Modeling and Analysis of Helical Springs Using CATIA-V5R19 and ANSYS 16.0

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Abstract -- **A spring is an elastic object which stores strain-energy upon action of an external force in the form of pull, stretch or twist and comes back to its initial contour or shape when the external force is released. When a spring fails, an investigation is needed to find out the quality of the material which is assembled in a part of any working equipment or a practical model. Considering the availability, quality level, price and the matching with working processes, the most suitable material can be chosen. In the present work, materials with different cross sectional areas were selected from the existing work bench of CATIA V5 R19 solid-modeling software. At present spring design engineers in manufacturing sector prefer this technique without taking real material. Once solid modeling is over, then one needs to test dynamic behavior of spring on virtual screen using commercially available analysis software like ANSYS. This reduces the investment cost.**

Keywords: Helical spring, Solid modeling, Static analysis, CATIA V5 R19, ANSYS 16.0

I. INTRODUCTION

HELICAL spring is one of the most fundamental flexible mechanical elements used in several industrial applications like balances, brakes, vehicle suspensions and engine valves to satisfy functions like applying forces, storing or absorbing energy, providing mechanical systems with the flexibility and maintaining a force or a pressure. In addition, helical springs serve as the elastic member for most common types of vibration absorbers. The most commonly known helical spring, used in these applications, is presented as a cylindrical three-dimensional curved beam, characterized by its spiral shape and its constant curvatures along the axis. For these kinds of springs, the demand of space in both lateral and vertical directions is undeniable. But for some very specialized applications, where there are lateral and (or) vertical space constraints, common springs may not be implemented with much success due to unwanted increase in stiffness mainly due to usage of multiple springs. This can be avoided by the usage of two special kinds of springs, *viz.* springs with noncircular shape to cater to restrictions in lateral space and springs of circular helical shape but non-prismatic profile to cater to restrictions in vertical space.

Among the non-circular helical springs, the rectangular springs are used in light firearms. Among the non-prismatic springs, conical springs are generally used in applications requiring low solid height and increased resistance to surging, like automotive engines, large stamping presses, lawn mowers, medical devices, cell phones, electronics and sensitive instrumentation devices. Volute shaped springs offer more lateral stability and less tendency to buckle than regular compression springs. Also, the possibility of resonance and excessive vibration (or surging) is reduced because volute springs have a uniform pitch, more damping due to helical structure and an increasing natural period of vibration (instead of a constant period of vibration as in a cylindrical spring) as each helical closes. For design and selection of springs for practical purposes, deflection of the spring under axial load and maximum stresses induced are two major factors. Stress analysis is one of the main themes of research in helical springs.

II. LITERATURE REVIEW

Investigations in this area began with the pioneering works of Ancker and Goodier [1, 2], who used the boundary element method (not to be confused with the modern boundary element method) to apply theory of elasticity and to develop an approximate result to satisfy governing equations and boundary conditions along the surface of the helical. For small deformations of the spring, Wahl [3] considered the wire of the spring as a round bar subjected to shear and torsion. The coupling between axial and torsional deformations was neglected in Wahl's approach and a correction factor was used to account for the curvature of the spring. Nagaya [4] solved equations governing the distribution of stresses in the spring and developed an analytical approach but the aforesaid solution was applicable only for a few types of cross sections (circular, rectangular, etc.). Kamiya and Kita [5] treated this problem also using boundary element method, and the analysis was limited to springs of small helix angle. Also, Cook [6] analyzed the same type of springs by using finite element method and showed the limitation of the work associated with the methodology's negligence to helix angle of the spring. Haktanir [7] solved the same problem by an analytical method to determinate the static stresses in the spring. Jiang and Henshall [8] developed an approach based on the finite element method to analyze the stresses in a circular cross section helical spring by developing accurate boundary conditions and using finite element analysis. Fakhreddine *et al.* [9] presented an efficient two node finite element with six degrees of freedom per node, capable of modeling the total behavior of a helical spring. Mukhopadhyay *et al*. [10], investigated on the premature failure of suspension helical spring of a passenger car, which failed during the service within few months and identified the reasons for the failure. In this investigation micro structural analysis, SEM analysis, hardness testing, and chemical analysis were applied. The results stated that the inherent material defect in association with deficient processing led to the failure of the spring.

Chang Hsuan Chiu *et al.* [11] explained about four types of helical compression springs made of unidirectional laminates, rubber core unidirectional laminates, unidirectional laminates with a braided outer layer, and rubber core unidirectional laminates with a braided outer layer respectively. The results indicated that the helical composite springs with a rubber core has 12% more load carrying capacity while for the spring with a rubber has 18% more load carrying capacity along with the improvement of 16% in spring constant. Gaikwad and Kachare [12] attempted to analyze the safe load of the helical compression spring. A typical helical compression spring configuration of two wheeler horn is chosen for study. This work describes static analysis of the helical compression spring performed using NASTRAN solver and compared with analytical results.

C. J. Yang *et al.* [13], investigated helical springs subjected to axial loads under different dynamic conditions. The mechanical system, composed of a helical spring and two blocks, is considered and analyzed. Multi body system dynamics theory is applied to model the system, where the spring is modeled by Euler–Bernoulli curved beam elements based on an absolute nodal coordinate formulation. Compared with previous studies, contact between the helicals of spring is considered here. A three-dimensional beam-to-beam contact model is presented to describe the interaction between the spring helicals. Chaudhury and Datta [14] presented a methodology for designing prismatic springs of non-circular helical shape and non prismatic springs of circular helical shape using analytical and numerical methods using CAD and FEM. Authors found that, numerous authors are still working on modeling and analysis of different types of helical springs with variable cross sections in their research works using different available softwares from past to present. So in this work, modeling of a helical spring with circular, elliptical and square cross sections for different materials were studied using CATIA V5R19.

