Design Optimization of Helical Coil Suspension using Steel Material

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Abstract: With increasing fuel prices and demand to reduce vehicle weight, automobile manufacturers are looking for lighter suspensions without compromising in strength. This research investigates structural steel material for helical coil suspension using finite element method by ANSYS software and later subjected to design optimization using response surface optimization considering coil diameter and coil mean radius as optimization parameters. Sensitivities of both input parameters are plotted for equivalent stress and deformation. Considerable weight reduction of helical coil suspension is achieved using response surface method.

Keywords: Helical Coil Suspension, Finite Element Analysis, Response Surface Method

I. INTRODUCTION

Vehicles generate vibration while passing through irregularities or bumps on roads which are absorbed by suspensions. The vehicles must have a good suspension system that can deliver a good ride and good human comfort. Suspension system separate the axle from the vehicle chassis, so that any road irregularities are not transmitted directly to the driver and the load on the vehicle. To reduce damage to vehicles and shocks to passengers it becomes imperative to improve suspension systems. The suspension system isolates vehicle structure and occupants from vibrations caused due to uneven road surface. This is achieved by elasticity property of helical coil suspension which is made up of spiral wire coil with constant cross section diameter and pitch. Suspension systems are made from both compression as well as tension spring. The important criteria in the design of suspension system is strength of steel which determines the acceptable stress level and desired spring rate.

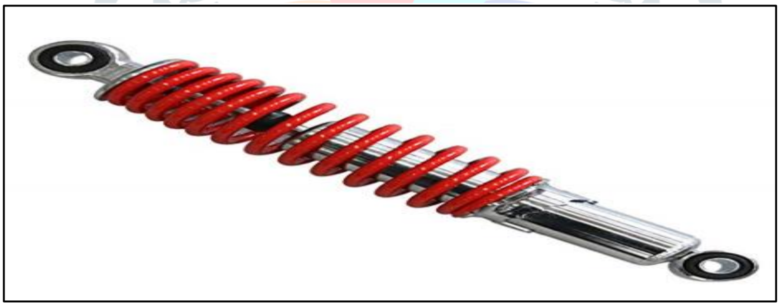

Figure 1: Helical Coil Suspension

II. LITERATURE REVIEW

Anil Antony Sequeira, Ram Kishan Singh, and Ganesh K Shettiet al [1] has conducted static structural analysis to study the behavior of carbon and Kevlar composite helical suspension and comparison is made from steel helical spring using ANSYS software. The properties investigated are load carrying capacity, stiffness along with weight reduction using FRP composite spring. The optimization design parameters are inner coil diameters, pitch length, height. Their researches show that the specific modulus (young's modulus (E) upon mass density of the material (ρ)) of CFRP composite spring is the highest and Kevlar FRP (KFRP) is lowest. Load and deflection characteristics of steel spring have been found better than composite ones. However, mass of the KFRP helical spring has been determined less than CFRP and steel ones. A good percentage of weight reduction is achieved using CFRP against steel suspension.

Nijssen, R.P.L et al [2] has investigated the effect of Fiber volume fraction on properties of composite materials used in analysis of helical coil suspension. A schematic of variation in fiber reinforced composite with amount of fiber volume fraction is shown in figure 2-1. Typically, fiber share 30% to 75% of volume of composites. At low fiber volume fraction, matrix properties are dominant while at high fiber volume percentage, behavior of composite is controlled by the fiber properties. Tensile strength increases with increase the fiber contents while compressive strength is high at low fiber contents and deceases with increasing fiber volume fraction.

Mehdi Bakhshesh et al [3] conducted comparative study using steel spring with composite helical spring and results have shown that composite helical spring is found to have lower stresses and performs best when fiber position has been considered to be in direction of loading. The spring weight is also reduced by changing fiber percentage of Carbon/Epoxy composite.

P.R. Jadhav, N.P. Doshi, and U.D. Gulhane et al [4] in this research steel coil spring is replaced by three different composite material. The results obtained from numerical method are in close agreement with results from analytical method. The stress generated in composite helical coil spring is found to be lower as compared to steel suspensions and considerable weight reduction is also achieved by changing fiber percentage.

III. PROPOSED WORK

The objective of this research is to optimize design of helical coil suspension to reduce weight using response surface methodology. The material used for analysis is structural steel material and sensitivities of input parameters (coil diameter and coil radius) are determined along with response surfaces.

IV. METHODOLOGY

In this stage the CAD model is developed using ANSYS software. ANSYS design modeler is specific tool used for designing and editing operation. The model is meshed using tetra elements of appropriate size and shape. After meshing appropriate loads and boundary conditions are assigned.

