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Design Analysis Fabrication and Testing of Progressive Air Suspension Strut

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Abstract—*Ride comfort and adjustability has always been deprived on low budget suspensions. The main problems faced in the current market shocks are that, they being heavy and having no adjustability. There should be a way to provide the masses with a highly efficient shock absorber for a very low price. The project aims to provide the reader an ideal way to design, analyze, simulate and manufacture a non-conventional shock absorber having adjustability in the ride parameters.*

Keywords—Venturi effect, Damping, Air as Spring, Adjustable, Serviceability.

I. INTRODUCTION

Suspension is the system of tires, tire air, springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two. Suspension systems serve a dual purpose — contributing to the vehicle's road holding/handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and a ride quality reasonably well isolated from road noise, bumps, vibrations, etc. These goals are generally at odds, so 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 job of a car suspension is to maximize the friction between the tires and the road surface, to provide steering stability with good handling and to ensure the comfort of the passengers. In this article, we'll explore how car suspensions work, how they've evolved over the years and where the design of suspensions is headed in the future.

II. PURPOSE

The main purpose of an automobile is to transport man, his livestock, machinery and equipment from one place to other. This transport has to be done with utmost care as the ride has to be safe and smooth to reduce fatigue on the in transit goods, people and also on the automobile as road shocks can cause collateral damage to the automobile parts as well as human body joints and spine. Hence there is a need to eliminate such road shocks and make the ride less bumpy.

III. PROBLEM STATEMENT

The suspension systems that are currently used in most automobiles have steel springs to store the energy and hydraulic oil passes through shims to damp these oscillations.These springs made of steel are heavy and increase the unsprung mass, the characteristics of the spring remain same irrespective of road profiles. The longitudinal length of these struts are huge and there is no adjustability until the strut is unmounted from the vehicle and the spring has been replaced. This job was tedious and requires a professional hence it consumes time, increases cost and hence is not a feasible idea as the ride parameters cannot be changed in real time.

Ethereal suspension strut combines air and hydraulic oil in a single assembly wherein the air acts in spring and being naturally progressive in nature and has the capability to store energy. Hydraulic oil passes through the orifice where the velocity and pressure of the oil changes and damps the oscillation. Changing the amount of air in gas chamber changes the stiffness of the suspension and by simple clicks on the knob the damping can be changed as it varies the area of the orifice.

IV. WORKING

1. Air as Spring-

1.1.Breakaway Force:-When a spring is compressed, it exerts a force against whatever is compressing it. This is called a breakaway force. In order to further compress the spring, the breakaway force must be overcome.

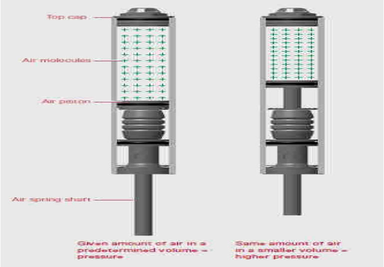

Fig.1:- Air Springs Sectional View

1.2. Breakaway force in an air spring

Pressurized air in a chamber creates force against all surfaces inside the chamber. The force acting against the piston creates a breakaway force. Because of this, an air spring can feel firm at the beginning of the stroke, similar to a preloaded coil.

1.3. Preload

A coil spring at rest is not under pressure and creates no break away force. Preloading a coil spring compresses the spring without initiating stroke. This results in a breakaway force and stiffer spring feel.

1.4. Air Spring

An air spring is the result of a sealed chamber filled with air that has one or more of the chamber walls able to move in and out of the chamber. In suspension, the moving wall is called the air piston. During the compression stroke, the air piston presses against the air as it moves into the chamber. The amount of air molecules in the chamber remains the same but the volume of the chamber is reduced. The result is an increase of air pressure in the chamber. Any air pressure creates a proportional amount force against the piston, opposing the force pushing the piston into the chamber. Pressure in an air spring is determined by the ratio of air in the chamber and the volume of the chamber. The pressure at any point in the stroke can be calculated by using the overall length of the air chamber and the air pressure at top out as a baseline; the percentage of change is the result of the amount of piston movement through the length of the air chamber. For example: Take an air chamber that is four inches long and pressurize it to 100 psi. Move the piston into the air chamber two inches. This reduces the volume of the air chamber by 50%, which doubles the pressure. The remaining chamber length is two inches. Move the piston into the chamber one inch. This reduces the remaining volume of the air chamber by 50%, which doubles the pressure again. Continue to repeat this process of reducing the volume by half and doubling the pressure. The result is an exponential increase in air pressure throughout the stroke.

