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Performance Analysis of Convex Helical Spring in ATV Suspension System using Non-Linear Static FEA Method

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Abstract - *Suspension system is a vital role playing mechanism in automotive vehicles. This systems major purpose is to damp the shock impulse applied on the vehicle due to road conditions. It also absorbs and dissipates energy so that comfort and safety is provided for the vehicle and passenger. ATVs (All Terrain Vehicle) are designed to be operated off-highway and rough grounds. So a modified and better suspension system is more vital to ATV's than other vehicles. In this paper performance analysis has been done on two suspension systems of an ATV, one with the constant pitch helical spring and other with Convex Helical Spring. The geometric modelling has been done in Solidworks 2017 and Non-Linear Static FEA simulation has been done using Simscale which uses open source codes Calculix and Code_Aster for FEA*

Key Words*: *Non-linear analysis, suspension system, convex helical spring, constant pitch helical spring.

1.INTRODUCTION

Suspension system is a mechanism of dissipating the kinetic energy and controlling the shock due to uneven road conditions. Shock absorber decreases the influence of traveling over the harsh road which is leading to improve the vehicle control and the quality of the ride. Usually there are two types of suspension systems:-
1.Rigid Suspension System, 2.Independent Suspension System [1]. A beam axle, rigid axle or solid axle is a dependent suspension design, in which a set of wheels is connected laterally by a single beam or shaft. Independent suspension is any automobile suspension system that allows each wheel on the same axle to move vertically (i.e. reacting to a bump on the road) independently of the others [2]. Independent Suspensions can be classified into following types:- 1. Double wishbone suspension 2. Multi-link suspension 3. MacPherson strut 4. Transverse leaf-spring. A suspension system consists of the certain basic components such as; Control Arm, which is a movable lever that fastens the steering knuckle to the vehicle frame or body. Control Arm Bushing, which is a sleeve, which allows the control arm to move up and down on the frame. Strut Rod, which prevents the control arm from swinging to the front or rear of the vehicle. Ball Joints, is a swivel joint that allows the control arm and steering knuckle to move up and down, as well as side to side. Shock Absorber or Strut, which keeps the suspension from continuing to bounce after spring compression and extension. Stabilizer Bar, which limits body roll of the vehicle during cornering.
Spring, which supports the weight of the vehicle; permits the control arm and wheel to move up and down [3]. In this performance analysis the front suspension of an ATV has been taken into consideration. The Reference 3D model which is a suspension system with constant pitch helical spring has been taken from Off-Road Vehicle Design Workshop of Simscale Academy [4]. The damper and fixation part have been kept same for both cases. The modified convex type helical spring design has been generated in a CAD software named Solidworks [5]. Non Linear Static analysis has been performed to determine, analyse the Von Mises Stress applied on the damper and Spring. Hand calculations have been performed to find out the maximum spring deflection using the spring rate before simulation. The maximum deflection has been kept same for both cases as well as the materials. Present study aims to compare the simulation data with the reference and to find out the deviation of the models load bearing capacity.

2. GENERATION OF 3D MODEL

The 3D model was Off-Road Vehicle Design Workshop of Simscale Academy. In the modified design the constant pitch helical spring has been substituted with Convex Helical Spring. The Damper and the fixation part has been kept same for both cases. The suspension system components and types of suspension system considered is stated Figures 1, 2(b) and 2(c) respectively. The nomenclature of the 3D model is stated in Table 1. The principal parameters required for designing the two suspension systems have been stated in Table 2.

