Design and Analysis of Active Suspension System

Harish C S[1], Naveen Lara[2]

[1]Research Graduate, Mechanical Engineer, Coimbatore, Tamilnadu, India.
[2]Student, Dept. of Automobile Engineering, SNS College of Technology, Coimbatore, India.

***Abstract-** Suspension system acts as an interface between the chassis and the vehicle frame, they add the definition to the vehicle characters like handling, comfort etc. An adaptive suspension system actively controls the vertical movement of the wheels through the electrical pulses processed by Electronic control unit with the help of G-Sensors and actuators in it. It introduces the possibility to assist passive force elements by the active force elements. The suspension system of the quarter car model is 3D-modelled in CATIA and analysed in ANSYS.*

Keywords: Suspension system, Types of Suspension, Active Suspension, Springs, Upper and Lower arm, FEA Analysis, CATIA, ANSYS.

1. INTRODUCTION

Suspension system is the one of the important systems in vehicle. It supports the weight transfer of the vehicle and provides the smooth ride. It allows rapid cornering without extreme body roll and keeps tire in firm contact with the road and it also prevents excess body squat and body roll. It allows front wheel to turn side to side steering. It also works with the steering to keep the wheels in correct alignment. The basic parts of suspension system an arm (control arm), spring, damper, knuckle etc.

Suspension is the system of tire pressure, shock absorbers, and linkages that connects a vehicle to its wheels and allows relative motion between the two. Suspension systems must support both road holding/handling and ride quality, which are at odds with each other. The tuning of suspensions involves finding the right compromise. It is important for the suspension to keep the road wheel in contact with the road surface as much as possible, because all the road or ground forces acting on the vehicle do so through the contact patches of the tires. The suspension also protects the vehicle itself and any cargo or luggage from damage and wear.

An active suspension is a type of automotive suspension on a vehicle. It uses an onboard system to control the vertical movement of the vehicle's wheels relative to the chassis or vehicle body rather than the passive suspension provided by large springs where the movement is determined entirely by the road surface. So-called active suspensions are divided into two classes: real active suspensions, and adaptive or semi-active suspensions. While adaptive suspensions only vary shock absorber firmness to match changing road or dynamic conditions, active suspensions use some type of actuator to raise and lower the chassis independently at each wheel.

These technologies allow car manufacturers to achieve a greater degree of ride quality and car handling by keeping the tires perpendicular to the road in corners, allowing better traction and control. An onboard computer detects body movement from sensors throughout the vehicle and, using that data, controls the action of the active and semi-active suspensions. The system virtually eliminates body roll and pitch variation in many driving situations including cornering, accelerating, and braking.

1.1 Purpose of Suspension

Basically, Suspensions are used for a comfortable ride of the passengers, which absorbs the tension, stress, damping, vibrations produced by the vehicle due uncommon roads. Those vibrations produce dizziness, illness to the passengers inside the vehicle and so suspension systems are used.

Suspensions are required for

1. Keeping the wheel in contact with the road surface as much as possible.
2. Absorbing and isolating the cabin from vertical ground forces which emanate from uneven road surface.
3. Absorb energy during hard braking.
4. Changing drive characteristics of the vehicle (soft suspension / hard suspension).

1.2 Role of Good Suspension

A good suspension system must make the wheels to be on road at all driving condition. It may be during hard acceleration (anti-squat), hard braking (anti-dive), heavy cornering, bumps, pit holes. Whatever be the obstacle its main aim is to keep the tires in contact with the road. (i.e., to maximize the friction between road and tire). It is used to absorb and dampen road shock by isolating the chassis from the shocks due to bumps. The suspension system must not be soft, it affects the dynamics of the car as there will be too much body roll while cornering. If it's too soft the car suspension will react too much for even small bumps. While a stiffer suspension will make the ride uncomfortable. A proper suspension will give good feedback about the car's dynamic to the driver. A suspension system makes the wheel to have uniform contact patch on the tire else the tire will suffer tread wear (inside or outside). A vehicle's handling and dynamics mostly depend on suspension geometries.

2. TYPES OF SUSPENSION SYSTEM

2.1 Dependent Suspension:

Dependent systems may be differentiated by the system of linkages used to locate them, both longitudinally and transversely. Often, both functions are combined in a set of linkages. When a wheel is experiencing a vibration in a vehicle, the vibration is partially transmitted through the linkages to the alternate wheels in dependant suspension system.