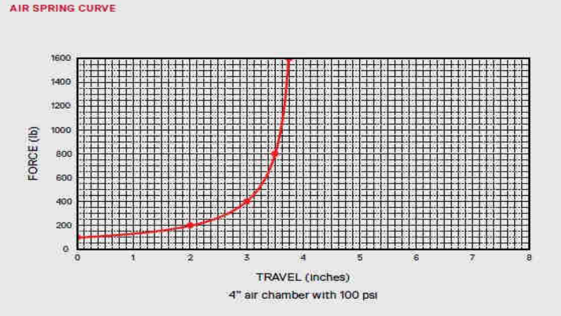

Fig 2:-Air Spring curve- Force vs Travel

1.5. Pressure vs. force

A common misconception is that the pressure in an air chamber is equal to the amount of force required to initiate compression. A simple way to think about the relationship between input forces and spring pressure is to look at a common way that pressure is expressed, pounds per square inch. In this case, pounds is a measure of force and square inches is a measure of the surface area of the piston. By determining the area of the piston surface, taking into account any curvature of the surface, and dividing the force by the result, the amount of pressure required to counter the force can be calculated as follows : Pressure = Force/area

2. DAMPING

2.1. Damping- is an influence within or upon an oscillatory system that has the effect of reducing, restricting or preventing its oscillations. In physical systems, damping is produced by processes that dissipate the energy stored in the oscillation. Examples include viscous drag in mechanical systems, resistance in electronic oscillators, and absorption and scattering of light in optical oscillators. Damping not based on energy loss can be important in other oscillating systems such as those that occur in biological systems.

The damping of a system can be described as being one of the following:

Over damped ($\zeta > 1$)

The system returns (exponentially decays) to equilibrium without oscillating. When $\zeta > 1$, the system is *over-damped* and there are two different real roots.

Critically damped ($\zeta = 1$)

The system returns to equilibrium as quickly as possible without oscillating. When $\zeta = 1$, there is a double root γ (defined above), which is real. The system is said to be *critically damped*. A critically damped system converges to zero as fast as possible without oscillating (although overshoot can occur).

Underdamped ($0 \leq \zeta < 1$)

The system oscillates (at reduced frequency compared to the *undamped* case) with the amplitude gradually decreasing to zero. Finally, when $0 < \zeta < 1$, γ is complex, and the system is *under-damped*. In this situation, the system will oscillate at the natural damped frequency ω_d, which is a function of the natural frequency and the damping ratio.

Undamped

The system oscillates at its natural resonant frequency (ω_o) without experiencing decay of its amplitude.

V. METHODOLOGY

1. Problem definition.

The problem of the suspension was noted down and the bump force and cornering force was calculated. The basic consideration was that the vehicle of 300kg is moving over a bump of 8 inches at a speed of 60 kmph. Accordingly the ride parameters were set. The amount of forces acting on the suspension was calculated and the gas pressures were noted.

2. Calculation for spring rate.

The spring ratio was calculated at all pressures and the pressure was noted down depending on the ride parameters needed viz. soft or hard. For off road terrains the suspension needs to be soft and the pressure of gas tube was calculated, for perfect tar and cement concrete roads the suspension needs to be hard so that it can work at high speeds and the pressure was calculated.

3. Calculation for volumn ratio.

The volume ratio was calculated for the required travel of 6 inches and the volume inside each of the tubes was calculated. Through this the diameter of the tubes and the length of the tubes were calculated keeping the eye to eye length as constant. the basic physical dimension of the strut was hence derived.

4. Market survey.

Market survey for standard size bearings and seals was done so that they could be readily available at cheap rates at common stores around the locality. Standard size helps to finalize the physical dimension of the components as having to order a nonstandard part increases cost and also increases lead time of the production.