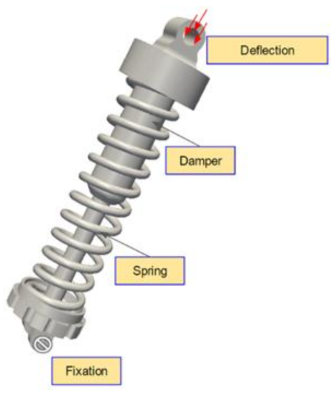


Figure 1. Components of Suspension Assembly

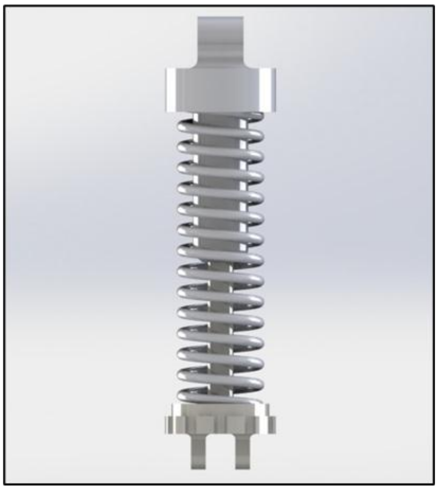


Figure 2(a). Constant pitch helical spring suspension assembly

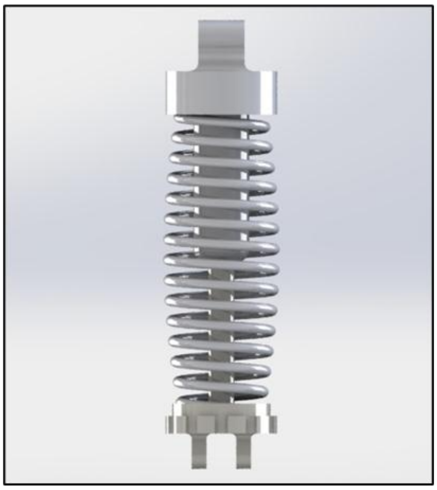


Figure 2(b). Convex helical spring suspension assembly

Table -1: Nomenclature

Spring Index D/d	C	Solid length	L_o
Wire Diameter	d	Total Number of Coils	n_t
Mean Spring Diameter	D	Active Number of Coils	n
Spring Inside Diameter	D_i	Pitch	p
Young's Modulus	E	Shear Stress	τ
Axial Force	F	Maximum Shear Stress	τ_{max}
Modulus of Rigidity	G	Larger Outer	D_{LOD}
		Diameter	
Free Length	L_s	Smaller Outer Diameter	D_{SOD}
Frequency	f	Deflection	θ
Mass of vehicle	m		
Spring Pre-Load	pL		
Spring Rate	k		
Distance Travelled	x		

Table-2: Principle Parameters

Serial No.	Principle Parameters	Symbol	Constant Pitch Helical Spring		Convex Helical Spring	
			Value	Unit	Value	Unit
1	Wire Diameter	d	8	[mm]	8	[mm]
2	Mean Diameter	D	57.61	[mm]	78.80	[mm]
3	Total Number of Coils	n_t	16	[nos]	16	[nos]
4	Active Number of coils	n	14	[nos]	14	[nos]
5	Free length	L_o	256	[mm]	256	[mm]
6	Solid length	L_s	128	[mm]	128	[mm]
7	Pitch	p	17.1428	[mm]	17.1428	[mm]
8	Spring Index	C	7.201	-	9.85	-
9	Larger outer diameter	D_{LOD}	-	-	86.8	[mm]
10	Smaller outer diameter	D_{SOD}	-	-	65.61	[mm]

3. GOVERNING EQUATIONS AND HAND CALCULATIONS

The pitch calculated for the spring considering ends to be squared and ground,

$$p = \frac{L_o - 2d}{n} \quad (1)$$

The number of active coils calculated for the spring considering the ends to be squared and ground,

$$n = n_t - 2 \quad (2)$$

In order to take into account the effect of direct shear and change in coil curvature, a stress factor is defined known as Wahl's factor.

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} \quad (3)$$

The direct shear stress and stress concentration due to curvature on the spring,

$$\tau = K\frac{8WD}{\pi d^3} \quad (4)$$

Where,
W = Axial Force
K = Wahl Factor
D = Mean Diameter
d = Wire Diameter

The spring rated is calculated for the spring of the front suspension of ATV from its relation with the frequency,

$$f = \frac{1}{2}\pi\sqrt{\frac{m}{k}} \quad (5)$$

Where,
f = frequency of an ATV at front
m = mass on the front suspension
k = spring rate of front suspension

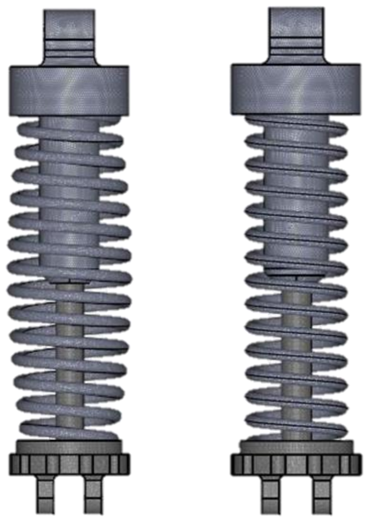
The maximum spring deflection is calculated from Hooke's law,

