

ARTICULATED SUSPENSION SYSTEM

Design and analysis of Human Knee Joint Suspension system

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Abstract -

This paper informs about the development of a new suspension system for two-wheeler vehicle based on the functional movement of human knee joint implementing biomimicry; utilizing torsional spring as a medium for generating the required restoring force. The main characteristics of this suspension system mechanism are the application of force in both vertical and horizontal direction and the elimination of high energy loss and friction damping from the suspension system to an extent. This system reduces mechanical trouble as a significant reduction in physical damage and stress to the rider.

Key Words: Damper, Torsional Spring, Biomimicry, Suspension system.

1. INTRODUCTION

We know that the basic principle of a knee is to absorb vibrations while running and vertical shocks while jumping. This human knee joint mechanism is used for composition of our new suspension system. The flexing of knees is required to reduce the shock of landing after a jump. This principle can be used to reduce the vibrations acting on the system. We have utilized torsional spring instead of regular helical spring. Torsional spring acts as a medium for generating the required restoring force. The mechanism works by splitting and converting the original fork suspension system into two different arms; representing an upper and lower arm. These arms mimic the anatomy of a Human leg. The main advantages of a torsion spring suspension are soft ride due to elasticity of the spring and durability. The torsional spring is placed between the upper and lower link of the suspension system. The components of suspension system are upper link, lower link, torsional spring, damper and hub.

In our daily lives we experience various sorts of trouble whilst traveling, for the two-wheeler vehicle riders it is essential for the rider to not only feel comfortable but also feel its performance improve. So, we decided to change the design part of the front suspension system of the two-wheeler vehicle utilizing the new principle of Bio-Mimicry such that its new design is not only to be revamped but also to provide better experience to the rider.

1.1 WHY THIS SUSPENSION SYSTEM

The conventional and common type of the front suspension used in motorcycle is Telescopic forks. But this system has some problems such as uneven vibration, changing of wheelbase etc. Due to vibrations the rider experience discomfort and this leads to medical issues to the rider. The heating causes wear and tear of the shock absorber.

These are the following advantages over the conventional suspension system:

- Input action for system is in vertical and horizontal direction.
- Torsion spring is used which is good in restoring forces.
- The design is Simple and Integrated.

2. MECHANISM AND WORKING

The mechanism works by splitting and converting the original fork suspension system into two different arms; representing a Knee. The arms represent the Bone in the human thigh whilst the spring acts as Muscle and the damper acts as Tendons which hold and forces the muscles in arm to contract and expand in controlled manner. or heads unless they are unavoidable.

2.1. CONSTRUCTION

The suspension system based on the articulation of knee and its impact dampening capability is constructed by mimicking its structure based on the human knee where the Upper arm represents the thigh bone whilst the lower arm represents the shin bone.

The upper arm and lower arm are attached via a bushing coupled with a torsion spring where the spring is attached to the main part of the arm through an internal bore which holds the end of the spring.

The integrity of spring is maintained by providing a shaft through the spring in between the coils; such that when exerted to impact the spring would not leave its body due to sudden load differential.

The damper is attached to the upper and lower arms respectively for absorbing the Impact of the quick reaction of torsion spring's restoring force; The measured distance is $1/3^{\text{rd}}$ of total length of the upper arm and $2/3^{\text{rd}}$ distance from the total length of lower arm starting from spring/pivot point.

The arms are provided with a curvature of 8R to handle the impact and its construction is hollow from inside leading to a crisscross patterned truss such that it retains its rigidity and integrity.

Parts in the assembly:

- Upper arm
- Lower arm
- Torsional Spring
- Damper
- Shaft pin

2.2. WORKING

The mechanism works by splitting and converting the original fork suspension system into two different arms; representing a Knee. The arms represent the Bone in the human thigh whilst the spring acts as Muscle and the damper acts as Tendons which hold and forces the muscles in arm to contract and expand in controlled manner.

When the suspension system travels on the uneven road surface the Tire maintains the road contact and whilst returning the impact/force is absorbed by the spring which springs back to its original state quickly, to prevent such action (such quick uncomfoting motion) damper is placed between two arms such that the returning motion is compensated to accomplish comfort yet at the same time performance.

When the tyre is in contact to the road surface and bumps are created the spring absorbs the shock experienced by the tire from its sudden displacement the spring contracts radially and expands releasing its stored energy from compression, the released energy should not be exerted rapidly to avoid shock to the rider hence Damper are mounted on each side of the arm to provide cushioning effect as well as an lenient way for the arms to stay stable during cornering. The Arm should not fall to the subjected force of the bike with the weight of rider hence the arms are given a curved profile to enhance its strength as well as its Aesthetics.

