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Adaptive Spring Development with the Help of CAD Tool

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Abstract: Modern adaptive springs are designed in such a way that they vary their parameters with respect to applied load as well as adapt the assembly to perform well and give maximum life. In most of the cases the springs are attached with the damper mechanism. Some other springs are also attached with leaf springs to absorb shocks. The main objective of adaptive spring is to support damper mechanism to kill or absorb shock. The adaptive nature itself makes it user friendly.

In this paper the development of adaptive spring is to be done with the help of CAD tool like CATIA V5R19 which is further imported into CAE Tool like ANSYS to perform various types of analysis. Structural Analysis and shape optimization analysis will give the stress and deformation values along with the scope for modifying the shape. By redesigning the spring, same analysis is to be repeated to check the results. Accordingly the conclusion will be drawn.

***Index Terms* - Spring, Adaptive spring in CAD, CAE Tool, Shape Optimisation, Structural Analysis.**

I. ADAPTIVE SPRINGS FOR SUSPENSION

Using adaptively generally means that certain aspects of a part will change as changes occur in the constrained assembly; the part will adapt to fit the assembly. This is very useful when parts such as springs, rubber or any other flexible components need to be presented as a part of an assembly. Suspension design is all about compromise. For optimal handling, a car ideally needs to be quite firm, avoiding body roll and pitch and maintaining a good tyre contact patch with the road. But a stiff setup also makes a vehicle ride harshly on the road. Soften the damping too much and you'll have a smooth ride, but some rather alarming lean when you arrive at the first corner.

Manufacturers need to precisely tune the springs, dampers and anti-roll bars of their cars to achieve the best possible compromise, but there is also an adaptive suspension which plays very important role in all suspension assembly. In fact it is only responsible for better result.

These systems allow users to decide how firm or soft their car is, while complex software systems constantly monitor conditions and make small changes in suspension behavior as necessary. But there's more than one way to do this. These are the main types of adaptive suspension systems which are given bellow.

1.1 Magnetorheological Suspension System

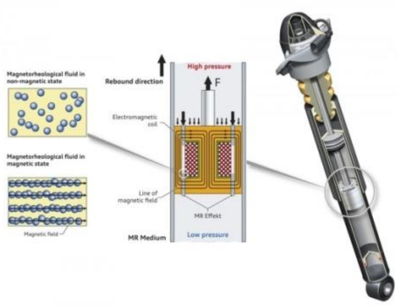


Figure 1: Magnetorheological Suspension system

Beloved of big car makers like General Motors and VW Group, the magnetorheological or MagneRide damper typically uses a monotube design filled with magnetorheological fluid. This is a synthetic oil containing iron particles that are only a few micrometres (a few thousandths of a millimetre) thick. When subjected to a magnetic field from one or more magnetic coils in the damper, the particles align. Although this doesn't - as some report - change the viscosity of the fluid, the realignment of the particles is capable of giving it an almost solid state, making it harder for the damper's piston to move through. The strength of the field determines how 'solid' the fluid is, allowing for the vehicle's software to control how firm or soft the damper is.

Most cars with MagneRide dampers will have presets to choose from that vary in their stiffness, but in addition to these general settings, the system's software will be constantly monitoring the road surface and how the car is being driven, making further adjustments to suit.

1.2 Valve-actuated Suspension System

Figure 2: Valve-actuatedSuspension system

It's possible to play with a damper's firmness on the fly without fancy magnetic fluid, however. Many systems use a valve to control the rate of flow of fluid through the piston, rather than alter the properties of the liquid itself. The more restricted the flow, the firmer the stroke of the damper's piston. Aston Martin, for instance, uses a system from Bilstein branded as 'Damptronic'. Here, the piston assembly features a firm valve and a soft valve. Flow through soft valve is controlled electronically via a solenoid, with the soft valve fully closed in the damper's firmest profile. Systems like these have settings that dictate general behaviour but - much like Magnetorheological dampers - operation varyies constantly. In the case of Damptronic, the damper's control system takes into account readings from various accelerometers and ride height sensors.