III. MODELING OF HELICAL SPRINGS

Helical springs can be classified into helical compression spring and helical extension spring according to the direction and the nature of the force exerted by the spring when it is deflected. In this section, the helical compression spring is discussed as an example. Similar procedure can be applied by changing the spring material from material library which is available in CATIA work bench.

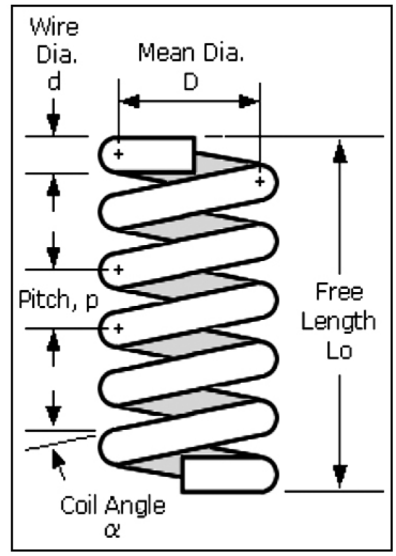

Figure1. Design parameters of a helical spring .

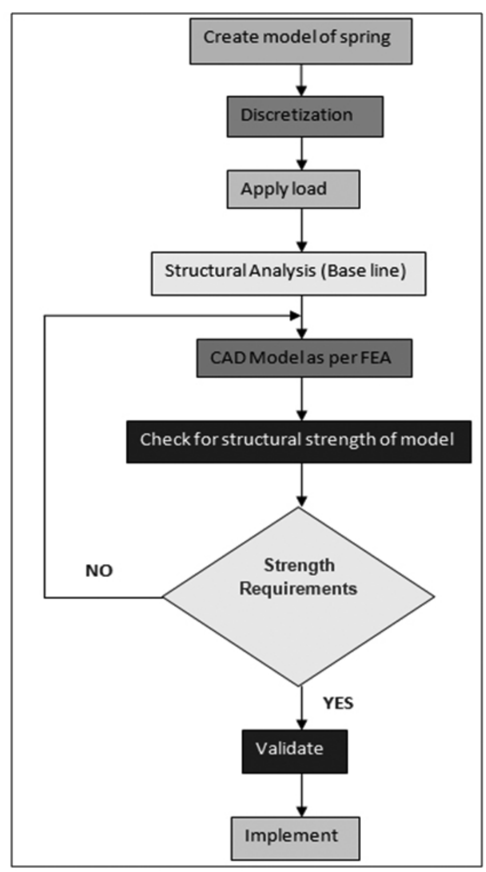

Figure 2. Flow chart of helical spring model design.

In the present work, modeling and analysis has been carried out on different materials for helical spring. The materials chosen are chrome vanadium steel material, low carbon structural steel material; the specifications, modeling and analysis are as follows.

Specifications of helical spring and Material data Specification of spring

Specifications	Material data(only few materials listed here)
Wire diameter = 9.49 mm, Helical outer diameter =56.94 mm, Helical free height =152 mm, No. of active helicals =11, Pitch =13.8 mm Test load on each spring =2750 N	For Chromium vanadium steel material properties are Young's modulus =207000MPa, Poisson ratio =0.27, Density =7860kg/m^3 For low carbon structural steel material properties are Young's modulus =198000MPa, Poisson ratio =0.37, Density =7700 kg/m^3

Tool Bars used in CATIA (computer Aided Three Dimensional Interactive Applications)		
Profile Tool Bar 1. Rectangle 2. Circle 3. Spline Sub toolbar 4. Conic Sub toolbar 5. Line Sub toolbar 6. Point Sub toolbar **Operation Toolbar** 1. Corner 2. Relimitation sub toolbar 3. Trasformation toolbar	**View Tool Bar** 1. Fly 2. Fit all in 3. Pan 4. Rotate 5. Zoomin 6. Zoomout 7. Normal view 8. Multiview 9. Shading sub toolbar 10. Hide/Show 11. Swap visible Space	**Sketch Based Toolbar** 1. Pad sub toolbar 2. Pocket sub toolbar 3. Shaft 4. Groove 5. Hole 6. Rib-which add material of given cross section along the profile 7. Slot 8. Combine 9. Multi section solid 10. Remove Multi section solid

Step-1: Go to the part design in the Mechanical design. Select the *xy* plane and click on the sketch.

Step-2: Select the point from the profile tool bar and place it at a distance of (47.45/2,0) from the corresponding axis.

Step-3: Click on the Exit app and select the helix tool and draw the helix profile with respective dimensions.

Step-4: Select the plane perpendicular to the helix profile and draw the circular cross section.

Step-5: Click on the Exit app and select the rip option from sketch based tool bar and rib along the profile.

By using sketch based tool bar and profile tool bar draw ends supports.

<u>With Square cross section</u>

Step-1: Go to the part design in the Mechanical design. Select the xy plane and click on the sketch.

Step-2: Select the point from the profile tool bar and place it at a distance of (47.45/2,0) from the corresponding axis.

Step-3: Click on the Exit app and select the helix tool and draw the helix profile with respective dimensions.

Step-4: Select the plane perpendicular to the helix profile and draw the Square cross section. By using corner option provide fillet between two adjacent sides.

Step-5: Click on the Exit app and select the rip option from sketch based tool bar and rib along the profile.

By using sketch based tool bar and profile tool bar draw ends supports.