5. Designing.

- Based on available bearing and seals (viz. v-groove seal, viper seal) sizes design the inner diameter of the central housing, the outer diameter of the gas tube was designed.
- From outer diameter of gas tube was assumed and a suitable wall thickness and conclude the inner diameter of the gas tube.
- Based on standard available size of piston seal, the piston grove was designed for the piston. The outer diameter of the piston seal should be compatible with inner diameter of gas tube.
- From the inner diameter of gas tube the basic dimensions for orifice was derived.
- Using the inner diameter of central housing the outer diameter for the oil tube was derived.
- The inner diameter of oil tube was found to be greater than the outer diameter of gas tube.
- The outer diameter for oil tube should be the driving dimension for the bottom cap
- The outer diameter for gas tube should be the driving dimension for the top cap
- Use the dimension of standard radial bearing to derive the hole size on the cap.
- Based on the size of bolt to be used to mount the suspension, the spacers for both ends were designed.
- Using the newly achieved dimension verify the strut travel through the volume ratio, if the travel is approximately 6 inches then finalize the dimensions.

6. CAD modelling

Use computer aided tools such as Solidworks® to model these dimension using the standard procedure depending on the modelling software being used.

7. CAE

Import the cad model into an analytical software, here Ansys® to check

A. effect of internal pressure on the tube
B. thermal effect on the tubes
C. effect of forces on the threads

On achieving satisfactory results confirm all dimensions

8. Simulation

Using the newly achieved dimensions calculate the spring rate and check all ride parameters on Lotus®

9. Drafting

Create a 2D sketch of all components which would include all basic views and an isometric view. Provide necessary tolerance where ever required.

10. Procurement

Procure the raw materials for all components keeping a minimum of 2 mm clearance to remove quality and to bring proper finishing to components. The test certificate of each material is to be collected from suppliers. Procure all the standard components required for assembling the suspension strut.

11. Manufacturing

- Using the 2D drawings start the manufacturing process.

- Turn the components on lathe and achieve a proper finish on the components. after threading the components check for proper fit.
- Honing process is to be carried out on the inner surface of the gas tube.
- The outer surface of the gas tube has to be ground.
- Mill the top and bottom caps post turning.
- Drill the top and bottom caps to incorporate the radial bearing.
- Machine the piston as per drawings.
- The orifice is a critical part and has to be dealt with utmost care.
- Mill the inner surfaces at angles to facilitate the movement of the shims.
- Conduct a quality check on all the parts

12. SUB-ASSEMBLY

Assemble the orifice together and screw the two parts.
Fix all bearings and seals to their respective positions.
Screw the valve on the top cover

13. Assembly

- Cap the oil tube securely and apply liquid sealant between threads.
- Fill the oil tube with oil to the predetermined level.
- Screw the orifice to the tube and insert the gas tube into the oil tube.
- Put the piston into the gas tube and open the bleed port.
- Bleed out all the air in the oil and seal the bleed port.
- Screw the top cap on gas tube.
- Fill in air through the valve at a predetermined pressure.
- Place the inserts

14. ON Road Testing

Mount the suspension strut on the vehicle and it is ready to race.

