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Design Optimization of Helical Coil Suspension for Mass Minimization

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Abstract—Helical coil suspensions are used to absorb vibrations as vehicle moves on rough roads. As automobile industry demands for increased fuel efficiency, the designers emphasize on weight reduction of automobile components to the maximum extent possible without much compromise in strength. The current research analyzes the Hero Honda suspension subjected to bumps on roads and causing deformation and stresses on the component. Using Taguchi Response surface optimization, response surface plots and sensitivity plots are generated for stress and strain energy. From the response surface optimization, it is evident that nearly 23% of mass reduction is possible. The CAD modelling and analysis is conducted using ANSYS 18.1 software which is based on Finite Element Analysis and response surface optimization is also conducted on the same platform.

Index Terms—FEA, Helical Coil Suspension, Response Surface Optimization.

I. INTRODUCTION

The suspension system are used in automobiles to absorb vibration or shocks as vehicle moves over uneven road surfaces. Without use of suspension systems the shocks would transfer directly to passengers of vehicle and thereby causing discomfort. In current automobile industry the helical coil suspensions are prominently used for front wheels and leaf spring for rear wheels. As vehicle moves over uneven surfaces these suspensions absorb shocks in the form of strain energy and then releases gradually thereby reducing shocks or vibrations experienced by passengers of vehicle. The shock absorption characteristics of helical coil suspension depends upon geometric parameters like mean diameter of coil, coil pitch and coil diameter.

II. LITERATURE REVIEW

Anil Antony Sequeira, Ram Kishan Singh, and Ganesh K Shettiet al [1] has investigated using helical suspensions made from kevlar composite and CFRP using Finite Element Analysis software ANSYS. The findings have shown considerable weight reduction using CFRP while load bearing and deformation of steel suspensions are lower than composite suspensions.

Nijssen, R.P.L et al [2] has investigated helical coil suspensions with varying fiber volume percentage from 30% to 75% . The findings have shown increase in tensile strength with increase in fiber contents and vice versa. The compressive strength reduces with increase in fiber volume fraction.

Mehdi Bakhshesh et al [3] has investigated the effect of fiber orientation in helical coil suspension using Finite Element Analysis technique. The findings have shown that lower stresses are developed when fibers are oriented along direction of loading. The weight reduction is also achieved 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 carbon steel and sensitivities of input parameters (coil diameter and coil radius) are determined along with response surfaces

IV. METHODOLOGY

The structural analysis of helical coil suspension is done using finite element method (FEM) which is based on discretization of domain. The analysis has three stages i.e. preprocessing, solution and postprocessing. The first stage is CAD modeling using ANSYS software. ANSYS design modeler is specific tool used for designing and editing operation. The CAD model of helical coil suspension is modelled as per dimensions provided in literature [5] and given in table 1 below.

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

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Pitch (p)	16mm
Spring index (D/d)	6

The CAD model developed is shown in figure 1 below as per dimensions provided in table 1 above.

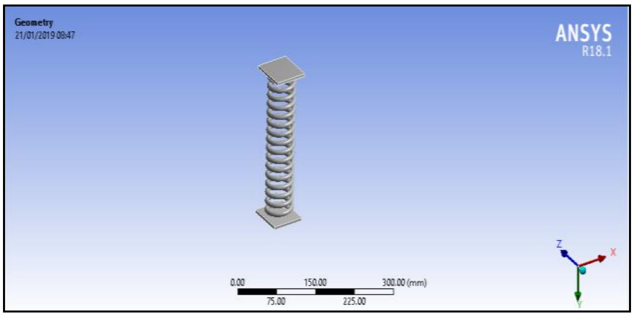

Figure 1: CAD modeling of helical coil suspension

The model is meshed using tetra elements of appropriate size and shape. After meshing appropriate loads and boundary conditions are assigned.

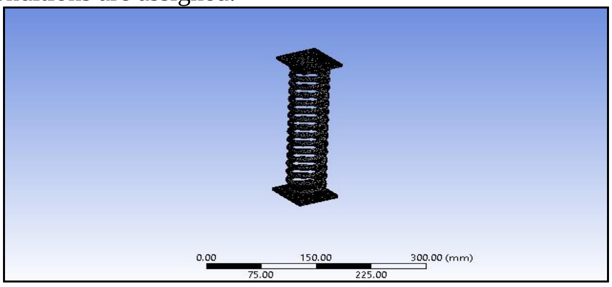

Figure 2: Meshed model of helical coil suspension

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 2.