Examples of location linkages include:

- Satchell link
- Panhard rod
- Watt's linkage
- WOB Link
- Mumford linkage
- Leaf springs used for location (transverse or longitudinal)
- Fully elliptical springs usually need supplementary location links, and are no longer in common use.

2.2 Independent suspension system:

The independent suspension system gives opportunity to independently move the wheels vertically, even any of the wheels get hit by a bump on the road, their vibrations does not transfer to the alternate wheels of the vehicle.

The variety of independent systems is greater, and includes:

- Swing axle
- Sliding pillar
- MacPherson strut/Chapman strut
- Upper and lower A-arm (double wishbone)
- Multi-link suspension
- Semi-trailing arm suspension
- Swinging arm

2.3 Passive suspension system:

The relative velocity between the body and the tire is limited to a rate by passive suspension to give a comfort ride. Traditional springs that are also called as energy storing elements and dampers as well as energy dissipating elements are referred to as passive suspensions — most vehicles are suspended in this manner. To understand the distribution of vibration and placement of springs and dampers the quater car model of sprung and unsprung masses,

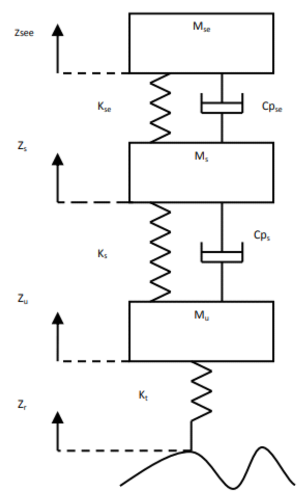

Fig 1: *Quarter car passive suspension model*

where,

- Zse is displacement of seat
- Zs is the displacement of the sprung mass
- Zu is the displacement of the unsprung mass
- Zr is the displacement of the road surface
- Mse is the mass of seat
- Ms is the mass of the sprung mass

- Mu is the mass of the unsprung mass
- Kse is the spring stiffness of the seat.
- Ks is the spring stiffness of the sprung mass.
- Kt is the spring stiffness of the tire.
- Cpse is the damping coefficient of seat.
- Cpu is the spring stiffness of the unsprung mass.

2.3.1 Spring:

A spring is considered as one of the components of the automotive suspension systems. The role of the spring is to absorb the energy by compression and releases the energy by expansion, which comes to its original state when load is removed.

- Leaf spring
- Torsion bar suspension
- Coil spring

2.3.2 Dampers:

Dampers also called as SHOCK ABSORBERS, they play an important role in suspension system by absorbing the kinetic energy of shocks or vibration into another form of energy (thermal energy), which is later dissipated.

2.4 Active and Semi-Active suspension system:

Active suspension is also called as adaptive suspension system, Active suspension system is controlled by an extrinsic operator by electrical signals, in some cases they are controlled even by the combination of physical components like springs and dampers and electrical signals which is also called as semi active suspension system. The adaptive suspension system sometimes is connected to drive trains to give different modes whether to get a softer or stiffer suspension. The devices include such as air springs, sensors, valves when the oil is less it is more easy to compress so the valve controls the dampers and vice versa and switchable shock absorbers, even magneto-rheological fluid which is the viscosity of the fluid is controlled electro magnetically, to a point is can be switched to VISCOELASTIC SOLID.

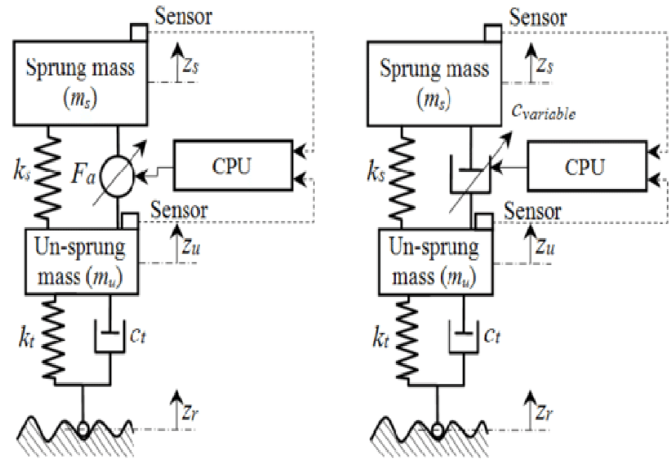

Fig 2: *Active and Semi-active suspension system quarter car model*

But one of the major cons to be considered in active suspension system is high energy consumption and complexity, compared to active suspension system semi active suspension system is consuming less power despite performance in vibration control is higher.