II. ADAPTIVE SPRING MATERIALS

The term "Spring Steel" encompasses a wide array of possibilities. Spring Engineers help in selecting the most appropriate and cost effective material for a particular application. Square, flat, rectangular and specially shaped wires are also available. Strip is available with normal mill edge as well as round edge, square edge, or slit & de-burred. Tempers are available from annealed to full hard. Standard raw material is bare wire but coatings include zinc, cadmium, tin, nickel, copper, galvanized and silver. Some common metals which are used for manufacturing of spring are as follows.

i) Alloy Steel

Spring steel is a name given to a wide range of steels used in the manufacture of springs, prominently in automotive and industrial suspension applications. These steels are generally low-alloy manganese, medium-carbon steel or high-carbon steel with a very high yield strength.

ii) Carbon Steel

High carbon steel springs are very popular due to their economical, strong, and durable nature. For higher quality springs, wires are cold drawn and heat treated before fabrication,

iii) Cobalt-Nickel

These alloys have ultra-high-strength, toughness, ductility, and outstanding corrosion and wear resistance. Cobalt Nickel alloy is also known as super stainless steel.

iv) Copper Base Alloy

Copper base alloys have high electrical conductivity and resistance to corrosion. Copper alloys have sufficient strength, ductility, and hardness which makes them best suited for springs operate in relay contacts and switch gears. Some of the key properties are given below:

- Strength at high operating temperatures.
- Excellent corrosion resistance.
- Can operate at super elevated temperature.

v) Nickel Base Alloy

Nickel alloy springs have outstanding corrosion and high-temperature resistance. Nickel alloys offer high strength, durability, and reliability even amid the harshest environments. They provide extreme resistance to corrosion under reducing chemical environment and sea water. Hence the use of this alloy for manufacturing of spring is suggested for particular applications.

vi) Stainless Steel

Stainless Steel Springs are manufactured out of grade 302, 316, or 17-7 spring tempered wire and have an ASTM A-313. Spring has many manufacturing capabilities and uses several types of wires in order to satisfy the customer needs. One of the most popular wire types besides music wire is stainless steel. Stainless steel is non-corrosive and may be used under high temperatures or moist environments.

vii) Titanium

Light weight, high strength, excellent elasticity along with these characteristics, Titanium springs are one of the strongest and most weight sensitive springs available. Titanium springs are not only strong, but they are also corrosion resistant. Titanium springs are used in many industries and in many applications, from motorbikes racing cars to aircraft.

III. LITERATURE SURVEY

K. Qusai, et al, In their examination a spring-damper is structured and a 3D copy is made utilizing for further strong works programming[1]. Anbu.G, et al, Discussed the design of adaptive suspension system for ride comfort and performance[2]. Mallick Kamran, et al, Their work is carried out on helical spring where, modelling, analysis and testing of suspension spring is done to replace the existing design of helical spring used in popular two wheeler vehicle using FEA[3]. P. Ravikanth Raju, K. Chinna Maddaiah, In their paper the importance of shock absorber in automobile design and various vibration theories are studied.Finally an active suspension is designed by making modifications and the method to improve the handling of the vehicle is discussed[4]. Shailendra Kumar Bohidar, et al, their article, discussion about the general review about the suspension system is done. According to them The suspension system of an automobile or a vehicle is the arrangement or a device which not provide the cushioning but also prevents the vehicle's engine from the road surfaces by providing the sufficient desired distance[5]. Rosmazi Rosli, et al, The paper describes the practical implementation of a new hybrid control method to a vehicle suspension system using Active Force Control (AFC) with Iterative Learning (IL) and proportional-integralderivative (PID) control strategy[6]. A.