Table 1: Dimensions of Helical Coil Suspension [5]

Free Length (lf)	256mm
Mean dia. (D)	48mm
Wire Dia (d)	8mm
No. of turns (n)	16
Pitch (p)	16mm
Spring index (D/d)	6

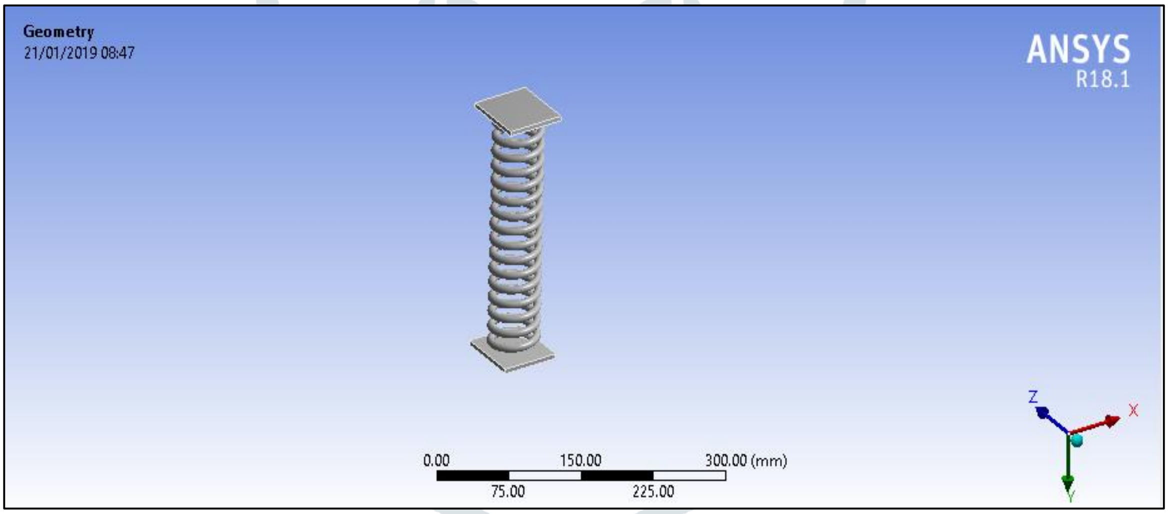

Figure 2: CAD modeling of helical coil suspension

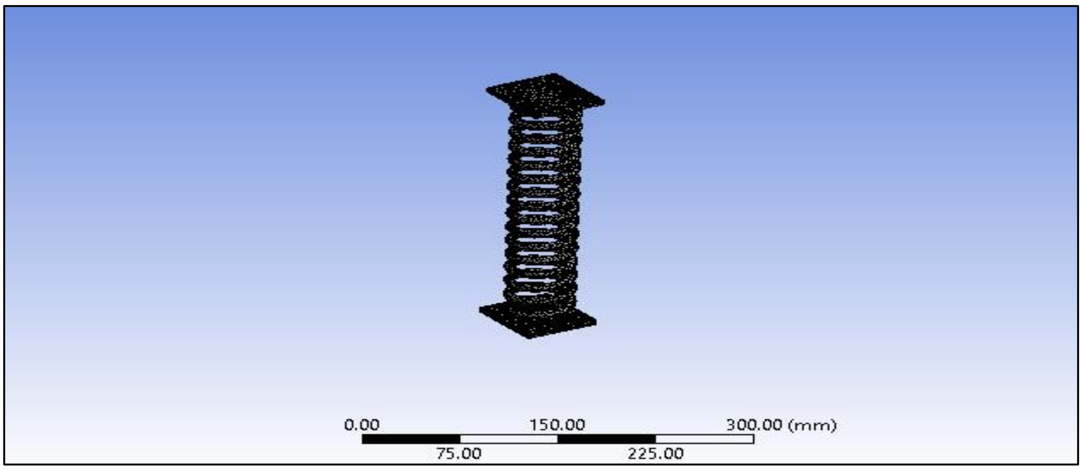

Figure 3: Meshed model of helical coil suspension

The CAD model is meshed using tetrahedral elements and fine sizing with curvature effects on. The number of elements generated is 17431 and number of nodes generated is 34996 as shown in figure 3 above. The element shape of tetrahedral element is shown in figure 3 below. It consists of 4 nodes connected to each other by tetrahedral shape. CAD model of suspension after being meshed is applied with appropriate loads and boundary conditions.

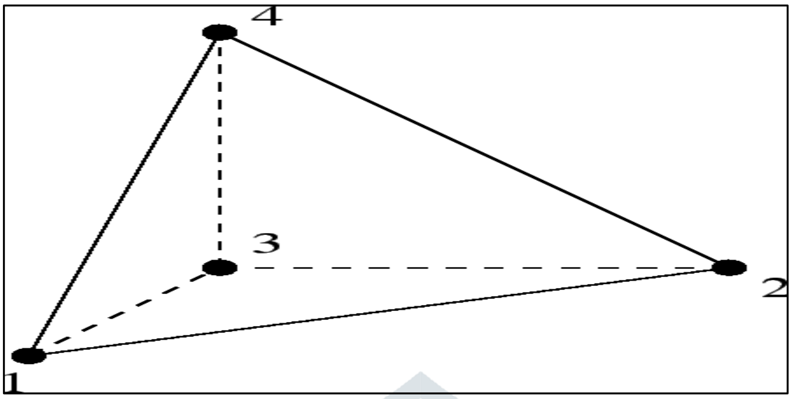

Figure 4: Tetrahedral element

The bottom face of suspension is kept fixed and top face is applied with force of 1356.4N in downward direction.