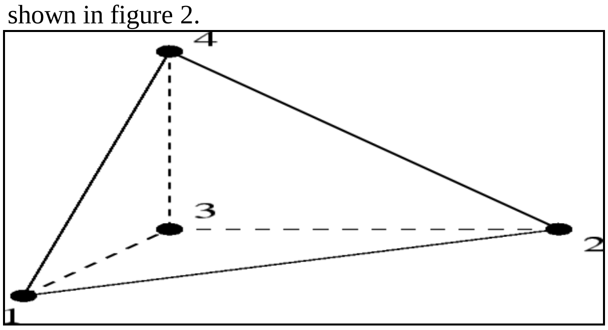

Figure 3: Tetrahedral element

The element shape of tetrahedral element is shown in figure 3. 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. The bottom face of suspension is kept fixed and top face is applied with force of 1356.4N in downward direction as shown in figure 4 below.

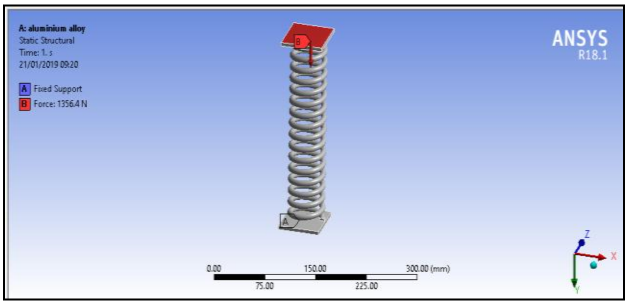

Figure 4: Loads and Boundary conditions

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 / ω_n = 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 $\frac{8FD}{\pi d^3}$

τ = (1.25 × 8 × 1356.4×48) / (π ×8^3)

τ = 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.

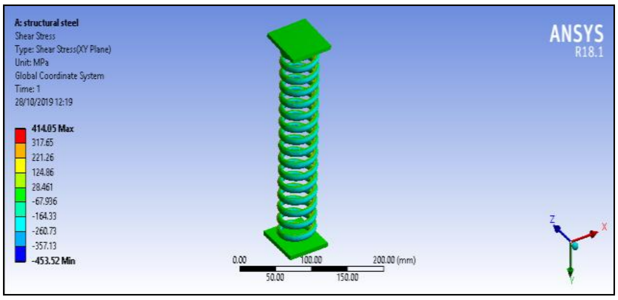

Figure 5: Shear Stress generated

Maximum Shear stress generated is denoted by red color shown in figure 5 above with magnitude of 414MPa on inner surface of coil.

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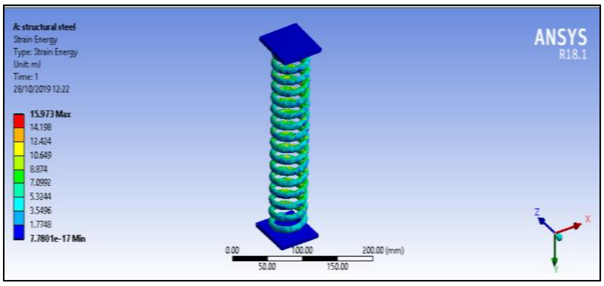

Figure 6: Strain energy generated

Maximum strain energy generated is denoted by red color shown in figure 6 above with magnitude of 15.973mJ on coil face at inner and side regions. Design points are generated from taguchi design of experiments (DOE) as shown in figure 7 below. Total 5 design points are generated and corresponding values of shear stress, strain energy and mass are calculated.

	A	B	C	D	E	F
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	25	7.85	428.34	4.093	1.2766
3	2	18	7.85	334.24	9.9601	1.0117
4	3	32	7.85	547.8	24.15	1.5452
5	4	25	6.5	823.06	62.458	0.98003
6	5	25	9.2	269.4	1.3394	1.6285

Figure 7: Design Points generated and corresponding stresses and strain energy at these points

These design points are generated on the basis of 2nd order polynomial function. On the basis of these design points software calculates response i.e. shear stress and strain energy which is shown in figure 7 above. The results are generated on the basis of sparse grid initialization scheme. The maximum value of shear stress is 823.06MPa and strain energy is 62.45mJ while minimum values of shear stress is 269.4MPa and strain energy minimum is 1.339mJ. The minimum mass obtained from analysis is .98003Kg and maximum mass is 1.5452Kg.

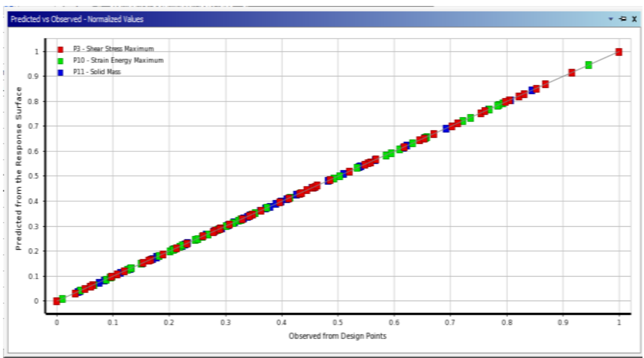

Figure 8: Goodness of Fit Curve

The goodness of fit curve plotted in figure 8 above shows deviation between observed values and expected values of shear stress and strain energy. Both shear stress and strain energy values doesn't show much deviation from expected values as can be seen in figure above both parameter values coin (red color for shear stress; blue color for solid mass, green color for strain energy) coincides with the linear curve.