$$F = k*x \quad (6)$$

Where,
F = Axial Force
k = spring rate
x = deflection

4. NUMERICAL MODEL OF SUSPENSION ASSEMBLY IN Simscale

In both cases, cloud computing based simulation platform Simscale has been used, which uses Open source code, Code Aster for solid mechanics FEA simulations. In this cases the analysis type is considered static. Static analysis type is used to determine the displacements and stresses in structures or components caused by the applied constraints and steady loads – inertia and damping effects are ignored. Static analysis can be either linear or nonlinear. In the cases static analysis has been considered non-linear. Bonded contacts have been defined between the springs, damper and fixation support. An additional concentric contact has been set up for damper and fixation support. A tetrahedral first order mesh has been executed on the suspension assembly. The material for the damper and fixation support is considered to be steel and spring material is considered stainless steel. A time dependent displacement boundary condition has been set on the damper to experience the maximum spring deflection. The displacement at the fixation support has been fixed to zero. MUMPS has been set up as the solver, Renumbering method has been fixed to SCOTCH and Non linear resolution type has been fixed to Newton-Raphson method. Von Mises stress has been calculated for the damper, fixation support and Spring. Reaction forces has been calculated for the fixed ends of the fixation support.



(a) (b)

FIGURE 3. Meshes of convex shape and constant pitch spring suspension systems

5. RESULTS AND DISCUSSION

In present study, the maximum spring deflection has been calculated using the spring rate formula and the Hooke's law. In the both cases the maximum spring deflection has been the most vital parameter as the relation between the applied force to the deflection is proportional. As stated before the Spring free length height, wire diameter and coil number have been kept same for both springs. In constant pitch spring the outer diameter has been constant and in the convex shape spring the diameter has increased from the both ends have the maximum outer diameter at the center of mass.

Calculating the maximum deflection of the springs:
Where,
Mass of car with passenger = 220 kg
Assuming a (40:60) distribution of the car weight to be the front weight.
The weight on the front suspension = 88kg
Average frequency on suspension of ATVs = 3.54 hz
From the equation below we calculate the spring rate (k);

$$f = \frac{1}{2}\pi\sqrt{\frac{m}{k}}$$

k = 17.2656 N/mm
Now applying Hooke's law for determining maximum spring deflection ;

$$F = k*x$$

x = 50 mm or 0.05 m

Due to the applied spring deflection calculated, Von Mises stress has been calculated by performing static non-linear analysis using Simscale. The following charts in figure 4(a) and 4(b) indicates maximum Von Mises Stress applied on the two different springs.

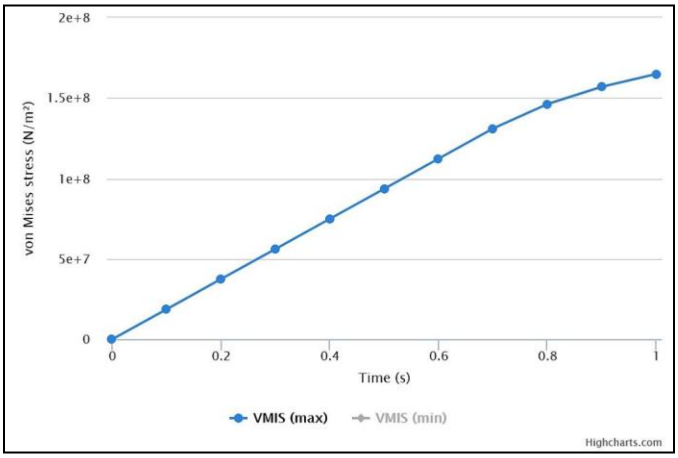


FIGURE 4(a). Maximum Von Mises stress on convex helical spring.