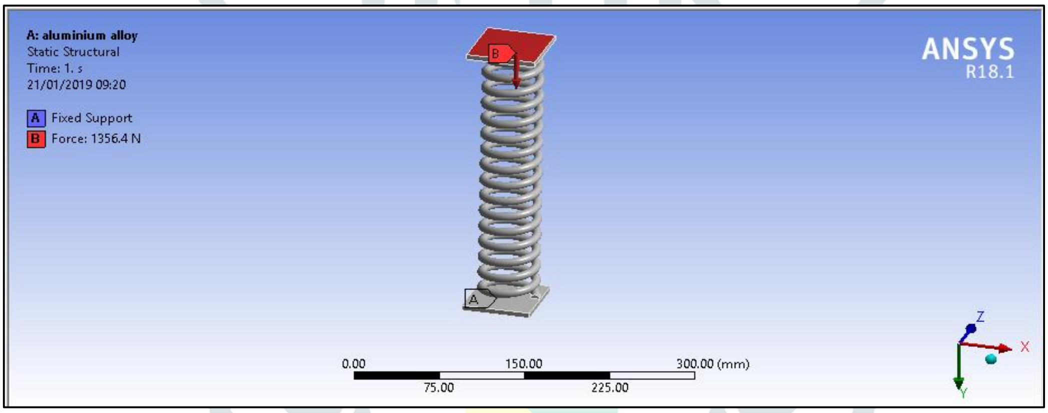

Figure 5: Loads and Boundary conditions

The vehicle has mass of 300kg.The suspension system has a spring constant (spring rate) of 46714.2N/m and here we consider a damping ratio of ξ =0.5. The road surface varies with an amplitude of Y = 50mm.Calculation made for 1km/hr to 40 km/hr& deflection & stresses value determine at various speed. The frequency ω of the base excitation can be found by dividing the vehicle speed v km/hr by the length of one cycle of road roughness.
or 3Km/hr

$\omega = 2\pi f = 2\pi$ (V × 1000) /3600×(1/1)=1.74 v rad/s
ω = 1.74 × 3 = 5.22 rad/s

The natural frequency of the vehicle is given by
$\omega n=\sqrt{}k/m=\sqrt{}46714.2/300=12.4$rad/s

Frequency ratio:-r = ω/ ωn = 5.22 /12.4 = 0.42
Amplitude ratio:-(Displacement transmissibility)
X/Y={1 + (2ξr)2 / (1 + r2)2+ (2ξr)2 }1/2 X/Y={1+(2×0.5×0.42)2/(1+0.422)2+(2×0.5×0.42)2 }1/2
X/+Y = 1.17

Thus the displacement of vehicle at 3 km/hr is given by
X= 1.17 × Y = 1.07 × 0.05 = 0.0586 m = 58.6 mm
This indicates that a 50mm bump in the road is transmitted as a 58.6mm deflection to the chassis.

Forces (F) = $\frac{\delta G\, d^4}{8\, d^3 n}$ = (58.6×42×103 × 84) / (8×483 ×6)

F= 1356.4 N

Stresses(τ) = K $\frac{8FD}{\Pi d^3}$

$\tau = (1.25 \times 8 \times 1356.4 \times 48) \;/\; (\pi \times 8^3)$

$\tau = 404.8$ N

V. RESULTS AND DISCUSSION

The static structural analysis is performed using techniques of Finite Element Method used by ANSYS software. The problem is formulated into spring matrix damper system as discussed in previous chapter, the force and stresses are determined analytically.

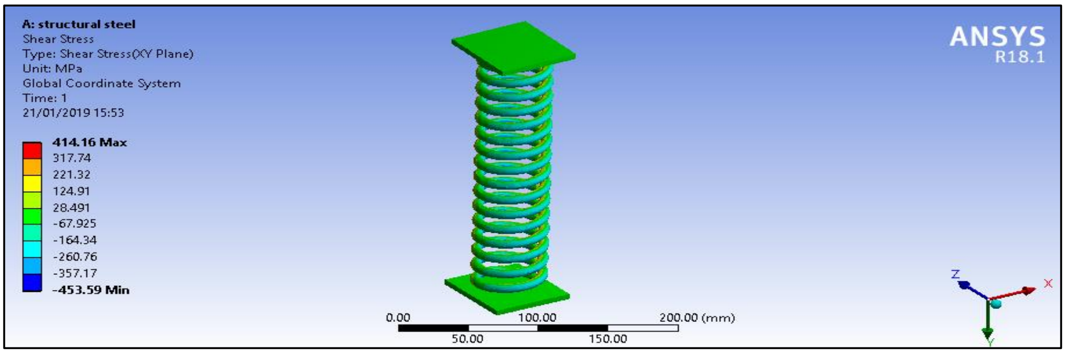

Figure 5: Shear stress generated

Maximum Shear stress generated is denoted by red colour shown in figure 5 above with magnitude of 414.16MPa. The maximum shear stress is developed on inner surface of coil with value of 248.49MPa.