A. Shafie, et al, This paper describe how vehicle suspension system keep the main body of the vehicle apart from any geometrical road irregularities thereby improving passenger comfort and also maintain good handling and stability. Their work proposes a design of a two loop PID controls of generated force (inner loop) and suspension parameters (outer loop) for a four degree of freedom, nonlinear, vehicle active suspension system model[7]. X. D. Xue, et al, In their study, research and development of automotive active suspensions are reviewed. Structures and models of various automotive suspensions are described[8]. Assaad Alsahlani, et al, In their paper, the simulation of spring is carried out by using Solid works with specific dimensions and analysis it with finite element analyzer ANSYS 14[9]. Aakash Bhatt, et al, Their project demonstrates the feasibility of adopting composite material for design of helical coil suspension system. In their project the design analysis of combination of steel and composite material isperformed. The authors proposed that this results into greater stiffness with reduced weight of the spring[10]. Abdolvahab Agharkakli, et al, The objectives of this study are to obtain a mathematical model for the passive and active suspensions systems for quarter car model.Comparison between passive and active suspensions system are performed by using different types of road profiles[11]. S. Hariharen, The major objective of their paper was to vary the stiffness of the spring according to the driver's decision. In this the stiffness of the spring is changed by varying the length of the liquid chamber[12]. Dishant, et al, In their paper different suspension systems are reviewed well[13]. Grzegorz Slaski, In this paper an application of concept to a mathematical quarter-car suspension model andused this application to control changes in the damping level of a physical quarter-car suspension model, coupled with an electrohydraulic vibrator is presented[14]. Łukasz Konieczny1, Rafał Burdzik2, Their article provides a discussion on various solutions used in modern suspension systems of automotive vehicles. Their paper presents shortly test methods used to evaluation of technical conditions of vehicle system[15].

3.1 Outcomes From Literature Survey

By studying all the above literatures and journal papers, it is observed that the detailed stress analysis and deformation due to shocks will provide the nature of spring behavior. Still further work is needed for the complete study of adaptive springs.

IV. Force Acting on Rear Shock Absorber

4.1 Total Weight on Bike

Total weight on the bike can be calculated as follows.

Total Weight on Bike = 110 (Self weight) + Riders Weight + Co-passengers Weight

W = 110 +80 + 80

W = 270 kg

4.2 Acceleration (a) of Bike

Here for Splendor+ bike it has acceleration 0 to 60 km/h in 6 to 8 second.

i.e. 60 km/h

Therefore

$$a = \text{if } \frac{60}{8} \text{ then } \frac{a}{1}$$

$$\boldsymbol{a = 7.5\ m/s^2}$$

Therefore,

Equation (2) will be,

$$\text{Rear Weight} = \text{Total Weight} * \frac{x}{WB} + \text{Total Weight} * \frac{h}{WB} * \text{Long. Accel.}$$

$$\text{Rear Weight} = 270 \times \frac{0.635}{1.27} + 270 \times \frac{0.635}{1.27} \times 7.5$$

Rear Weight = 1147.5 N

Hence Weight acting on single shock absorber = 1147.5/2 = 573.75 N

By considering factor of Safety = 1.5

Amount of Load acting on single shock Absorber = 573.75 × 1.5 = 860.62 N

4.3 Damping Force

A displacement of the body is obtained by integrating the speed. Also if we consider the maximum displacement (D_s) of the bike in vertical direction then it can be found by following Formula.

D_s = Length of Spring – (Number of turns × Spring Wire Diameter)

In our project spring have 15 numbers of turns. Hence the displacement will be

D_s = 142 - (15 ×6) = 52 mm

We know that,

- The **formula to calculate** the **spring constant** is as follows:

k= F/x = 573.75/52

k =11.033

where,

k = **Spring constant,** F = **Force,** x = change in **spring's** length.

- A **Reaction force** of the spring is calculated by multiplying the displacement and a spring **constant** of the spring.

