and P. I. Ro, ―An Accurate Full Car Ride Model using Model Reducing Techniques‖, Journal of Mechanical Design, December 2002, Vol.124 , pp 697-705
[5] K. Lee, ―Numerical Modeling for the Hydraulic Performance Prediction of Automotive Monopipe Dampers‖, Vehicle System Dynamics ,29 (1997) , pp 25-39
[6] P. V. Kumar and P. S. Rao, ―Vibration Isolation Performance of a Full Car Suspension System Model using Delayed Resonator Vibration Absorber‖, Proceedings of The National Conference on Advances in Mechanical Sciences AIMS07 , 22th – 24th March 2007, Sponsored by AICTE , New Delhi , pp 85-90
[7] T. R. Gawade , Dr. S. Mukharjee and Prof. D. Mohan , ―Wheel Lift-Off and Ride Comfort of Three-Wheeled Vehicle Over Bump ‖, IE (I) Journal MC ,Vol. 85, , July 2004 , pp 78-87
[8] R. Majjad, ―Estimation of Suspension Parameters‖, Proceedings of The 1997 IEEE International Conference on Control Applications, Hartford, CT, October 5-7, 1997 , pp 522-527 140
[9] N. Karuppaiah , P. S. Deshapande , C.Sujata and V. Ramamurti , ―Vibration Analysis in a Light Passenger Vehicle by Rigid Body / Finite Element Modeling‖, Advances in Vibration Engineering,2(2) 2003 © Universities Press (India) Pvt. Ltd., pp 107-120
[10] A. Sueoka , T. Ryu , T.Kondu , M. Togashi and T. Fujimoto , ―Polygon Wear of Automobile Tyre‖, JSME International Journal ,Series C, Vol. No.2 ,1997, pp 209-217