<u>With Elliptical cross section</u>

Repeat the above steps and change the cross section as ellipse

Meshing of the model

A helical spring is designed and modeled by using CATIA as per the specifications. In this the spring behavior will be observed by applying different materials loads, to optimum stresses and the result shows best material. Model of the spring will be first created by using CATIA. Begin by drawing a line of 152 mm length and it is the free height of spring. The line is at a distance of 56.94 mm from vertical axis and it is outer diameter of the helical as shown in Fig. 3. Next enter the pitch of spring. Pitch is calculated by free height of helical the spring divided by the number of turns. In this 152/11=13.8mm. Create the circle of wire diameter 9.49mm of spring as shown in figures 4 and 5 then create Solid model of helical spring as shown in Fig. 6. Similarly, remaining cross sectional helical springs are modelled and shown in figures 7 to 10.

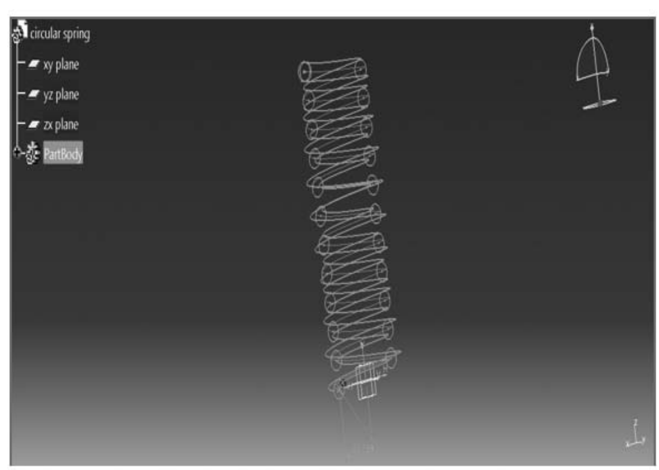

Figure 3. Selection of a point w.r.t vertical axis of a spring.

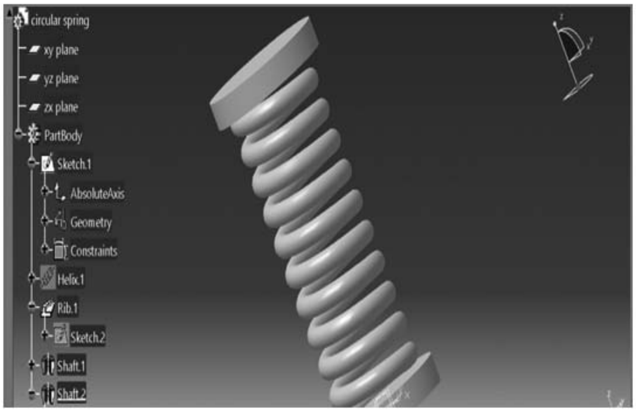

Figure 4. Generated Helix Profile.

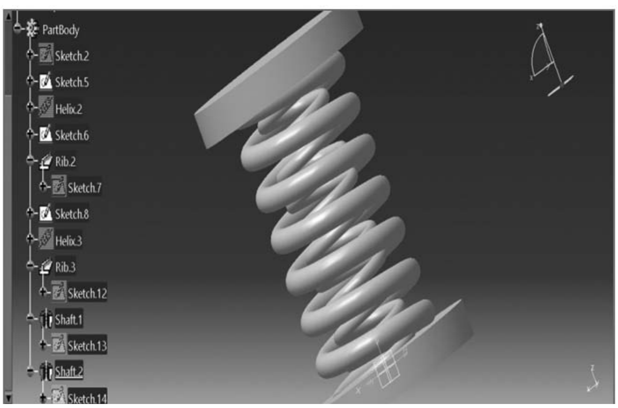

Figure 5. Circular cross section along helix using Rib.

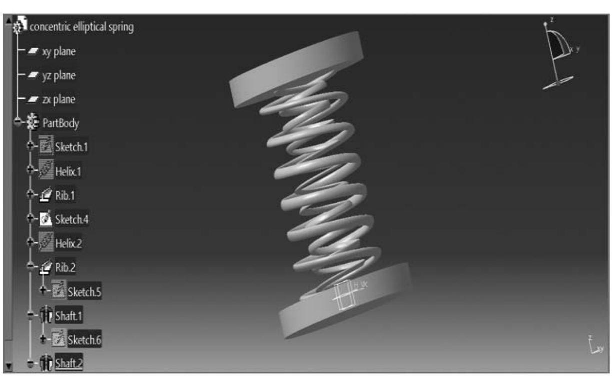

Figure 6. Concentric helical compression spring. (Elliptical Cross section)

After generating the meshing models with various cross sections through finite element analysis, then using CATIA solid modelling software three-dimensional helical spring models are generated. In the static modelling analysis, we utilized the DASSULT Systems 3D experience Lab to achieve the static analysis results espicially concentrated on various stresses and strains (static analysis is beyond the scope of the paper but in results case it is given for a circular cross section).

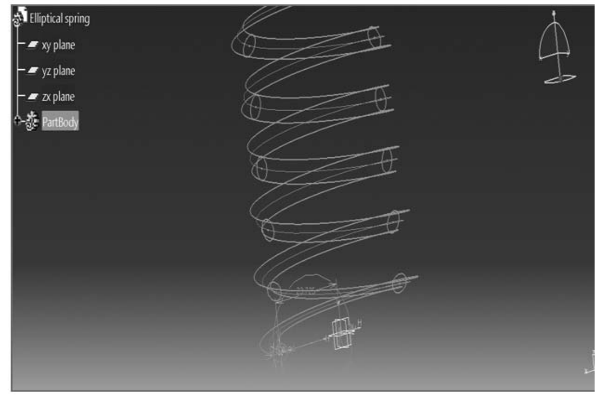

Figure 7. Elliptical cross section along helix using Rib.