$F_r = D_s \times k = 52 \times 11$

F_r = 572 N

- A **damping force (F_D)** is calculated by subtracting the spring reaction **force** from the transmitted load

F_D = 860.62 – 572

F_D = 288.62

4.4 Deflection and Stress Calculation

We have,
D= Mean Coil Diameter, mm = 36 mm
d= Wire Diameter, mm = 6 mm
N = Number of active coils = 15
P = Axial force, N = 860.62 N

(1) Spring index,
$C=D/d= 36/6 = 6$

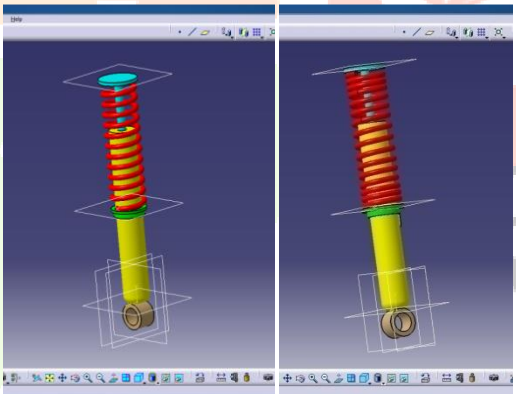
(2) Wahl's stress factor,
$k = [(4C-1)/ (14C-4)+(0.615/C)]$
$k = 0.2871$

(3) shear stress,
$\tau= (k\times8PD)/\pi d^3$
$\tau = (0.2871x\ 8\ x\ 860.62\ x36)/ (3.14\ x6^3)$
$\tau = 71143.6556/ 678.24$
$\tau= 104.89$ MPa

(4) Deflection of spring,
$\delta=8PD^3N/Gd4$
$\delta= (8\times860.62\times36^3\times15)/ (85000\times6^4)$
$\delta = 23.23$ mm

V. CAD Modeling of Adaptive Spring

Figure 3 shows the CAD model of adaptive spring used in two wheeler suspension system. It is developed in CATIA V5R19 software with part and assembly module environment. Various commands are used for this purpose like Pad, Pocket, Shaft, Rib, Pattern etc. from part module and manipulation, coincident constraint, contact constraint and offset constraint etc from assembly module are used. This developed module is further imported into FEA package for Analysis. Here the spring with uniform spacing is called as existing spring.



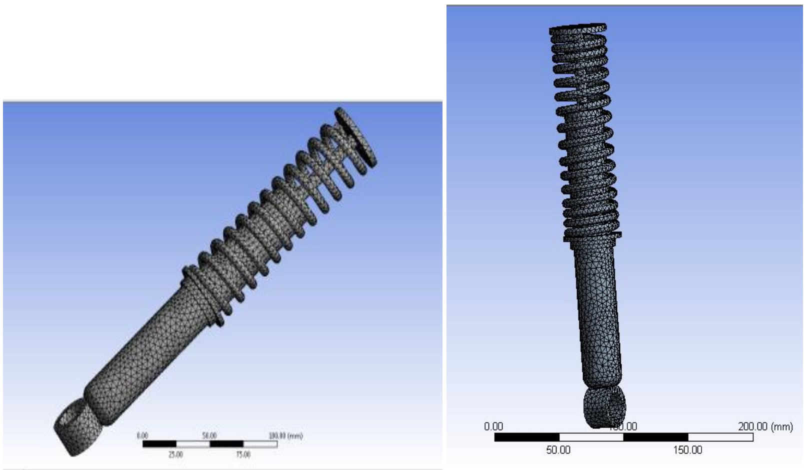
(a) Existing spring (b) Adaptive spring

Figure 3: CAD Model of Adaptive and Existing spring used in Two Wheeler

VI. VIRTUAL ANALYSIS

Table 1: Material Properties of Steel

Property	Unit	SAE 1020
Young's Modulus (E)	MPA	2.05e5
Poisson's Ratio	-	0.29
Density	Kg/m^3	7870