The active suspension system works as a closed loop control system. The active suspension system consists of four important components viz.

2.4.1 Linear ElectroMagnetic Motor (LEM)

A highbandwidth linear electromagnetic motor is installed at each wheel of the vehicle with active suspension system. Inside the LEM, magnets and coils of wire are installed. When electrical power is applied to the coils, the motor retracts and extends, creating motion between the wheel and the car body. Thus, electrical energy is converted into linear mechanical force and motion. The LEM can counteract the body motion of a car while accelerating, braking, and cornering, thus ensuring vehicle control. It also responds quickly enough to counter the effects of bumps and potholes, thus ensuring passenger comfort. The motor is strong enough to put out enough force to prevent car from rolling and pitching during aggressive driving maneuvers. In addition to the motor, the wheel dampers inside each wheel hub further smooth out road imperfections. Torsion bars take care of supporting the vehicle, thus optimizing handling and ride dynamics.

The LEM is essentially a multi-phase alternating current (AC) electric motor that has its stator unrolled. Thus, instead of producing a torque (rotation) it produces a linear force along its length. It has the ability to extend (as if into a pothole) & retract (as if over a bump) with much greater speed than any fluid damper (taking just milliseconds). These lightning-fast reflexes and speed along with the precise movement finely controls motion of the wheel. Thus, the body of the car remains level, regardless of the terrain. This is also a failsafe system because this system will still continue to function as a passive suspension system even if the power supply to the LEM is cut off.

2.4.2 Sensors:

A sensor measures a physical parameter (vertical displacement, acceleration and velocity) and decodes it into an electrical signal. In this system three types of sensors are used. The sensor measurements are used to instantaneously counteract the road forces. The sprung mass acceleration sensor gives a direct measure of comfort of the vehicle. The suspension travel sensor gives direct measure of suspension travel, which is the measure of distance from the bottom of the suspension stroke (when the vehicle is on a jack and the wheel hangs freely) to the top of the suspension stroke (when the vehicle's wheel can no longer travel in an upward direction toward the vehicle) This sensor is aligned with the passive spring and damper and hence the stroke can be measured directly. The unsprung mass acceleration sensor is installed to estimate the state of the tyre since it is not possible to measure the tyre compression directly. Thus, this set of three sensors provides all the information needed for the operation of the system.

2.4.3 Power Amplifier:

A bidirectional power amplifier sends the power to the LEM during extension and the LEM returns the power to the amplifier during retraction. The electrical power is delivered to the LEM by a power amplifier in response to signals from the control algorithms. The system uses compressive force to recover the energy or power, and store it either in the engine battery or in some other external storage device. Thus, when the suspension encounters a pothole, power is used to extend the motor and isolate the vehicle's occupants from the disturbance. On the far side of the pothole, the motor operates as a generator and returns the power back through the amplifier. This regenerative action results in a very efficient suspension system design.

2.4.4 Control algorithms:

The sensor measurements are used by the control algorithms and they send command to the power amplifiers which in turn operate the LEM. These electrical signals from the sensors are processed by the PID and it generates a control signal which controls the action of the actuator for fine response in real time.

3. GEOMETRICAL CONFIGURATIONS

First, we have to first calculate the spring rate for a particular ride frequency and motion ratio. Then we have to set the spring ratio and assume the wire diameter. With the help of these data then find the factor of safety using Soderbergh equation. If it is not so good, then again change the wire diameter. By this repetitive process find the correct wire diameter. Following it we can find the outer diameter, number of turns, stiffness, pitch, free length of the spring and with these we have to complete the CAD model of the spring. For the control arms it is purely done by sketching with the help of LCA and UCA axis, UBJ and LBJ points and anti-dive and anti-squat. Then with that sketch we have to finish the CAD modelling of the control arms. Here, AISI 4130 is used as the material for control arms and chrome vanadium for springs.