VI. RESULTS

1. THREAD ANALYSIS:-

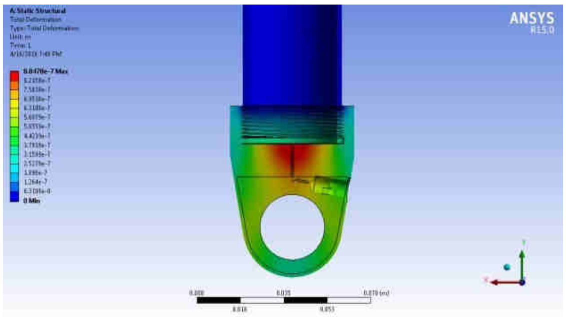

Fig.3 : Deformation

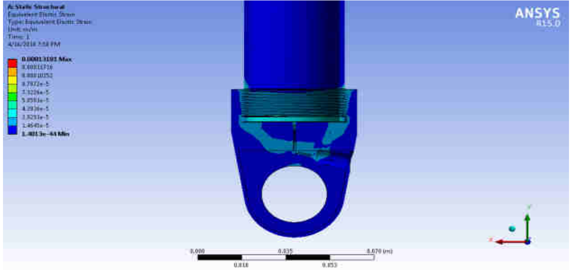

Fig.4 : Equivalent Elastic Strain

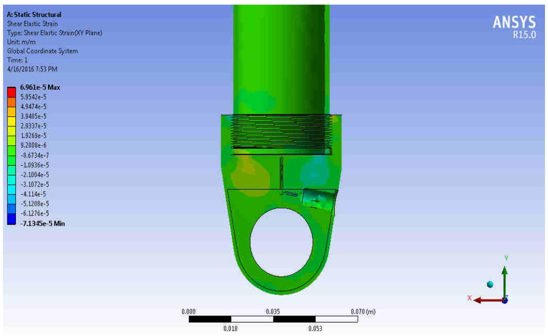

Fig.5 :Equivalent Stress

2. FATIGUE ANALYSIS:-

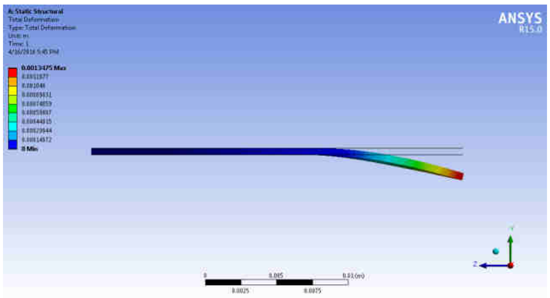

Fig 6 :Deformation

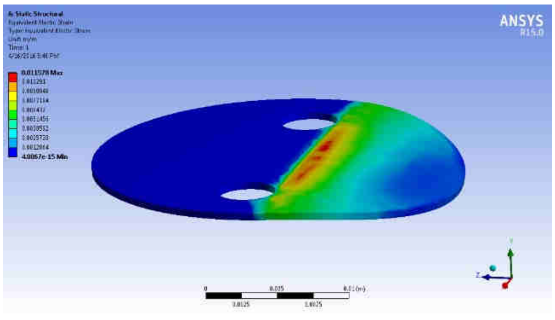

Fig.7 :Elastic Strain

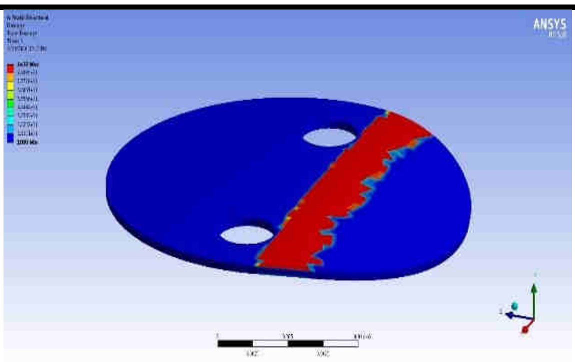

Fig.8 : Life

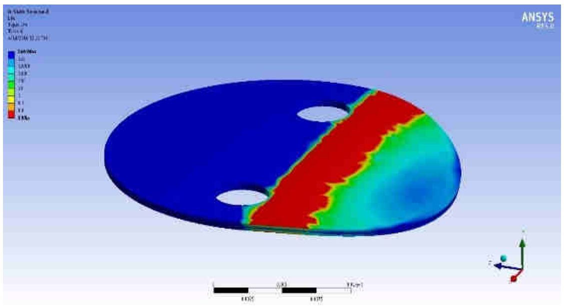

Fig.9 : Damage

3. FLUID SOLID INTERFACE:-

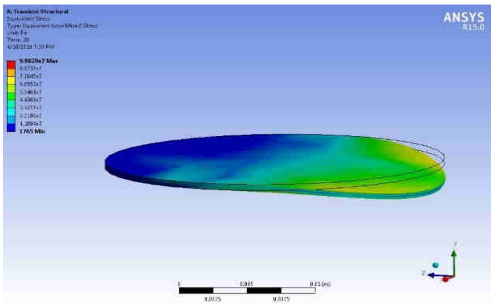

Fig.10 : Total Deformation

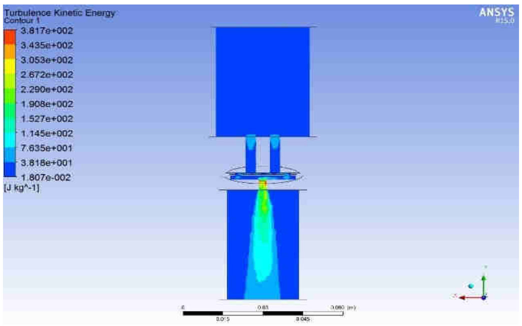

Fig.11 : Pressure

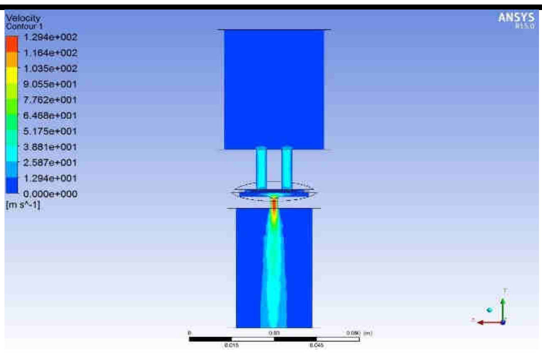

Fig.12 : Velocity

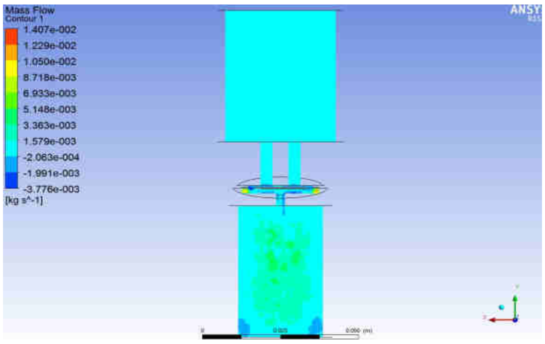

Fig.13 : mass flow rate

4. STATIC ANALYSIS:-

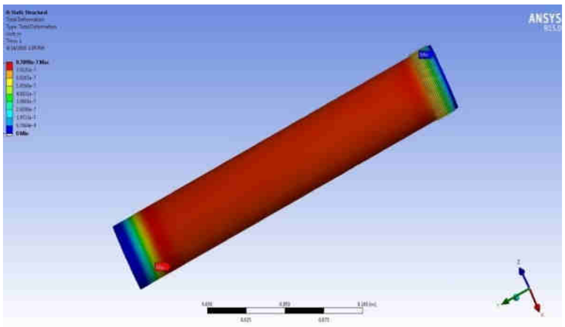

Fig.14 :Déformation

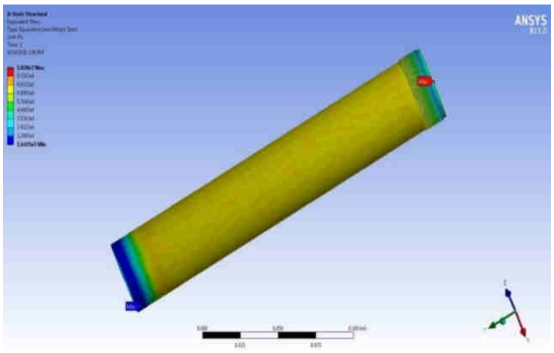

Fig.15 :Stress

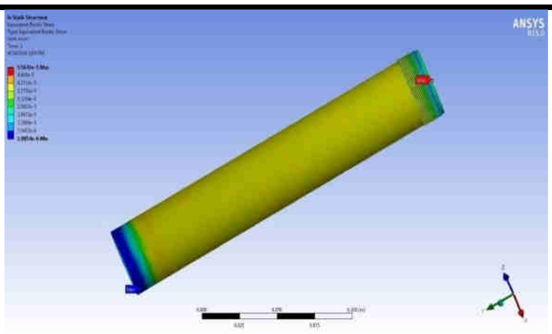

Fig.16:Strain

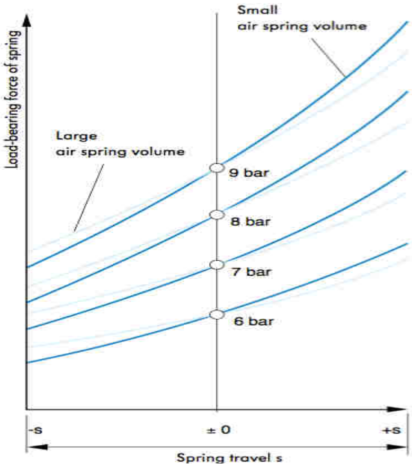

Fig.17:Déformation

Input	Input	Input
Mass, m[kg]=	100	Kg
Damper Travel, x[m]=	0.0700	M
Time taken, s[sec]=	5	S
Coefficient of damping, c[Ns/m]	350.16	Ns/m

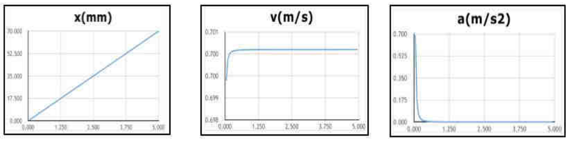