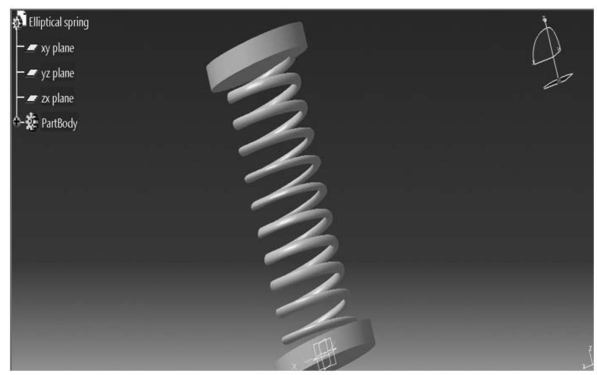

Figure 8. Helical Compression Spring (Elliptical).

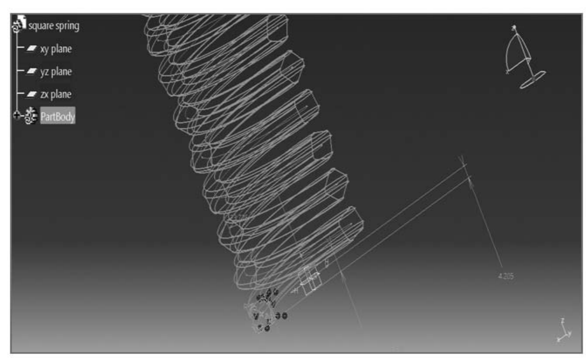

Figure 9. Square cross section with fillet edges along the helix using Rib.

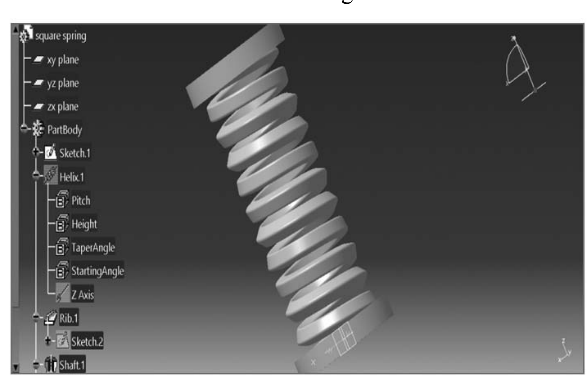

Figure 10. Helical compression spring of square cross section.

IV. ANALYSIS OF HELICAL SPRINGS

ANSYS 16.0 are used as software for pre and post processing of the static analysis of conventional helical coil springs. Mesh type, mesh size, spring seat types and spring end connection types are all examined in this section. While expecting accurate results, it is also aimed to have an analysis model that can respond faster. Firstly, the spring is meshed with different mesh types and sizes and convergence of results is examined. Then, spring seat types are defined and it is decided to use square blocks as spring seat to apply the load easily and accurately. Spring end connection types are examined finally and the analysis model is obtained according to all these considerations. In the analysis process, the maximum shear stress and the deformation of the coil spring according to applied force are the specified variables that are selected and their convergences monitored. During analyses, rigid blocks are designed at the top and the bottom of the spring as spring seats. At the bottom seat, only rotational degree of freedom in *z* direction is free while only translational degree of freedom in *z* direction free at the top seat.

After the meshing type is specified, analyses are repeated with same element type but with different sizes until the convergence of the results is obtained. Smaller elements make results better till some limiting size with which unexpected results arise around the spring ends and contact regions of the spring end and spring seat. Since the results are justified by investigating the maximum shear stress value which should be at the inside of the coil, the unexpected results at the spring ends and contact regions can be accepted inaccurate results due to the analysis model and are not of concern. On the other hand, very small mesh elements increase the setup time and computational expenses inherently. Static analysis determines the stress and deflection of the helical compression spring in finite element analysis (FEA). The model is used to analyze the spring on the ANSYS 16.0 under different materials conditions. FEA (WORKBENCH) is a mathematical tool for solving engineering problems. The modeling of spring is developed on CATIA and analysis is carried out on ANSYS WORKBENCH 16.

In the present work, the simulation and analysis of helical spring which is the main part in the suspension system in modern vehicles were carried out by using ANSYS 16. The results showed that the less value of total deformation happened in spring made of low carbon steel for all the values of load. The deformation reduced by 15% in low carbon steel compared with the deformation in steel and reduced by about 54% compared with total deformation in vanadium steel. The deformation, strain, stress and shear stress increased by increasing the load. The stress and shear stress are approximately the same for the three materials under the same load (tested under a load of 2750N, 4000N and 5000N). Low carbon steel has advantages for the suspension system such as reduced weight and greater strength to the system in spite of its cost.

The deformation, strain, stress and shear stress increased by increasing the load from 2750 N to 5000N for different materials corresponding respective cross sections are generated