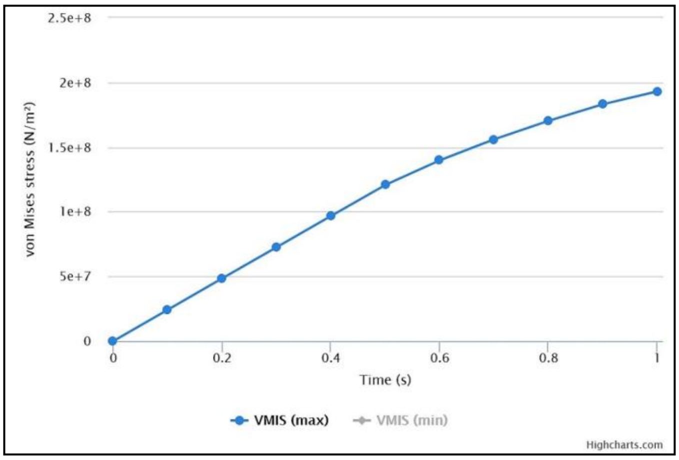


FIGURE 4(b). Maximum Von Mises stress on constant pitch helical spring

The load are initially applied on the damper upper surface and then transmitted through the spring. As the damper and fixation support are concentrically mated so the maximum Von Mises stress on damper and fixation support has been plotted together in the charts provided in figure 5(a) & 5(b). The numeric values of the results for two suspension assembly cases has been provided in Table 3(a) and Table 3(b)

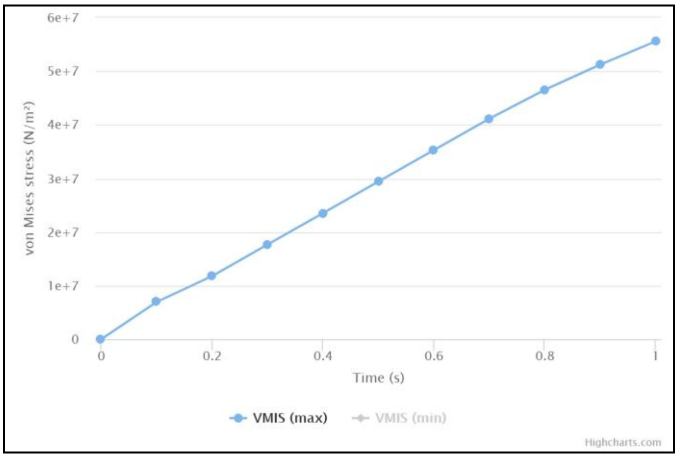


FIGURE 5(a). Maximum Von Mises stress on damper and fixation support with convex helical spring

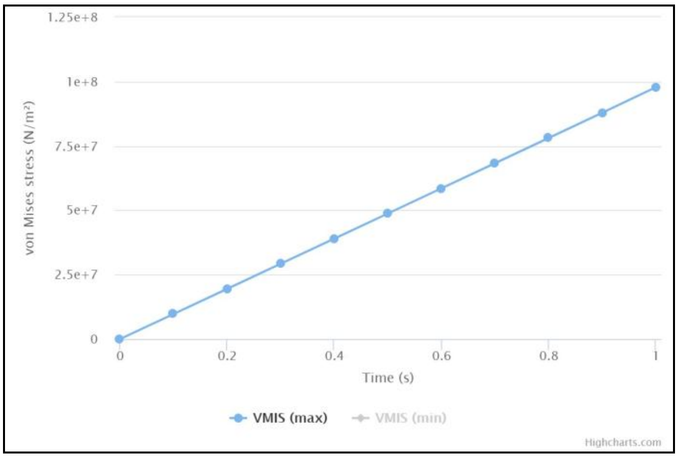


FIGURE 5(b). Maximum Von Mises Stress on damper and fixation support with constant pitch helical spring

Table -3(a): Result Comparison Von Mises Stress

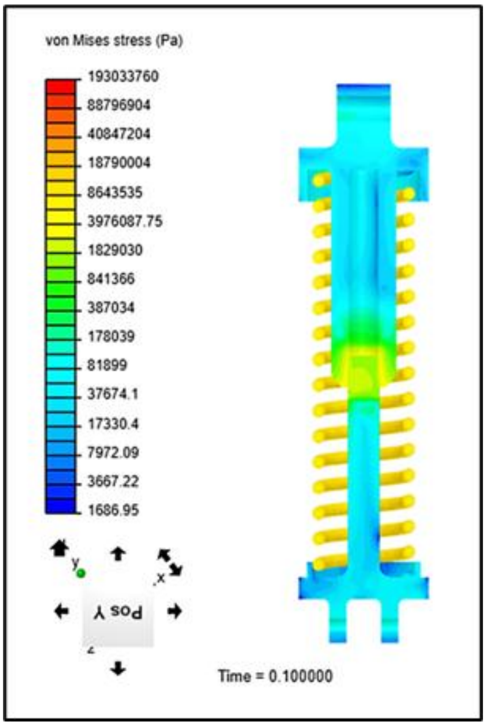
Sl no	Spring type	Part Name	Max VMIS	UoM
1	Constant Pitch Spring	Damper & Fixation Support	97.7992	MPa
2		Spring	193.034	MPa
4	Convex Helical Spring	Damper & Fixation Support	82.8085	MPa
5		Spring	170.891	MPa