Table 1: *Spring specification of active suspension*

Geometry	Size
Wire Diameter	10 mm
Outer Diameter of spring	95 mm
Solid Length	80 mm
Free Length	244 mm
Pitch	39 mm
No. of active turns	6
Total no. of turns	8
Deflection of spring	70 mm
Kerb Weight	825 kg

4. DESIGN AND ANALYSIS OF SPRING

Fig 3: *CAD Model of Spring*

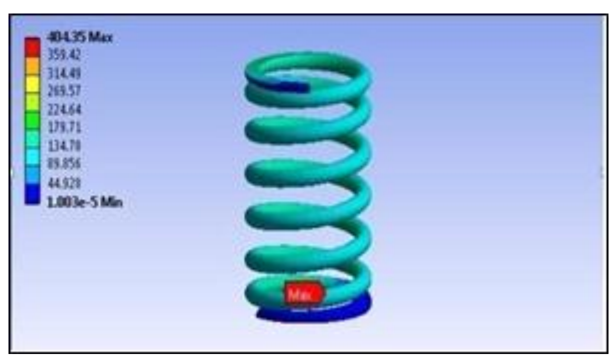

Fig 4: *Maximum Shear Stress analysis of spring*

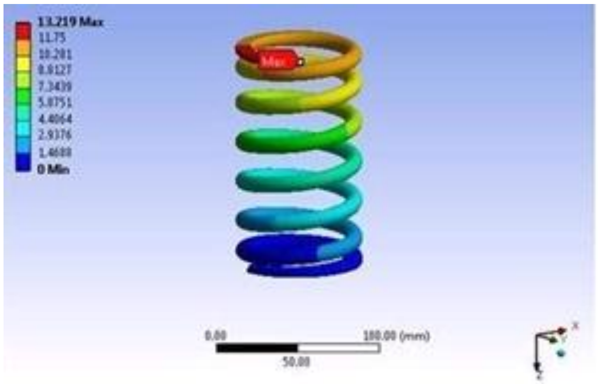

Fig 5: Deformation at pre-load

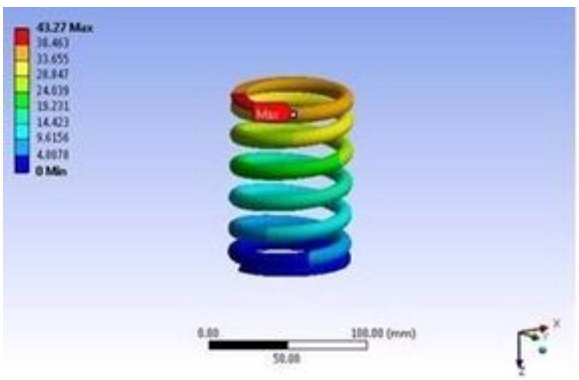

Fig 6: Deformation at maximum load

5. RESULTS

Summarized, result from FEA analysis of spring,

1. Initial deformation - 13.219 mm
2. Deformation at maximum load - 43.27 mm
3. Actual deformation = (43.27 – 13.219)
 = 30.051 mm
4. Equivalent Shear stress - 404MPA
5. Factor of Safety - 1.53

Table 2: Comparison of Active and Passive Suspension

Performance Parameters	Passive Suspension	Active Suspension	Change
Sprung mass Displacement (m)	0.04	0.018	55%
Settling Time (sec)	100	8	92%

6. Conclusion

From the above comparison it is clear that, Active suspension has lesser displacement and quicker settling time. So, an active suspension will give us a better comfort and riding stability.

REFERENCES

1. Race Car Vehicle Dynamics by William F. Milliken, Douglas L. Milliken

2. Mohammad Ali Nekoui, Parisa Hadavi, "Optimal control of an active suspension system", 14th International Power Electronics and Motion Control Conference, EPE-PEMC 2010.

3. Mouleeswaran Senthil Kumar, "Development of Active Suspension System for Automobiles using PID Controler", World Congress on Engineering London, U.K, Vol II WCE 2008, July2008.

4. T.P.J. van der Sande, B.L.J. Gysen, I.J.M. Besselink, J.J.H. Paulides, E.A. Lomonova, H. Nijmeijer, "Robust control of an electromagnetic active suspension system: simulations ns and measurements", Department of Mechanical Engineering, Eindhoven University of Technology.

5. Mats Jonasson, Fredrik Roos, "Design and Evaluation of an Active Electromechanical Wheel Suspension System", KTH Vehicle Dynamics, SE-100 44 Stockholm, Sweden.

BIOGRAPHIES

Harish C S[1]
Research Graduate
Mechanical Engineer
Coimbatore, Tamilnadu, India

Naveen Lara,
Student,
Department of Automobile Engineering,
SNS College of Technology
Coimbatore, Tamilnadu, India.