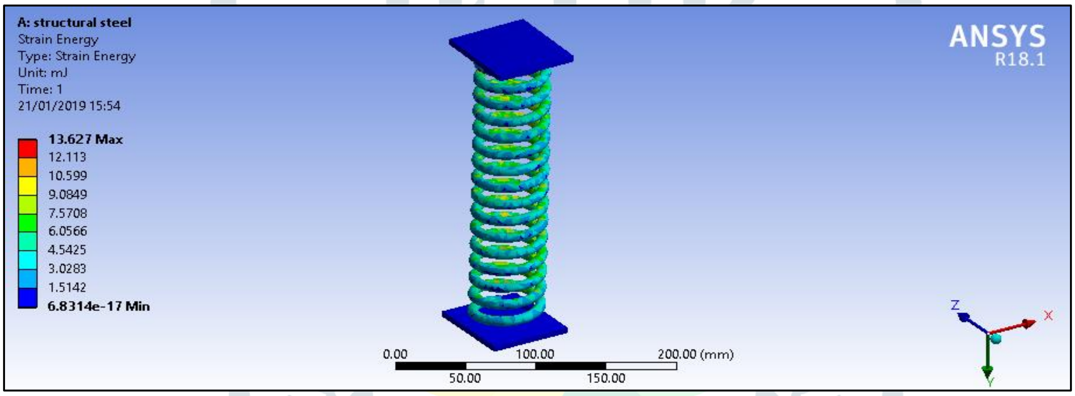

Figure 6: Strain energy

The maximum amount of strain energy developed is 13.62 mJ. Similar to shear stress this strain energy is developed on inner face of coil shown by dark red colour. After conduction of Finite Element Analysis and determination of stresses, on the basis of input variables for optimization i.e. coil radius and mean diameter, design points are generated using design of experiments.

1	Name		P1 - radius (mm)	P2 - coil_dia (mm)	P3 - Shear Stress Maximum (MPa)	P10 - Strain Energy Maximum (mJ)	P11 - Solid Mass (kg)
2	1	DP 0	24	8	414.16	13.627	1.2769
3	2		21.6	8	373.08	10.842	1.1824
4	3		26.4	8	426.96	11.196	1.3717
5	4		24	7.2	533.05	19.415	1.0977
6	5		24	8.8	309.49	9.3533	1.4746
7	6		21.6	7.2	495.54	18.479	1.0211
8	7		26.4	7.2	591.9	18.975	1.1745
9	8		21.6	8.8	280.91	6.8492	1.3604
10	9		26.4	8.8	331.07	8.8115	1.5894

Figure 7: Design Points

These design points are generated on the basis of 2^{nd} order polynomial function. On the basis of these design points software calculates response i.e. shear stress and strain energy. On the basis of design of experiments the maximum value and minimum value of output parameters are shown in figure 8 below.

	A	B	C	D
1	Name	Calculated Minimum	Calculated Maximum	Maximum Predicted Error
2	P3 - Shear Stress Maximum (MPa)	279.83	591.9	9.7704
3	P10 - Strain Energy Maximum (mJ)	6.8492	19.579	0.46107
4	P11 - Solid Mass (kg)	1.0211	1.5894	1.9819E-05

Figure 8: Maximum and Minimum Values

Figure 8 above shows maximum and minimum values of shear stress and strain energy obtained from response surface optimization. The maximum value of shear stress is 591.9MPa and strain energy is 198.38mJ while minimum values of shear stress is 279.83MPa and strain energy maximum is 19.57mJ while minimum strain energy is 6.849mJ.