Table-3(b): Result Comparison Surface Area and Weight

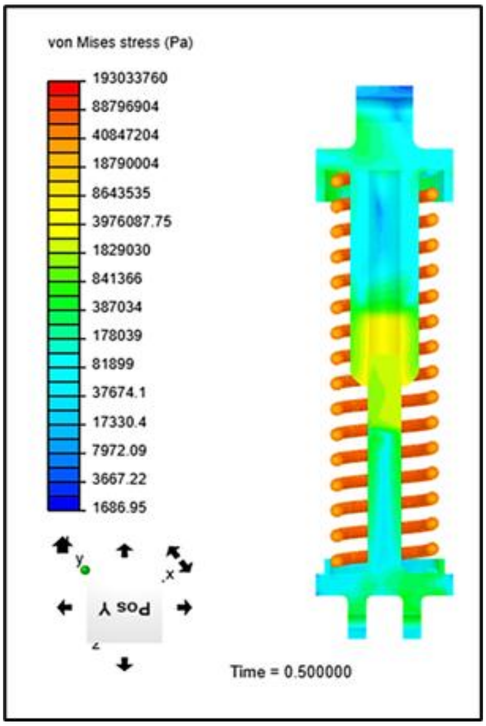
Sl no	Spring type	Weight	UoM	Surface Area	UoM
	Constant Pitch Spring	1.11	Kg	0.07	m^2
	Convex Helical Spring	1.38	Kg	0.09	m^2

From the tables above it can be originated that due to being applied with same deflection the convex spring experiences 22.143 MPa less stress rather than the constant pitch spring. Moreover the maximum stress on the damper & fixation support is 14.9907 MPa less experienced in convex spring rather than the constant pitch spring. Due to its variable diameter the surface area of the convex spring is 0.02 m^2 larger than of the constant pitch spring. Maintaining same material for the both springs, convex springs weight is to be found 0.27 kg more than constant pitch helical spring. From figure 4(a) and 4(b) it can be observed that for convex spring the stress has increased linearly with time up to 0.7 second and have experienced the amount of stress which is experienced at 0.5 second for constant pitch spring. For the convex spring the stress has been developed linear for 70% of the time and then have been slightly non-linear. As the damper and fixation support geometry and material configuration are same for both the suspension assemblies the stress developed in damper and fixation support are found to be linear with respect to their concern springs.

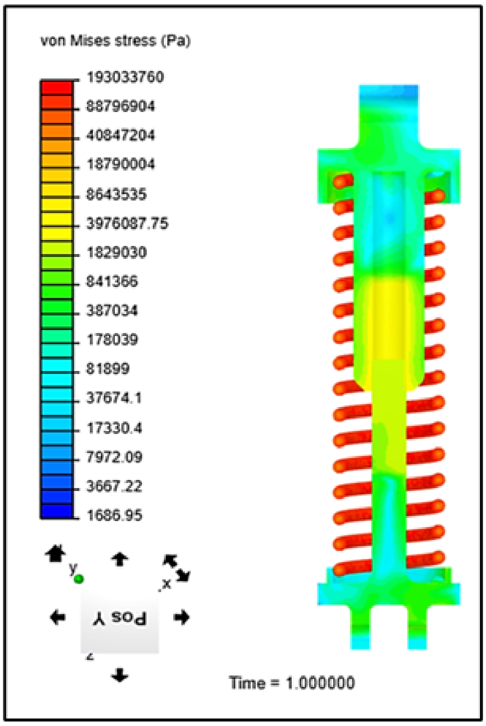
From the visual representations of the von mises stress applied on the suspension assemblies which is provided in Figure 6(a), 6(b), 6(c) and 7(a), 7(b), 7(c) it can be established that for constant pitch spring the maximum stress has been spread to almost the core of the wire at 1 second. For convex spring the stress has been spread mainly to the surface and inner adjacent region of the wire.