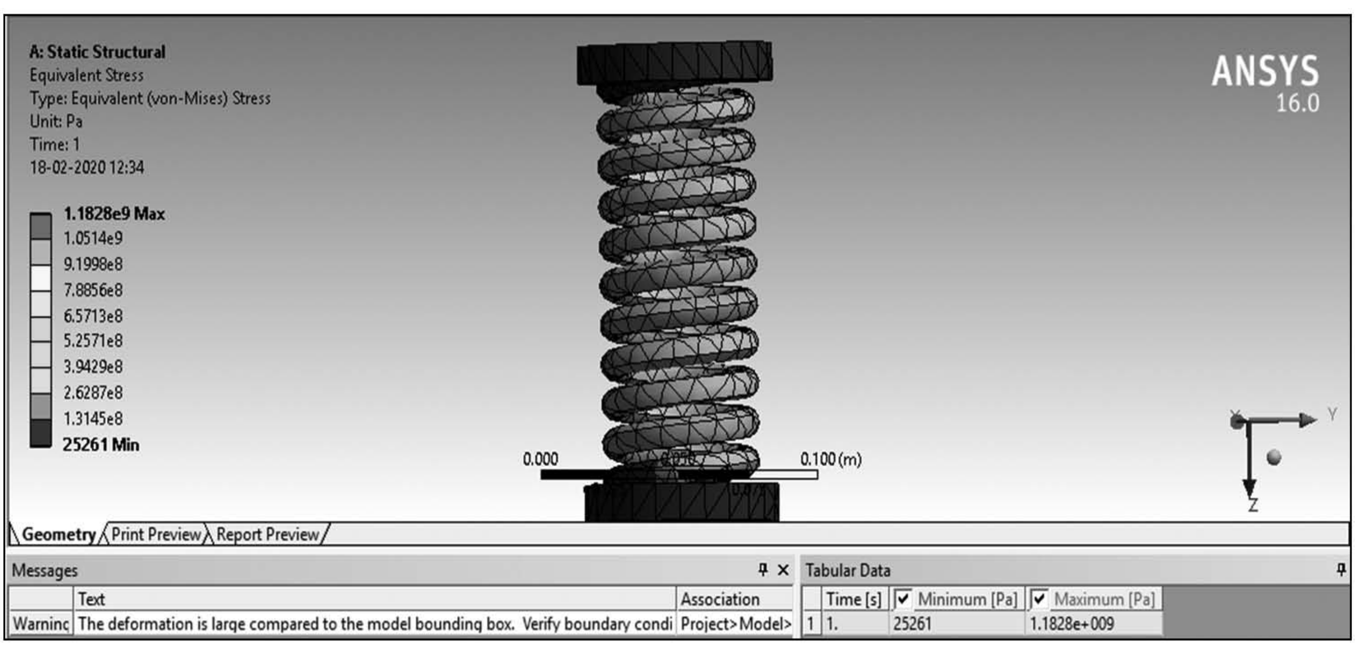

Figure 11. Vonmises stress of circular helical cross section.

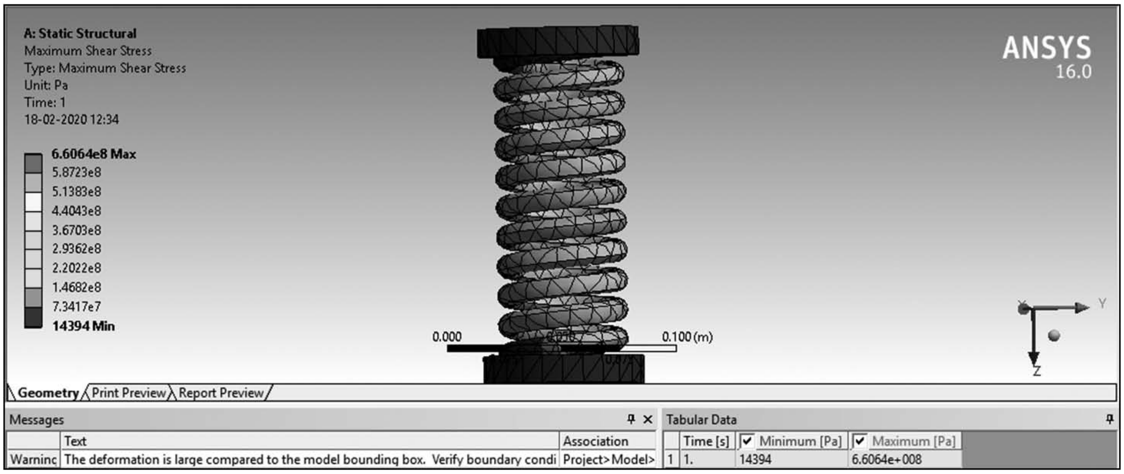

Figure 12. Maximum shear stress of circular helical cross section.

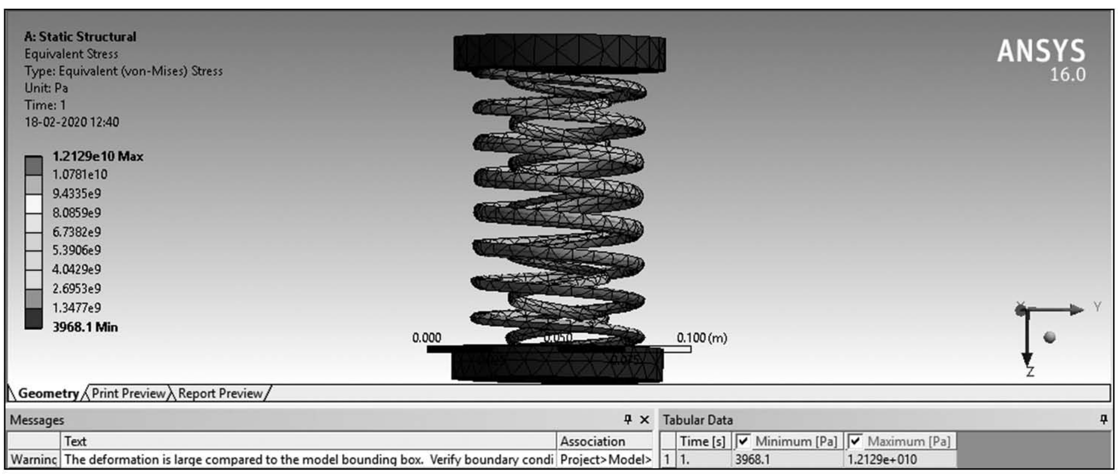

Figure 13. Vonmises stress of elliptical cross section.