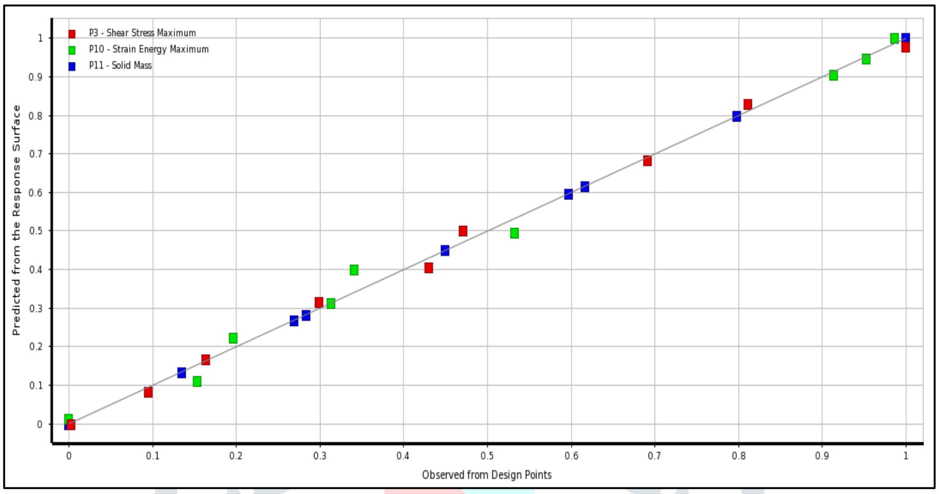

Figure 9: Goodness of Fit Curve

The goodness of fit curve plotted in figure 9 above shows deviation between observed values and expected values of shear stress and strain energy. The curve above shows considerable deviation of observed values of shear stress and strain energy from expected values.

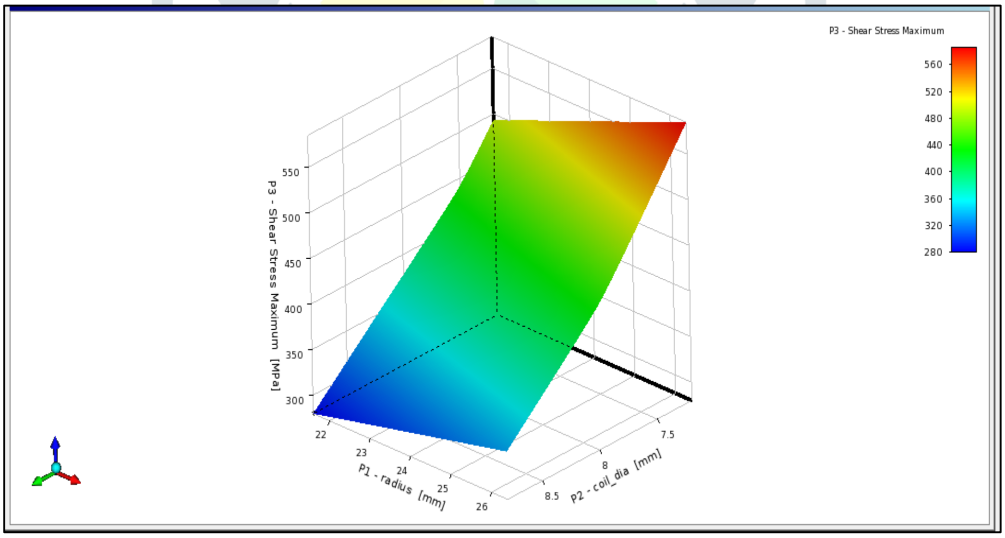

Figure 10: Response Surface for shear stress using Structural Steel material

The response surface plot of shear stress is shown in figure 10 above. The plot shows maximum value of shear stress of 560MPa for coil mean diameter less than 7.5mm and coil radius more than 25mm. The minimum value of shear stress is near to 280MPa for coil radius less than 22mm and coil mean diameter greater than 8.5mm.

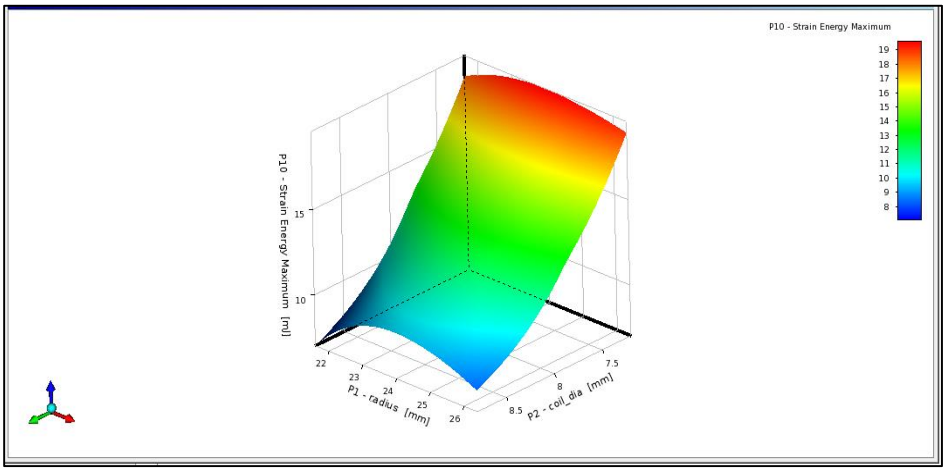

Figure 11: Response Surface for strain energy using Structural Steel material

The response surface plot for strain energy is shown in figure 11 above. The maximum value of strain energy is near to 19mJ for coil mean diameter less than 7.5mm and coil radius greater than 26mm. The minimum value of strain energy is neat to 8mJ for coil mean diameter less than 22mm and coil mean diameter greater than 8.5mm.