(a) Existing spring (b) Adaptive spring

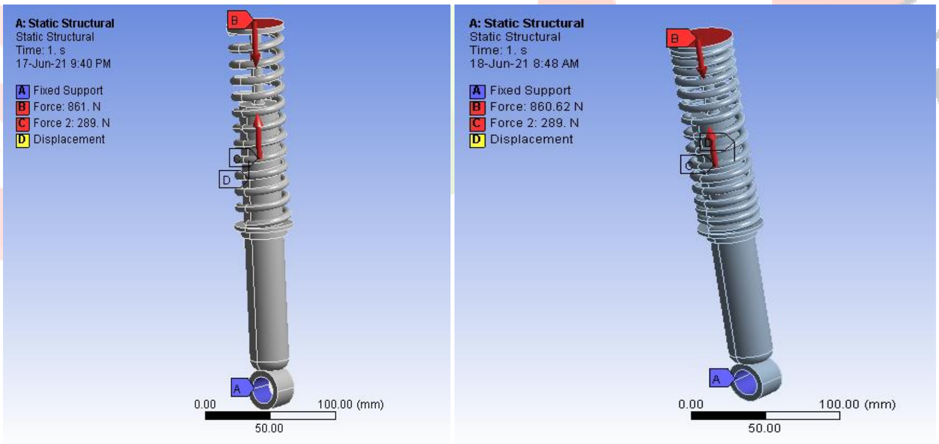
Figure 4: Meshed View of Adaptive and Existing Spring in 3D Tetragonal Element

Table 2: Nodes and Elements

Type of Element	3D Tetragonal
No. of Elements	18997
No. of Nodes	37259

6.1. Boundary Conditions

To simulate the proper physical condition, loads and fixed displacement are to be attached properly. In case of adaptive spring, it is fixed at the bottom hole. For this paper, adaptive spring used in two wheeler is considered. Here the load which is to be applied on adaptive spring is considered including thrust and torque. Hence the Actual Boundary Conditions are as follows.