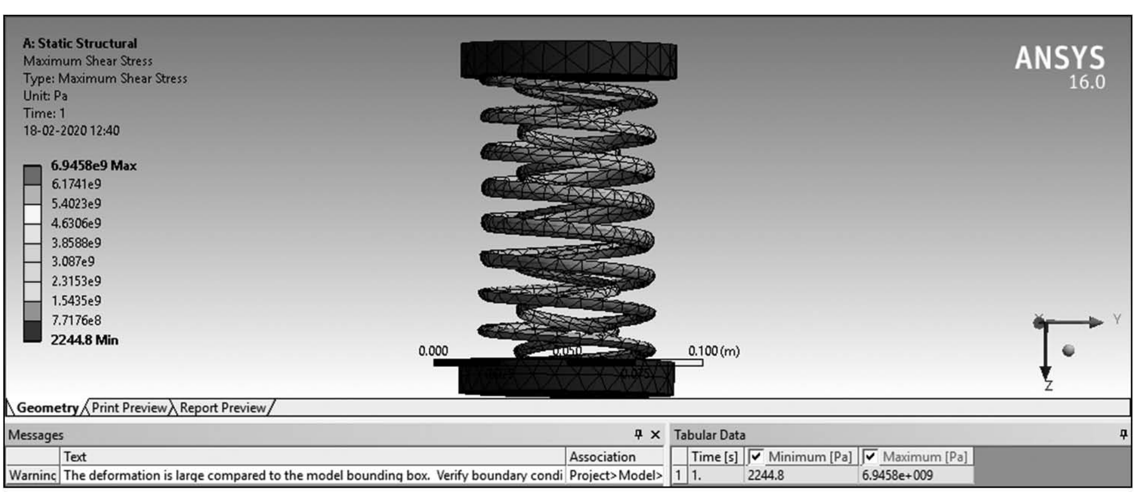

Figure 14. Maximum shear stress of elliptical cross section.

from ANSYS 16.0 software and the images are depicted in Fig.11 to Fig.16. The magnitudes of deformation, strain, vonmises stresses and maximum shear stresses are tabulated (from table 1 to table 6) and graphs are plotted with those obtained values to analyze.

V. DISCUSSION

In the preliminary investigation, it was evident that extensive study has been done in the design of circular cross-section springs, specifically in determining the stiffness due to various loading conditions. This investigation focused on determining

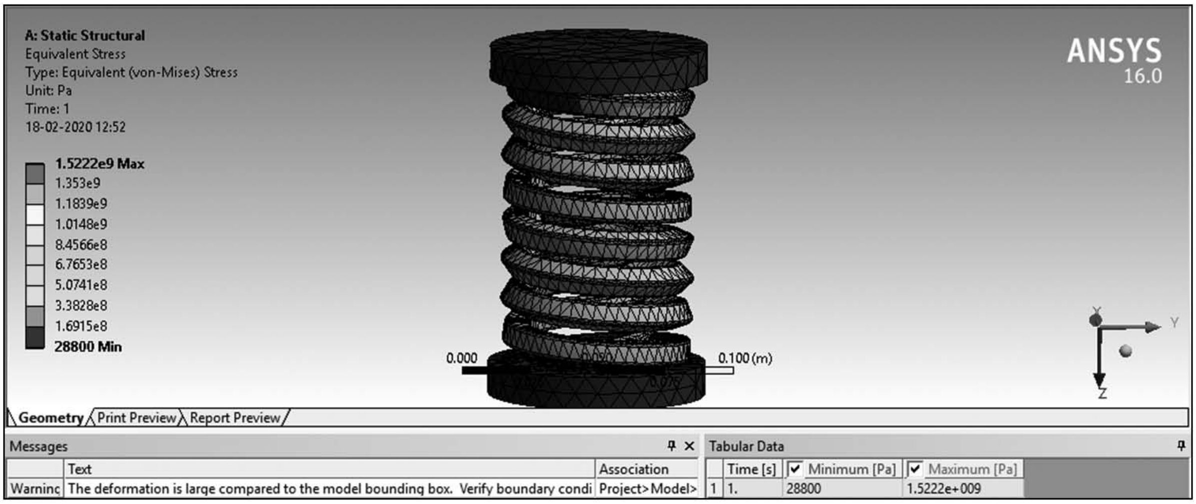

Figure 15. Vonmises Stress of square cross section.

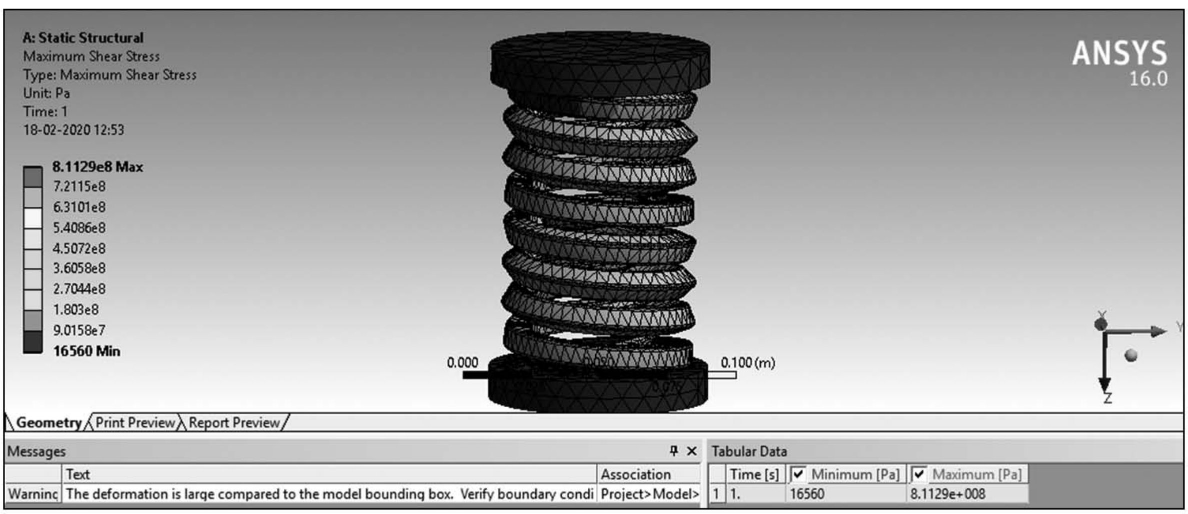

Figure 16. Maximum Shear stress of square cross section.

the stiffness for a circular cross-section helical compression spring and slotted cylinder spring and utilized theoretical methods and finite element analysis. FEA using ANSYS based on the linearity between load and deformation and the results of the analysis must be accepted subject to the validity of this assumption. The work done due to the deformation of helical of the spring is stored as strain energy. For a unit volume of the linear elastic spring, it was determined by comparison of results that the strain energy in the finite element model adequately represented the strain energy determined theoretically.