The point of making such changes to a pre-existing suspension system is that there is no balancing effect on the front suspension system when cornering/banking, here the articulated system helps by distributing the load from back of the front wheel to its center.

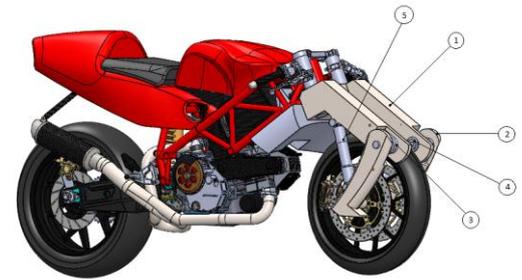


Fig. 2.2.1: Assembled Articulated Suspension system

From the above figure 2.2.1 the given terms are:

1. Upper Arm
2. Lower Arm
3. Torsion Spring
4. Shaft Pin
5. Damper

3. DESIGN AND DEVELOPMENT

3.1. PROBLEM STATEMENT

The telescopic fork suspension has following problems such as uneven vibration, leakage of oil, changing of wheelbase, uneven compression of shock absorbers, uneven vibrations potentially causing discomfort to the rider and wear and tear to the system.

OBJECTIVE:

1. To perform statistical analysis of the articulated suspension system
2. To determine the comfort level of the system to the rider.

3.2. METHODOLOGY

To obtain the solution/desired result, for the Articulated Suspension system, the methodology we followed are:

We built a 3D model in SolidWorks; each and every part of our system was built in SolidWorks and assembly was performed with no interference present in it. We then proceeded with the Analytical solution and then performed Static Structural analysis in ANSYS Workbench Software on the Model. The desired results were obtained.

3.3. MATERIAL SELECTION

Upper and Lower Link:

The material used for upper and lower link is AHSS (Advanced High Strength Steel).

Properties of AHSS (Advanced High Strength Steel)

- Low weight
- High Strength
- Optimised Formability
- High Stiffness
- Yield Strength more than 550 MPa.

Torsional spring:

The material used for torsional spring is Beryllium Copper.

Properties of Beryllium Copper:

- High Strength
- Sustain High temperature
- Wear resistance
- Fatigue resistance

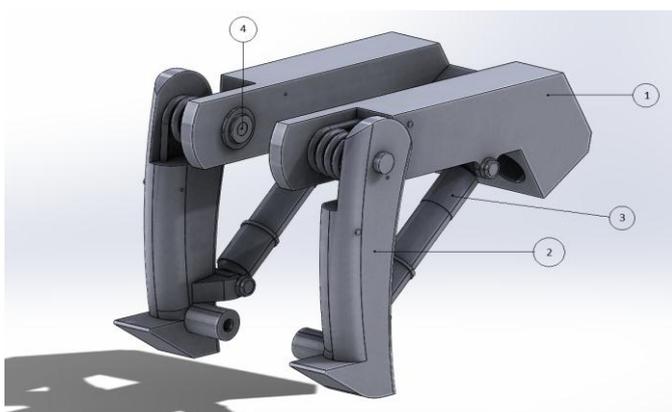
Damper:

The material used for damper body is steel and for the rod material is Chrome plated steel

Properties of damper:

- Durable
- Shock Resistance
- During the operation damper gets less heated.

3.4. MODEL SPECIFICATIONS



- 1.Upper Arm: L-385mm_W-100mm_T-80mm
 - 2.Lower Arm: L-297mm_W-100mm_T-60mm
 - 3.Damper (3.4.1.2. Damper)
 - 4.Steering shafts distance - 205mm
- Link shaft
D 20mm

3.4.1. ESSENTIAL PARTS

3.4.1.1 Torsional Spring

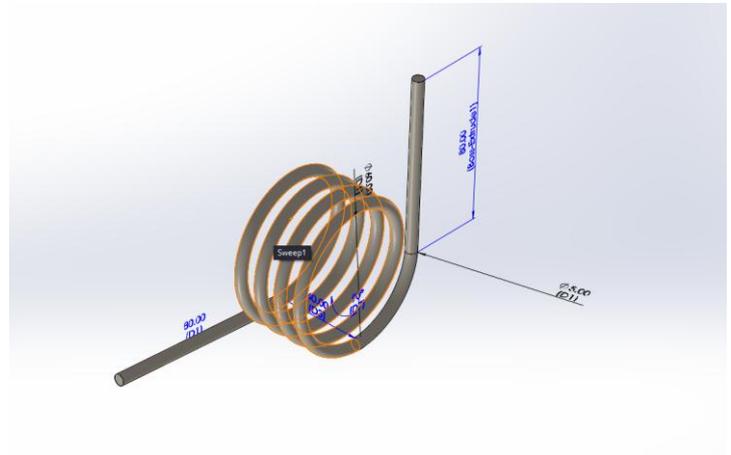


Fig 3.4.1.1-Torsional Spring

Torsion Spring Design:

Refer to PSG 7.131 for calculation.

$$\begin{aligned} \sigma_u &= 1380 \text{ N/mm}^2 \\ \sigma &= 0.678 * \sigma_u \\ \sigma &= 0.67 * 1380 \\ \sigma &= 924.6 \text{ N/mm}^2 \\ d &= 5 \text{ mm} \\ F &= 2501.55 \text{ N} \\ D_o &= 60 \text{ mm}, d = 50 \\ D_{\text{mean}} &= 50 \text{ mm} \\ D_{\text{in}} &= 40 \text{ mm} \\ L &= 80 \text{ mm} \\ a &= 25 \text{ mm} \\ M &= F * a \\ &= 2501.55 * 25 \\ \text{BM} &= 62538.75 \text{ N.mm} \\ D_{\text{mean}} &= 60 \\ D &= 10, C = 6 \\ K_b &= 1.2525 * d^3 \\ \sigma &= \sigma_u = 1380 \text{ N/mm}^2 \\ D_{\text{mean}} &= 60 \\ D &= 10, C = 6 \\ K_b &= 1.2525 * d^3 \\ \sigma &= \frac{32 * K_b * M}{\pi * d^3} \\ &= \frac{32 * 1.2525 * 62538.75}{\pi * 10^3} \\ &= 797.86 \text{ N/mm}^2 \\ \theta &= \frac{\pi * M * D * N_c}{EI} \end{aligned}$$

$$\frac{\pi \times 62.53875 \times 60 \times 8}{130 \times 10^3 \times 490.873} = 1.477 \text{ rad}$$

Mean Diameter of Coil (D_{MEAN})	= 60mm
Outer Diameter (D_{OUT})	= 70mm
Inner Diameter (D_{IN})	= 50mm
Wire Diameter (d)	= 10mm
Length (L)	= 73.71mm

The above spring design is Safe.

Calculation of Spring Constant.... [6]

Spring terms:

- Inside diameter (D_i): 40mm
- Outside diameter (D_o): 60mm
- Mean diameter (D_m): 50mm
- Length of spring (L): 73.71mm
- Number of active coils (N_a): 4
- Wire diameter (d): 10mm
- Leg length (a): 25mm
- Spring force (F): 2501.55N

Calculation:

Moment = $F \times a$
 $= 2501.55 \times 25$
 (M) = 62538.75N-mm

Spring Index (C) = $D_m / d = 50 / 10$
 (C) = 5

Spring Constant (S)
 $S = 32M / (\pi \times d) \times 4c^2 - c - 1 / 4c(c - 1)$ [6]
 $= 32 \times 62538.75 / (\pi \times 10) \times (4 \times (5)^2 - 5 - 1) / 4 \times 5 \times (5 - 1)$

$S = 764.417 \text{N/mm}^2$

3.4.1.2. Damper

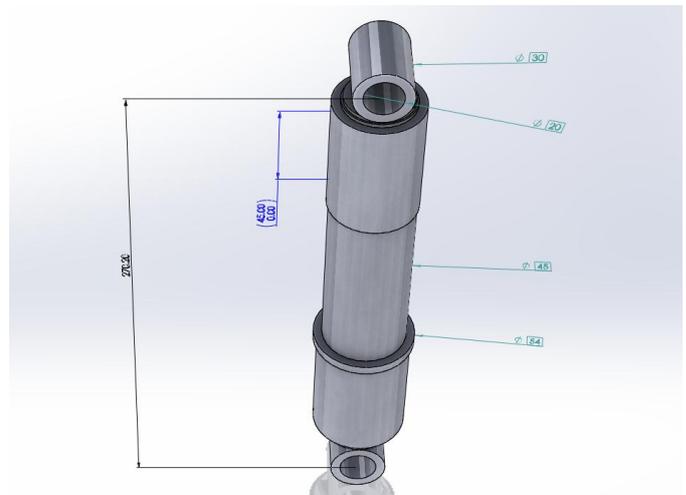


Fig.3.4.1.2- Damper

Damping Coefficient:

- Speed (v) = 60kmph = 16.66m/s
- Damping ratio (ϵ) = 0.5
- Wavelength of sinusoidal surface (λ) = 6m
- Natural frequency (W_n) = 2 rad/s
- Frequency of external force (w) = 17.44 rad/s
- Damping Force (W_d) = 300N
- Amplitude of sinusoidal surface = 20mm
- Steady state amplitude due to excitation of support is

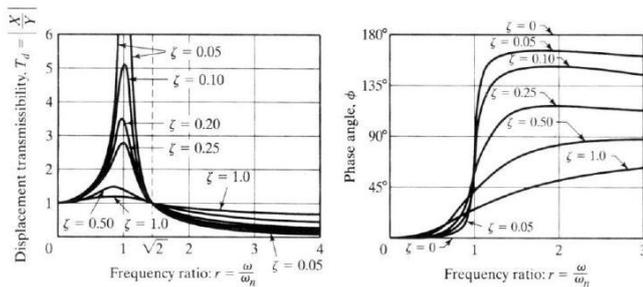
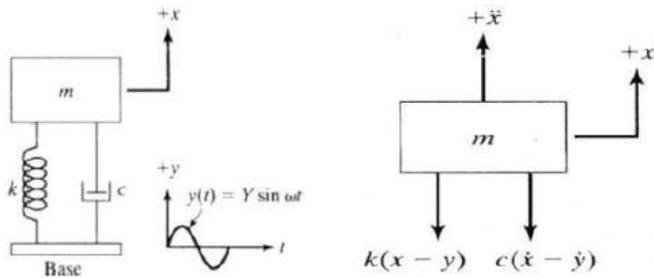
$$X = \frac{Y * \sqrt{(1 + (2 * \epsilon * (\frac{W}{W_n})^2)^2)}}{\sqrt{[(1 - (\frac{W}{W_n})^2)]^2}} + (2 * \epsilon * (\frac{W}{W_n}))^2} \dots [2]$$

$= 0.02 \times \sqrt{(1 + (2 \times 0.5 \times 1.995)^2)} / \sqrt{(1 - 2^2)^2 + (2 \times 0.5 \times 1.995)^2}$
 $X = 0.0124 \text{m}$

Damping Coefficient Calculation:

$C = W * d / (\pi * w * X)$
 $= 300 / (\pi \times 17.44 \times 0.0124)$

C = 441.57 Ns/m



3.4.3 MOTION ANALYSIS

Assumption of a simple model of motor vehicle as a bike that can vibrate in the vertical direction while travelling over rough road. Vehicle has mass of 192 kg (including weight of passenger). The suspension system has a spring constant of 764.417 N/m (Calculated by online spring stiffness calculator) and a damping ratio of $\epsilon = 0.577$ for vehicle speed 20, 40, 60 Kmph. The road surface varies sinusoidal with an amplitude of $Y = 0.05$ to 0.2 m with interval of 0.05 and wavelength here I consider 6 m, Spring Stiffness calculation: as on the basis of dimensions measured from shock absorber.

Wire diameter (d) = 10 mm,

No of active coils (n) = 4,

Outer diameter of spring coil = 70 mm,

Mean diameter of spring coil = 60 mm,

Force on spring = 2501.55 N.

Damping Coefficient(C):

$$C = WD / (\pi \times w \times X) = 300 / (\pi \times 17.44 \times 0.0124)$$

C = 441.57 Ns/m

Critical Damping (Cc): $Cc = 2m\omega_n = 2 \times 192 \times 1.992$

Cc = 764.928

Damping ratio: $\epsilon = C/Cc = 0.577$

Frequency (ω) = $2\pi f = 2\pi \times (V \times 1000 / 3600 \times 6)$

$$\omega = 0.29089 \times V \text{ rad/s}$$

Natural Frequency (ω_n) = 1.995 rad/s

For V1 = 20kmph, $\omega = 5.8178$ rad/s

For V2 = 40kmph, $\omega = 11.64$ rad/s

For V3 = 60kmph, $\omega = 17.45$ rad/s

Frequency Ratio (r)

(r) 20kmph = 2.91

(r) 40kmph = 5.832

(r) 60kmph = 8.748

For 20 km/hr:

Amplitude Ratio is:

$$(X1/Y) = \sqrt{1 + \frac{(2\epsilon r)^2}{(1-r^2)^2 + (2\epsilon r)^2}}$$

$$= \sqrt{1 + (2 \times 0.5 \times 2.91)^2} / \sqrt{(1 - 2.91^2)^2 + (2 \times 0.5 \times 2.91)^2}$$

$$(X1/Y) \text{ 20 km/hr} = 0.384$$

Displacement Amplitude of vehicle at different road amplitude:

$$X1 = 0.384 \times 0.05 = 0.0192\text{m}$$

$$X1 = 0.384 \times 0.1 = 0.0384\text{m}$$

$$X1 = 0.384 \times 0.15 = 0.0576\text{m}$$

$$X1 = 0.384 \times 0.2 = 0.0768\text{m}$$

Acceleration: -

$$\ddot{X}1 = -\omega^2 X1 = - (5.8178)^2 \times 0.0192 = 0.649\text{m/s}^2$$

$$\ddot{X}1 = - (5.8178)^2 \times 0.0384 = 1.299\text{m/s}^2$$

$$\ddot{X}1 = - (5.8178)^2 \times 0.0576 = 1.95\text{m/s}^2$$

$$\ddot{X}1 = - (5.8178)^2 \times 0.0768 = 2.599\text{m/s}^2$$

Similarly, for further speeds.

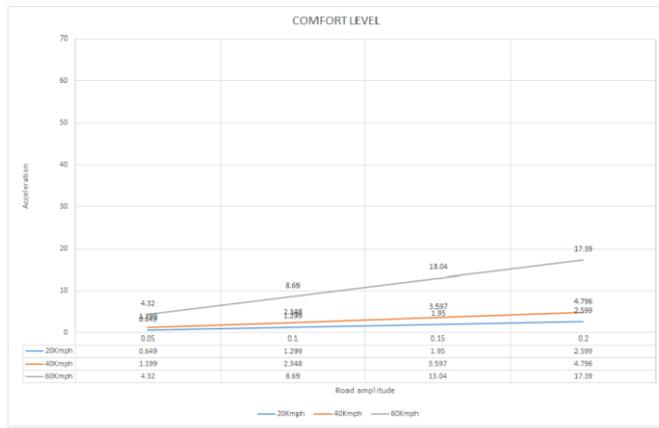


Fig.3.4.3.1. Comfort Level Chart

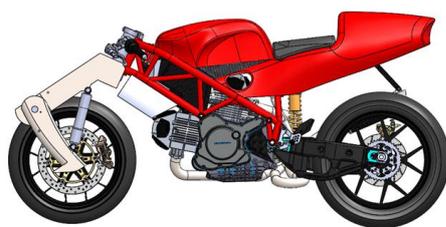


Fig.3.4.3.2. Side View of the Assembled suspension system.

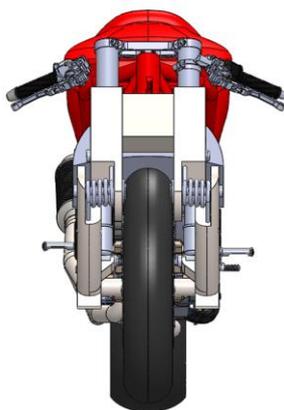


Fig.3.4.3.3. Front View of the Assembled suspension system.



Fig.3.4.3.4. Isometric View of key components assembled. (Rendered version)

3.4.2. ANSYS CALCULATION

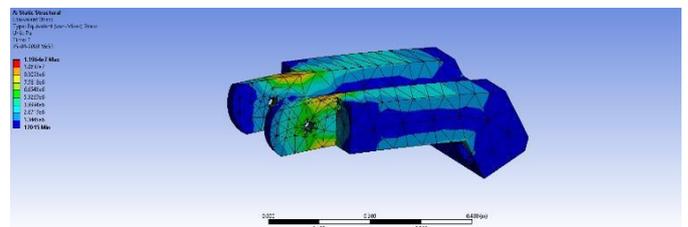


Fig.3.4.2.1.- Maximum Deformation on upper link.