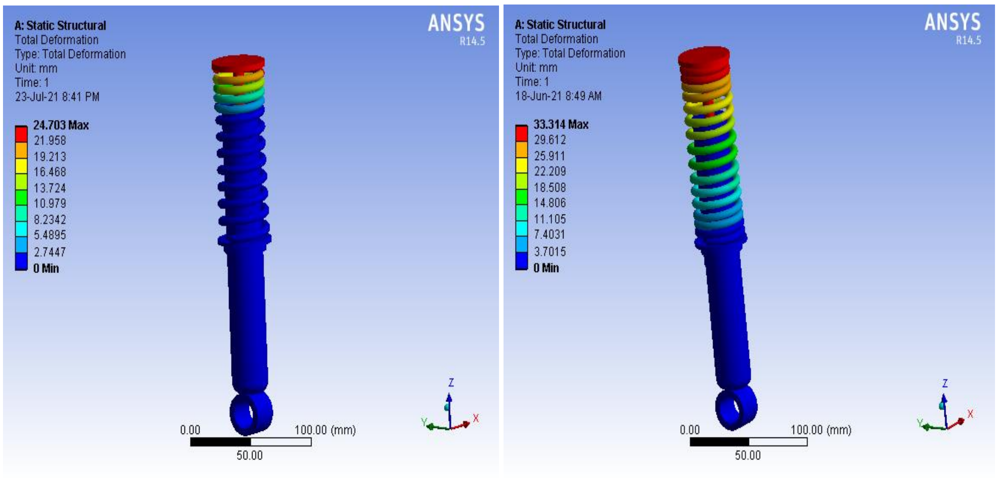


(a) Existing spring (b) Adaptive spring

Figure 5: Boundary Conditions on adaptive and existing spring

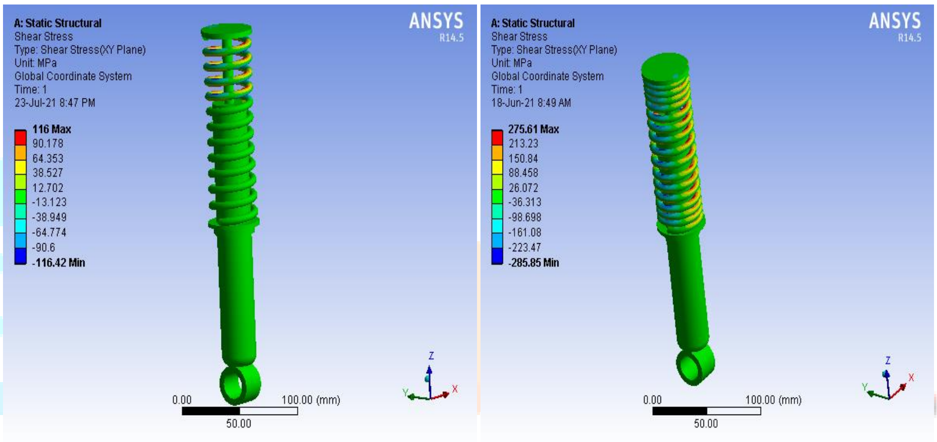
6.2 Generated Results

By performing Structural Analysis following results are obtained. Figure 6 shows the total deformation by the application of structural load as shown in boundary conditions. It is observed that the maximum deformation is 33.31 mm only. This deformation is having acceptable range. Also at the top only maximum deformation occurs. Remaining adaptive spring body having minute deformation.



(a) Existing spring (b) Adaptive spring

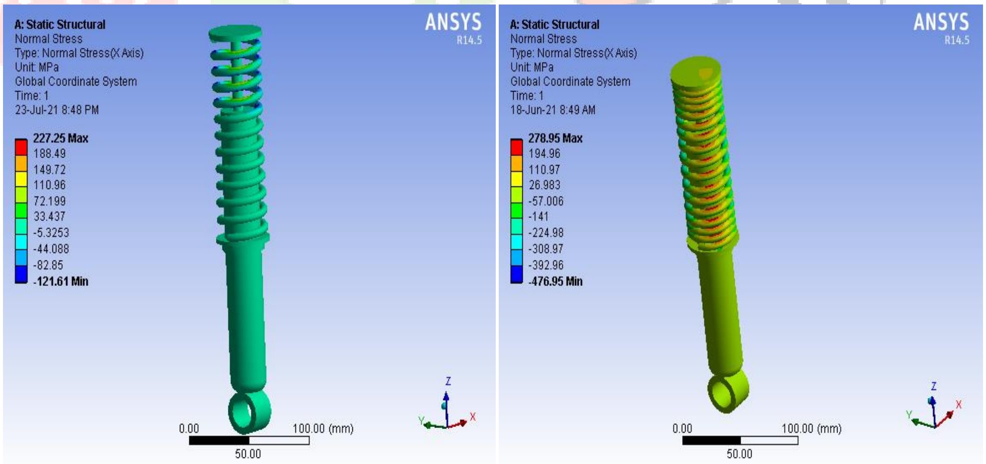
Figure 6: Total Deformation obtained in Structural Analysis



(a)Existing spring (b) Adaptive spring

Figure7: Shear Stresses developed in adaptive and existing spring

Above Figure 7 shows the shear stresses developed in adaptive spring and existing spring. These stresses are in acceptable range. Hence there are less chances of failure. It is occur on the top of the spring.



(a) Existing spring (b) Adaptive spring

Figure8: Normal Stresses developed in adaptive and Existing spring

Figure 8 shows the Normal stresses in structural analysis. The maximum stresses and minimum stresses are at the centre of the adaptive spring. It has 278.95 MPA value which is in acceptable range.

Table 3: Tabulated Analysis results

Sr. No.	Spring Type	Shear Stress (MPa)	Normal Stress (MPa)	Total deformation (mm)
1	Existing Spring	116	227	24.70
2	Adaptive Spring	275	278	33.31

7. Conclusion

By observing all the values in structural analysis result, it is found that all values are in acceptable range for adaptive spring. Also the regular application of such load will not affect the adaptive spring life. From results adaptive spring is taking more deflection and hence absorbing the shock and possessed flexible nature.

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