TABLE 1-- RESULTS FOR STRUCTURAL STEEL MATERIAL FOR LOAD OF 4000N

S.No	Spring cross section	Total deformation	Elastic strain	Principal stress	Maximum shear stress
1	Circular helical	Max=0.052488 Min=0	Max=0.056829 Min=2.0126e-7	Max=1.4552e9 Min=37421	Max=9.6093e8 Min=18936
2	Elliptical helical	Max=0.068124 Min=0	Max=0.098746 Min=1.0737e-7	Max=1.1472e10 Min=19524	Max==3.7587e9 Min=11745
3	Square helical	Max=0.068887 Min=0	Max=0.007818 Min=1.874e-7	Max=1.5124e9 Min=20149	Max=7.3523e8 Min=13213

TABLE 2 -- RESULTS FOR STRUCTURAL STEEL MATERIAL FOR LOAD OF 5000N

S.No	Spring cross section	Total deformation	Elastic strain	Principal stress	Maximum shear stress
1	Circular helical	Max=0.042375 Min=0	Max=0.02351 Min=2.3283e-7	Max=2.0208e9 Min=35629	Max=1.0087e9 Min=23171
2	Elliptical helical	Max=1.0105 Min=0	Max=0.073195 Min=1.4276e-7	Max=1.40608e10 Min=29565	Max=7.4534e9 Min=17197
3	Square helical	Max=0.064572 Min=0	Max=0.0177785 Min=2.0541e-7	Max=1.8974e9 Min=30472	Max=1.2301e9 Min=15221

TABLE 3 -- RESULTS FOR CHROMIUM VANADIUM MATERIAL FOR LOAD OF 4000N

S.No	Spring cross section	Total deformation	Elastic strain	Principal stress	Maximum shear stress
1	Circular helical	Max=0.050238 Min=0	Max=0.010859 Min=1.9106e-7	Max=1.7205e9 Min=36743	Max=9.6093e8 Min=20936
2	Elliptical helical	Max=0.80067 Min=0	Max=0.058716 Min=1.2703e-7	Max=1.1672e10 Min=25044	Max==6.7386e9 Min=13758
3	Square helical	Max=0.058874 Min=0	Max=0.007818 Min=1.5874e-7	Max=1.6141e9 Min=22539	Max=9.3125e8 Min=13003

TABLE 4 -- RESULTS FOR CHROMIUM VANADIUM MATERIAL FOR LOAD OF 5000N

S.No	Spring cross section	Total deformation	Elastic strain	Principal stress	Maximum shear stress
1	Circular helical	Max=0.062797 Min=0	Max=0.013573 Min=2.3882e-7	Max=2.1506e9 Min=45929	Max=1.2012e9 Min=26171
2	Elliptical helical	Max=1.0008 Min=0	Max=0.073395 Min=1.5879e-7	Max=1.459e10 Min=31305	Max=8.4232e9 Min=17197
3	Square helical	Max=0.073593 Min=0	Max=0.0097725 Min=1.9843e-7	Max=2.0176e9 Min=28174	Max=1.1641e9 Min=16254

TABLE 5 -- RESULTS FOR LOW CARBON STEEL MATERIAL FOR LOAD OF 4000N

S.No	Spring cross section	Total deformation	Elastic strain	Principal stress	Maximum shear stress
1	Circular helical	Max=0.056228 Min=0	Max=0.011607 Min=1.8493e-7	Max=1.7968e9 Min=8927	Max=9.3984e8 Min=5079.4
2	Elliptical helical	Max=0.88129 Min=0	Max=0.059342 Min=1.0908e-7	Max=1.1646e10 Min=19408	Max=67235e9 Min=10696
3	Square helical	Max=0.066289 Min=0	Max=0.0082207 Min=1.6285e-7	Max=1.5991e9 Min=28523	Max=9.2238e8 Min=16260

TABLE 6 -- RESULTS FOR LOW CARBON STEEL MATERIAL FOR LOAD OF 5000N

S.No	Spring cross section	Total deformation	Elastic strain	Principal stress	Maximum shear stress
1	Circular helical	Max=0.070285 Min=	Max=0.014509 Min=2.3117e-7	Max=2.246e9 Min=11159	Max=1.1748e9 Min=6349.3
2	Elliptical helical	Max=1.1016 Min=0	Max=0.074178 Min=1.3635e-7	Max=1.4557e10 Min=24260	Max=8.4044e9 Min=13370
3	Square helical	Max=0.082861 Min=0	Max=0.010276 Min=2.0356e-7	Max=1.9988e9 Min=35653	Max=1.153e9 Min=20325

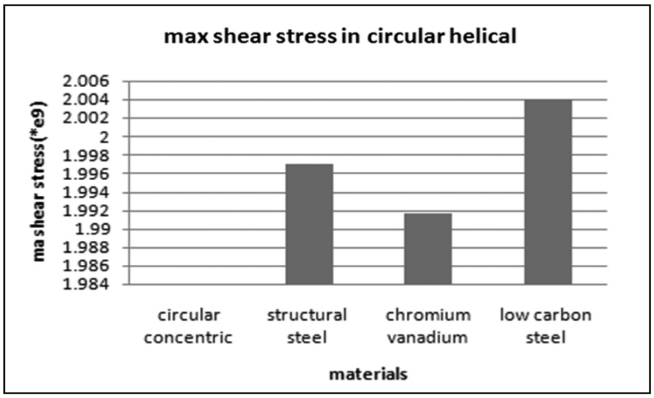

Figure 17. Variation of stress w.r.t different materials.