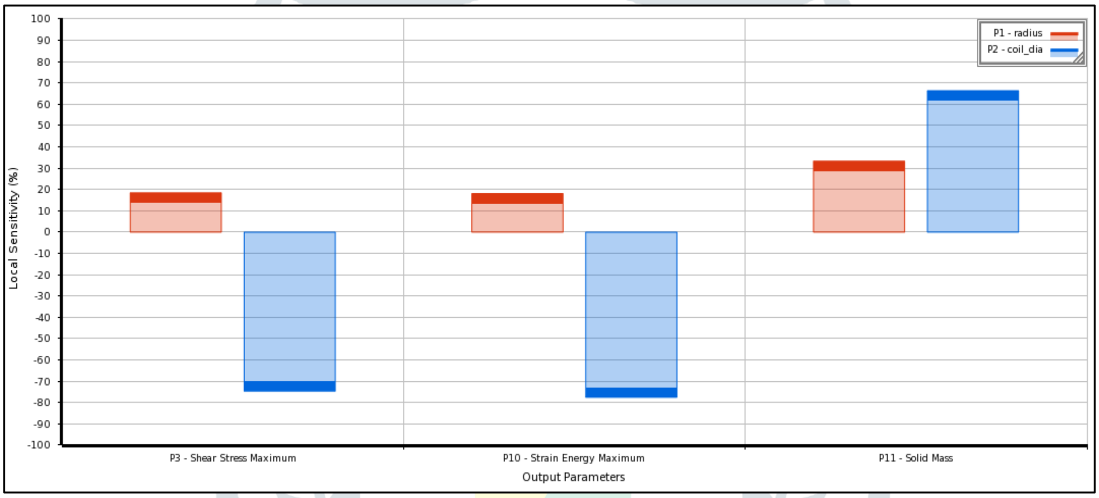

Figure 12: Sensitivity plot for different input parameters on shear stress, strain energy and mass

Local sensitivity plot of responses (shear stress and strain energy) is for input variables (coil radius and coil mean diameter) is shown in figure 12. The coil radius positive sensitivity for both shear stress and strain energy while coil mean diameter shows negative sensitivity for both shear stress and strain energy. This means if coil radius increases the shear stress decreases with sensitivity value of 18.43% for shear stress and 18.08% for strain energy. The increase of coil mean diameter decreases shear stress with sensitivity percentage of -74.60% for shear stress and -77.51% for strain energy.

After conducting FEA analysis using chrome vanadium material shear stresses, deformation and strain energy plots are generated as shown below.

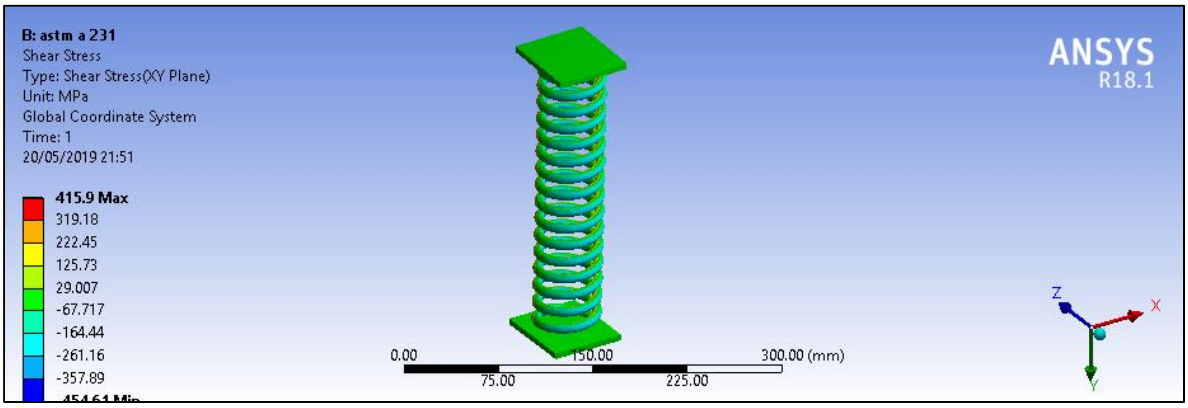

Figure 13: Shear stress using chrome vanadium

The maximum shear stress generated is on inner portion coil with magnitude of 415.9 MPa and reduces on outer portion of coil with magnitude of 29MPa.