Fig.18 : Load result

Input	Input	Input
Mass, m[kg]=	2	Kg
Damper Travel, x[m]=	0.1200	M
Time taken, s[sec]=	4.5	S
Coefficient of damping, c[Ns/m]	351.06	Ns/m

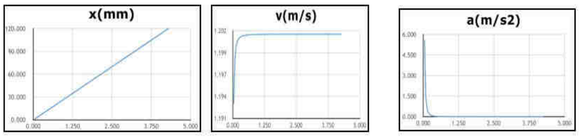

Fig.19 : Load result

Input	Input	Input
Mass, m[kg]=	3	Kg
Damper Travel, x[m]=	0.1540	M
Time taken, s[sec]=	3.7	S
Coefficient of damping, c[Ns/m]	352.73	Ns/m

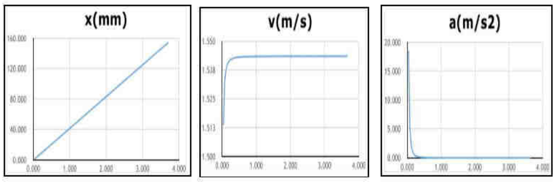

Fig.20 : Load result

VII. CONCLUSION

1. Adjustability

Ethereal shocks have a very high level of adjustability. A few clicks on the knob and Ethereal is ready to pounce on the track. The simple aim that any common person should be able to adjust the ride parameters has been achieved.

2. Low cost

An upgrade to Ethereal shocks cost merely one fifth of the cost of most available after market suspensions offered in the global market. Being low in cost Ethereal hasn't compromised on the quality and safety aspects and it has raised the standards for comfort and drivability.

3. Light weight

F=m x a. This law clearly brings to light that lower the mass of the vehicle higher the acceleration of the car. Ethereal has come out with a light weight and highly efficient solution into one of the major weight defaulter. Ethereal weighs under 2 Kilograms which is 7 times lighter than the conventional steel spring suspension which in any ways has no susceptibility to adjustability.

4. Serviceability

Ethereal shocks are an assembly of simple components and has no component fastened to each other by permanent mechanical connections. Each component is fastened through threads and the service time for Ethereal is minimal. It takes under 12 minutes to assemble a complete Ethereal strut from stage scratch.

VIII. FUTURE SCOPE

The quest to improve and rise each day never ends. By the addition of sensors the strut can adapt to the road conditions. The next generation Ethereal shocks will be equipped with sensors that would read the road conditions and understand the terrain, calculate the spring and damper parameters and adjust accordingly. Depending on the terrain it would also increases or decreases the riding height of the vehicle.

By adding a few extensions in the orifice rebound adjustability can be achieved.

Few more designs incorporations are aimed and when achieved would make the ride quality even more self-indulgent. The new add ones would provide adjustability in the bounce and jounce characteristics.

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