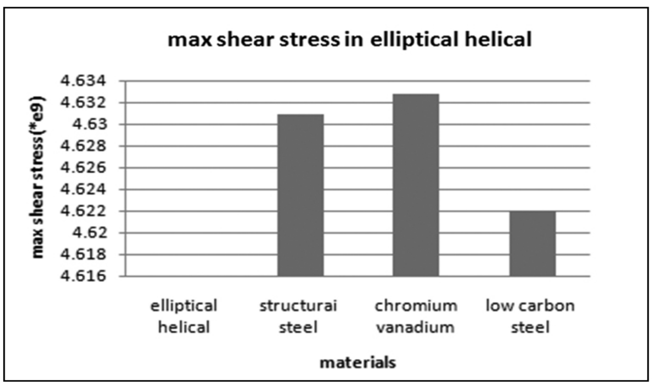

Figure 18. Variation of stress w.r.t different materials

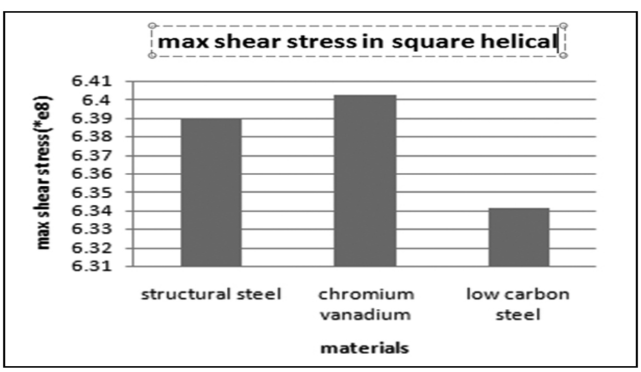

Figure 19. Variation of stress w.r.t different materials.

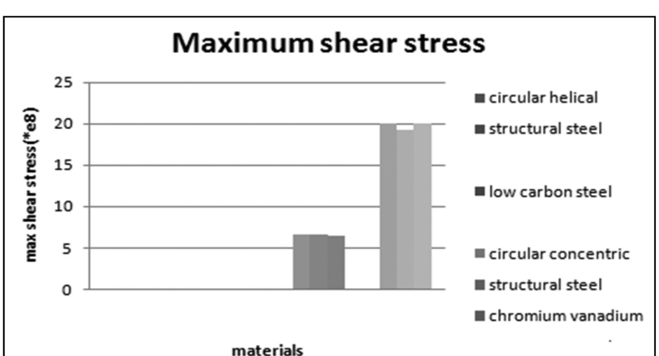

Figure 20. Variation of stress w.r.t different section of materials.

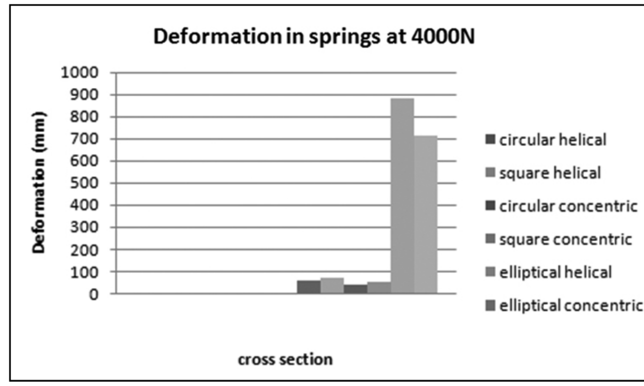

Figure 21. Deformation w.r.t different section of materials.

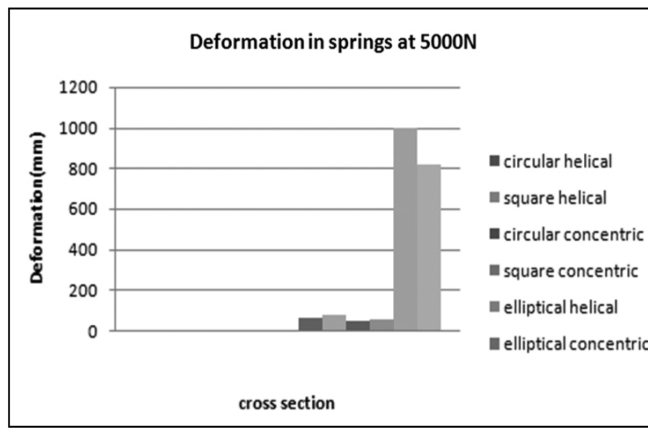

Figure 22. Deformation w.r.t different section of materials.

VI. CONCLUSION

In this study, the simulation and analysis of coil or helical spring which is the main part in the suspension system in modern vehicles were carried out by using CATIA V5R19 and ANSYS 16.

Three different materials were chosen to simulate the spring under various values of load. The results showed that the less value of total deformation happened in the case of spring made of structural steel for all the values of load. The deformation reduced by 12% low carbon steels compared with the deformation in chrome vanadium steels and reduced by about 14% compared with total deformation in structural steels. The deformation, strain stress and shear stress increased by increasing the load.

For future work, it is recommended to simulate the coil spring with different materials and various load and change the type of spring from the coil to leaf spring in addition to changes in dimensions of spring such as the outside diameter, free length, pitch etc.

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