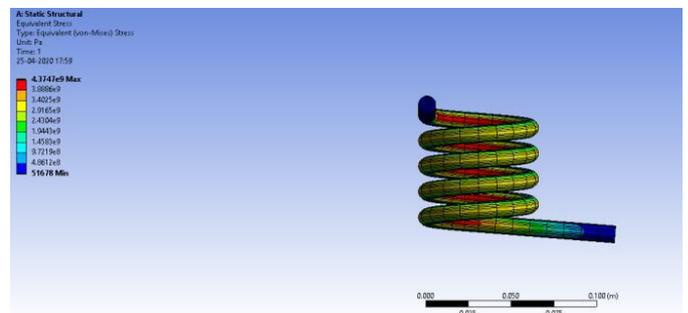


Fig3.4.2.2.- Stress on Spring due to static load.

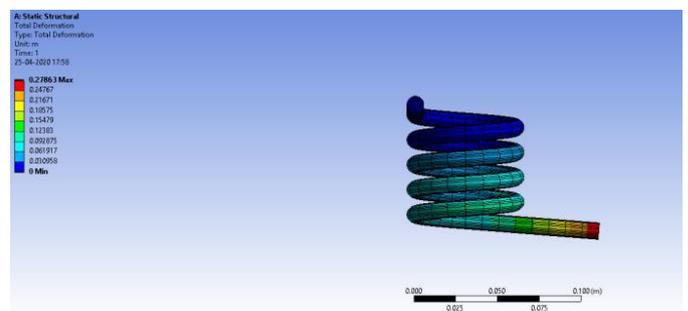


fig.3.4.2.3.- Spring Deformation under maximum load

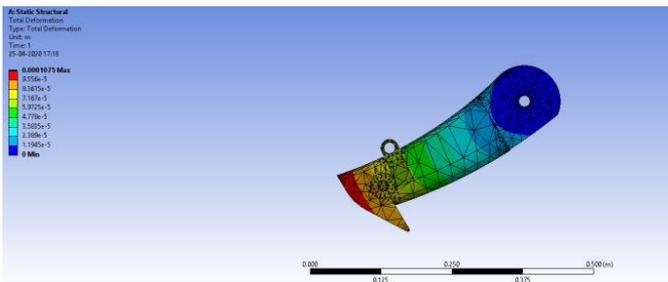


Fig.3.4.2.4.- Maximum stress on lower link from static load.

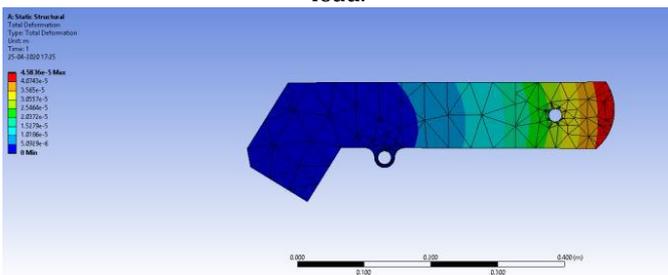


Fig3.4.2.5- Stress on Upper link from static load.

3.4.3 COMFORT LEVEL REFERENCE

ISO STANDARDS WITH RESPECT TO THE VIBRATION EXPOSURE AND ITS EFFECTS ON HEALTH OF RIDER/DRIVER.			
EXPOSURE DURATION IN Hrs	INTERNATIONAL STANDARD		
	ISO 2631-1,1997 AVERAGE RMS ACCELERATION LIMITS IN M/S ²		
	LIKELY HEALTH RISK	CAUTION ZONE	COMFORT LEVEL
8	0.8	0.5	0.315
12	0.7	0.4	0.315

Fig.3.1-Iso standards with respect to Vibration exposure and its effects on rider.

The reference comfort range is in between 0.218m/s² to 0.315m/s².

4. RESULT

From the following ANSYS Calculation:

1. The maximum displacement on upper arm: 4.5836e-5m.
2. The maximum displacement on lower arm: 0.0001075m.
3. The maximum displacement on spring:0.27863m.
4. The maximum stress on spring: 4.3747e9 Pa.
5. The maximum stress on upper arm:1.1964e7 Pa.

5. APPLICATION

1. Used for Prosthetic Leg.
2. This system used for all terrain vehicles.
3. Used for Robotic Legs.

6. CONCLUSION

From the above results we find that the Articulated Suspension System is stable and balanced, based on our calculated values.

It is found that the new system provides better comfort to rider, through a series of test that we performed from analytical and force tests so we can safely say that the articulated suspension system provides the suitable comfort level and has an different Aesthetic for the future generation of two wheeler vehicles.

7. FUTURE SCOPE

In future we are planning to perform Dynamic analysis to the Articulated suspension system and implement the system in medical field such as Prosthetics. Also, in the field of Robotics.

8. REFERENCES

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9. BIOGRAPHIES



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