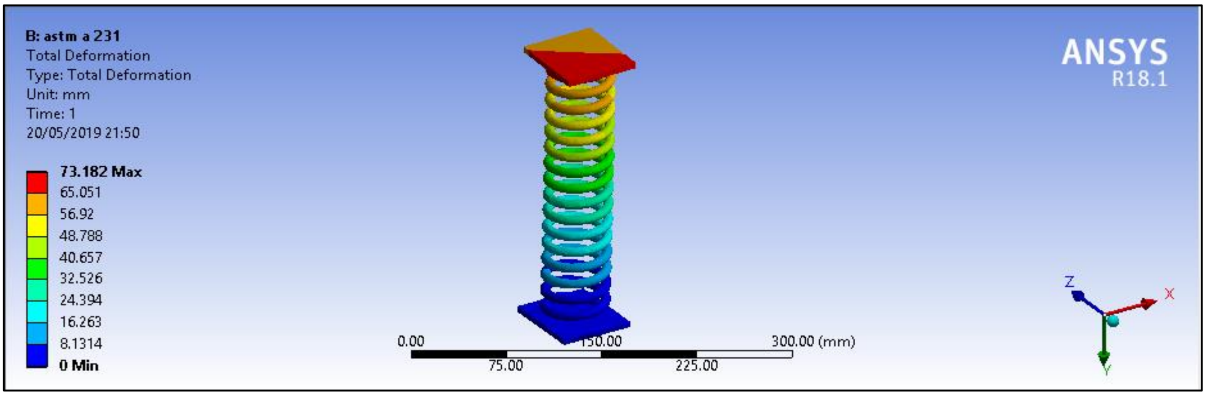

Figure 14: Total deformation using chrome vanadium

The maximum deformation is observed on top flat portion of coil with magnitude of 73.18mm and minimum deformation is at bottom portion of coil. The deformation reduces on moving from top to bottom of coil as shown in figure 14 above.

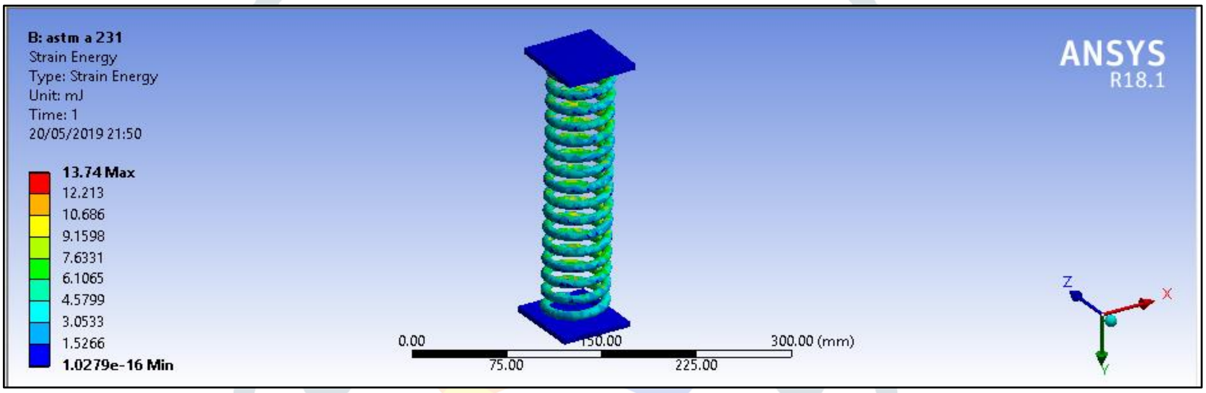

Figure 15: Strain energy using chrome vanadium

The maximum strain energy observed using chrome vanadium material is observed at discrete portions with magnitude of 13.74mJ and minimum strain energy is 1.52mJ. After conducting FEA analysis using SAE 1025 material shear stresses, deformation and strain energy plots are generated as shown below.