6(a)

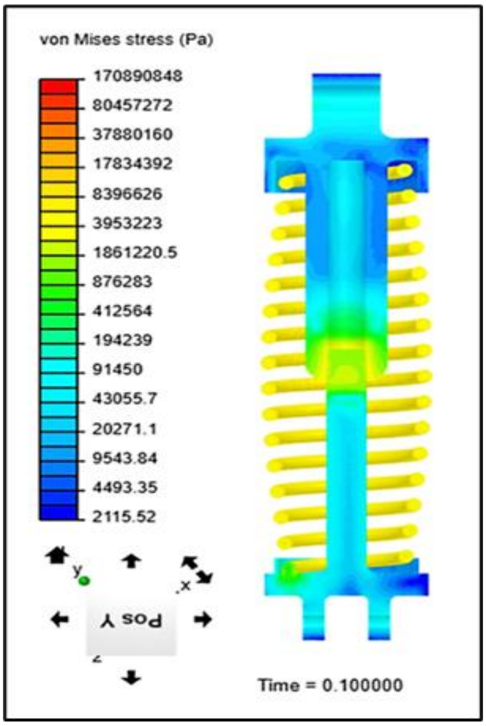


6(b)

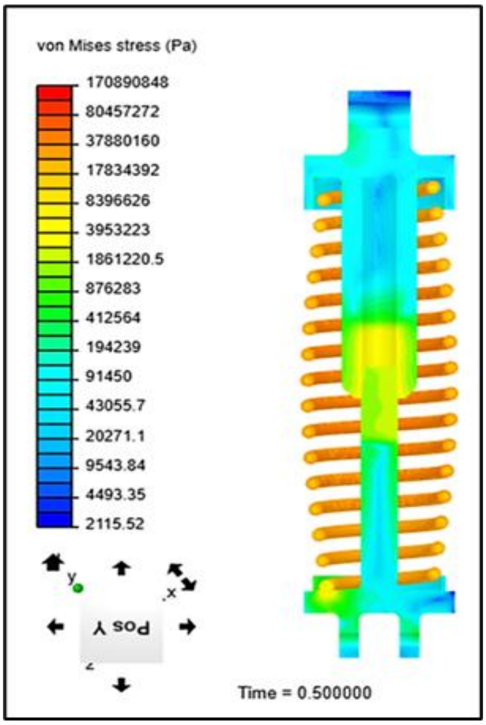


6(c)

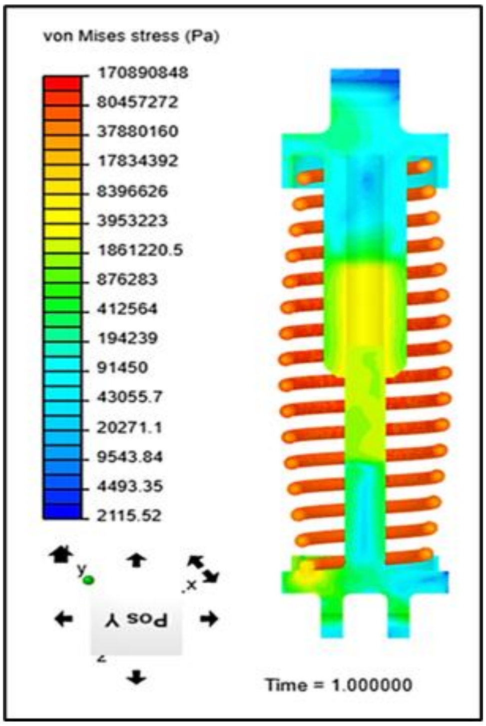
FIGURE 6(a)(b)(c). Visual representation of Von Mises stress on suspension assembly with constant pitch helical spring



7(a)



7(b)



7(c)

FIGURE 7(a)(b)(c). Visual representation of Von Mises stress on suspension assembly with convex helical spring

6. CONCLUSION

In the present study, 3D models of two suspension assemblies has been generated. One with a constant pitch helical spring and another with convex helical spring. Von Mises stress have been calculated for both the assemblies using static non-linear FEA method in Simscale. Simcale uses open source code, Code Aster for performing these simulations. In these two cases first observation that has been found is that due to same deflection applied on same period of time, convex helical experiences 11.47% less stress than the constant pitch spring. Which means convex helical spring is capable of bearing much more shock and stress than the constant pitch spring. Which also would increase the longevity of the spring. Another observation has been found that the stress increase rate is much linear for convex helical spring rather than constant pitch spring, which indicates that it is less probe to plasticity. The only drawback of this spring is due to having variable diameters at both ends and the center the weight of the spring is 24.32% more than the constant pitch spring with the same free length and wire diameter. Finally it can be concluded that using convex helical spring would provide more stability and shock absorbance in the suspension assembly but it would increase the weight of the assembly.

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