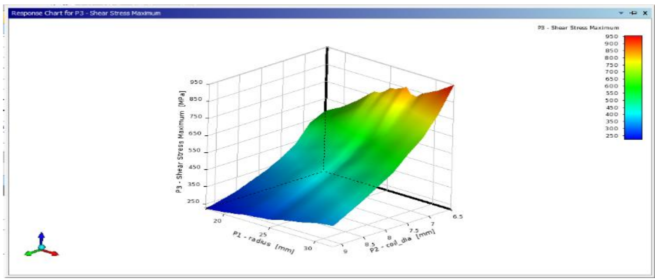

Figure 9: Response Surface for shear stress using Carbon steel

The response surface plot for shear stress is plotted in figure 9 above shows maximum magnitude of shear stress with red plots with magnitude of 930MPa and more for coil mean dia. Ranging from 6.5mm to 7mm and coil radius more than 25mm. The minimum value of shear stress is below 250MPa to 350MPa is shown by dark blue color for coil mean dia. ranging from 8.5mm and coil radius less than 22mm.

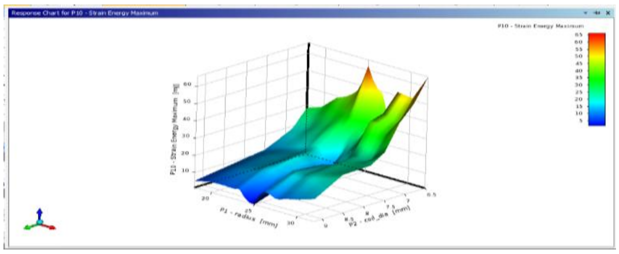

Figure 10: Response Surface for strain energy using Carbon steel

The response surface plot for strain energy is plotted in figure 10 above shows maximum magnitude of strain energy with red plots with magnitude of 60mJ and more for coil mean dia. ranging from 6.5 to 7mm and coil radius ranging from 23mm to 27mm. The minimum value of strain energy is below 8mJ is shown by dark blue colour for coil mean dia. more than 8.5mm and coil radius near to 24mm to 26mm.

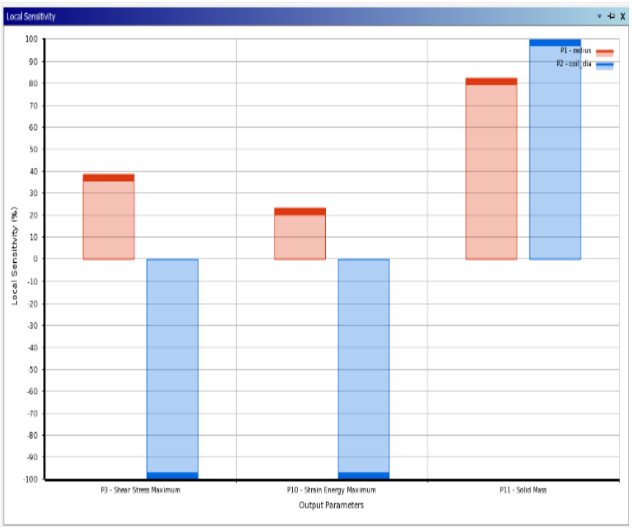

Figure 11: Sensitivity Charts

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Figure 11 above shows sensitivity chart for shear stress, strain energy and solid mass. For shear stress, coil radius shows positive sensitivity of 38.574 and coil diameter shows negative sensitivity of 97.8. For strain energy coil radius shows positive sensitivity 23.217 and coil diameter shows negative sensitivity of 98.82. For solid mass coil radius shows positive sensitivity of 82.28 and coil diameter also shows positive sensitivity of 96.54. Thus, for all the output parameters, coil diameter has larger effect as compared to coil radius as sensitivity percentage of coil diameter is more than 90. Therefore, it's better to work on coil diameter against coil radius to improve the mechanical characteristics of coil.

VI. CONCLUSION

As experimental testing of components has become costly and requires manpower and support therefore numerical method of analysis involving use of computer programmes has become viable option. From the structural analysis of helical coil suspension conducted using ANSYS software stresses and strain energy are determined. The model is optimized using sparse grid initialization scheme and minimized mass is found to be .98Kg as compared to initial mass of 1.27Kg. Therefore nearly 23% weight reduction is obtained from Taguchi response surface optimization technique. The sensitivity plot has shown that coil diameter has higher effect on all the mechanical parameters and therefore it is more feasible to work on coil diameter as compared to radius.

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