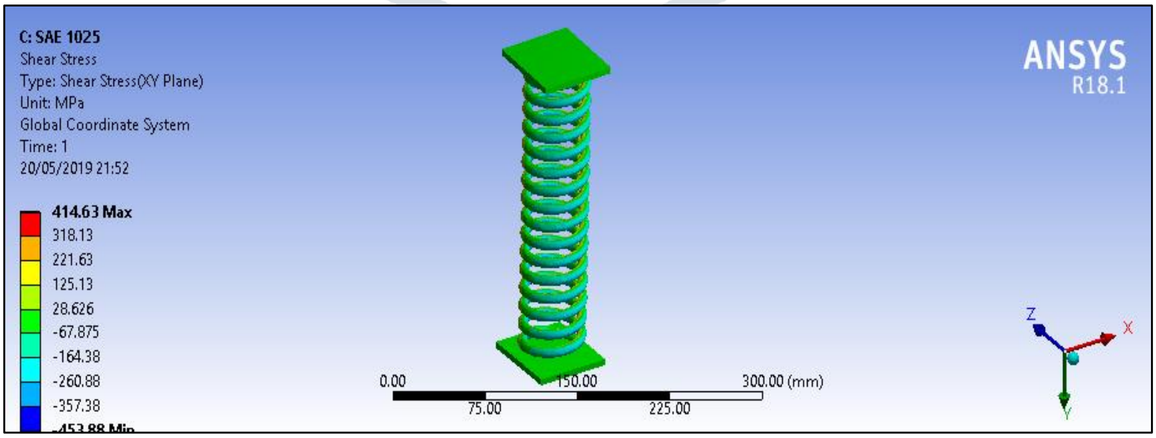

Figure 16: Strain energy using SAE 1025

The maximum shear stress generated is on inner portion coil with magnitude of 414.63 MPa and reduces on outer portion of coil with magnitude of 28.62MPa.

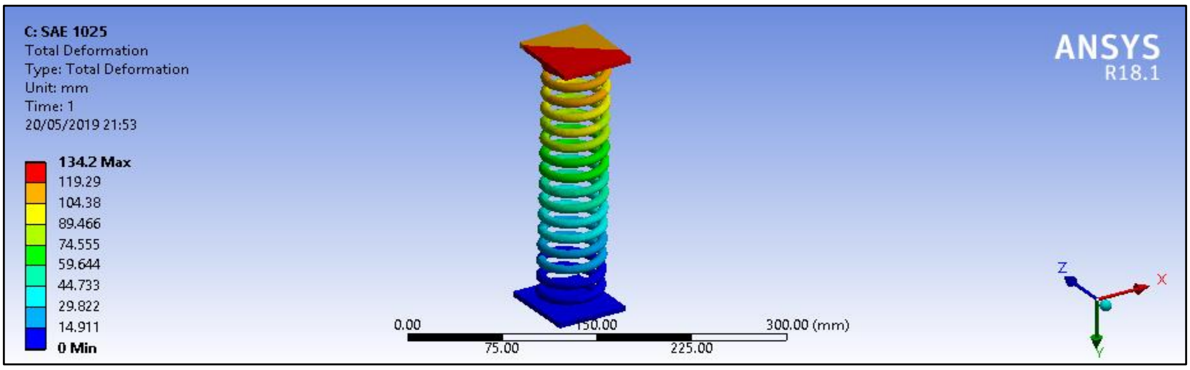

Figure 17: Total deformation using SAE 1025

The maximum deformation is observed on top flat portion of coil with magnitude of 134.2mm and minimum deformation is at bottom portion of coil. The deformation reduces on moving from top to bottom of coil as shown in figure 17 above.

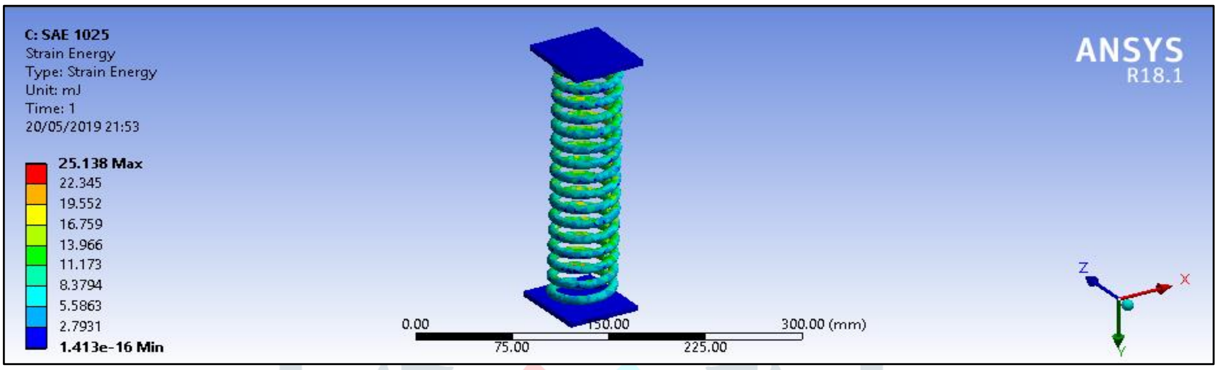

Figure 18: Strain energy using SAE 1025

The maximum strain energy observed using SAE 1025 material is observed at discrete portions with magnitude of 25.13mJ and minimum strain energy is 2.79mJ.

6. CONCLUSION

From sensitivity analysis of structural steel the coil radius positive sensitivity for both shear stress and strain energy while coil mean diameter shows negative sensitivity for both shear stress and strain energy. This means if coil radius increases the shear stress decreases with sensitivity value of 18.43% for shear stress and 18.08% for strain energy. The increase of coil mean diameter decreases shear stress with sensitivity percentage of -74.60% for shear stress and -77.51% for strain energy. The maximum weight of helical coil suspension using response surface method for structural steel is 1.58Kg and minimum mass obtained is 1.021Kg

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