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DESIGN AND ANALYSIS OF HELICAL COIL SPRING TO IMPROVE ITS STRENGTH THROUGH GEOMETRICAL MODIFICATION

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Abstract-A suspension system or compression coil spring is designed to reduce shock impulse, and generate kinetic energy. The coil spring operation is to dissipate or absorb energy. it also absorbs the shock generated by road irregularities in a vehicle, results in enhanced ride quality, and an increase in ride comfort due to reduction of disturbances. In a movement of a vehicle on a road when the wheels meet with a bump, the spring undergoes compression load. This load compresses the spring and try to return to its original loaded length which in the process of rebounding go past its normal height, results in lifting the body. The extended length of the coil due to rebound tries to contract which way past its normal length and again rebound occurs with lower amplitude. This bouncing process of the coil occurs repeatedly until it finally stops. If this bouncing process occurs without any control, it causes uncomfortable ride and also leads to difficult handling of the vehicle. Therefore, designing of spring in the suspension system is very important. In this work, a coil spring is designed and a 3D model is created using CATIA V5. The model is also changed by geometrical modification of the coil. Structural analysis is carried out on the different geometries of coil spring. Structural analysis is done to analyse the strength through stress calculation using ANSYS. The results are compared for the designed coil spring geometries. CATIA is the standard 3D product design software and ANSYS is a general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called element.

Index Terms- Compression, Conical Spring, Geometry, Helical Coil Spring.

1. INTRODUCTION

The primary function of the suspension system is to protect the vehicle chassis from being damaged due to irregularities on the road or uneven surface on which it is moving. For this purpose, springs are used in the suspension system as shock absorbers which absorbs shock impulse and dissipate kinetic energy. Without these suspension systems, passengers will have a bouncing ride or damage of goods occurs as all energy is transferred directly to the chassis in the absence of suspension. Compared to the stiffer springs, soft springs damp the vertical motion of un-sprung mass and results in efficient damping of wheel bounce. Metal springs reduce the shock loading and collision speed by absorbing the impact loads within the minimum cost. These can be operated in a big temperatures range. Metal springs store energy rather than dissipating it. Metal springs are usually operated with viscous dampers [1]. Different types of metal springs include helical springs, leaf springs, Wave springs etc. Each spring type has its own physical, chemical and operating properties.

The helical springs are considered as primary elastic members of the suspension system, which act as energy storage and also connect the body to the wheel. The helical spring reduces the shock transmitted to the vehicle body due to irregular roads and uneven surface [2]. the dynamic load acting in different ways to the suspension causes fatigue failure. One of the reasons of the failure is due to maximum stress on the inner surface of the active coil and another reason is unsuitable material, which results in high-stress concentration at various location leads to initiation of a fatigue crack. Helical springs are classified based on loads as helical compression, tension and torsion spring. The springs are commercially manufactured with metals like vanadium chromium steel or different grades of spring steels due to its high strain energy. Springs are supposed to support axial as well as torsion loads which cause bending and shear stresses in the compression coil spring respectively. Open coiled springs can be used as tensioning or compression elements due to the presence of large helix angles and large pitch. The open coil springs have a wide range of applications as in brake drums, vehicle suspension system or sometimes used as tensioning element etc.

2. LITERATURE REVIEW

In this section, the literatures survey is presented on the information about the various factors of the helical coil spring. Various research approach like Numerical, theoretical and experimental are proposed by the various researchers throughout the years. Study-related to various methods concluded that Finite Element Method is best suited for numerical solution and calculating the stress, life cycle and shear stress of helical compression spring [3]. A shock absorber of 150cc bike was designed by Poornamohan et al. [4] using PTC product pro/engineer, and comparison between spring steel and beryllium copper was made to find the best material for the selected

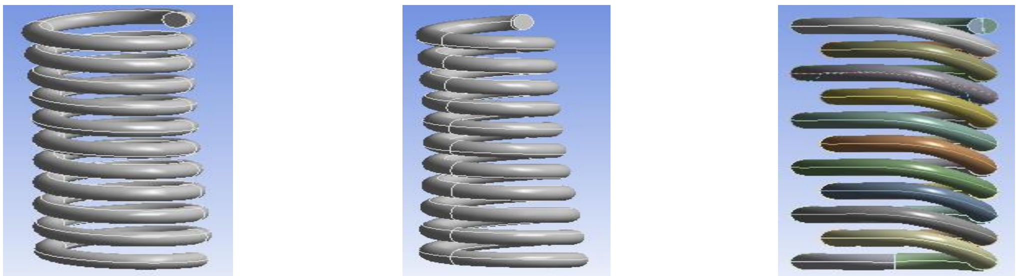
design. A structural analysis was carried out to analyse the design in ANSYS and it was found that the stress induced in the spring was less than the yield stress value and it is also less for spring steel than Beryllium copper. The existing design was then modified by reducing the diameter of the spring by 2 mm and analysis was done which results in reduction of spring weight and again stress values reduces for modified design as compared to present design. The results showed that best material for spring was spring steel and modified design was safe to use. A. M. Wahl [5] has summarized basic and essential definitions, characteristics, behaviour models, and calculation methods, load-deflection equation relating to the main types of springs. According to Wahl's assumptions, the derivation is accurate for cases where deflections per coil in the axial direction of the springs are not too large and pitch angles are less than 10º. J. A. Haringx [4],[6], demonstrated that an excellent agreement exists between the experiments and the results of a new theoretical calculation for the elastic stability of helical compression springs of circular wire section. This calculation showed that the critical relative compression at which buckling occurs depends only on the ratio of initial length, to the coil diameter and on the method of attaching the spring ends. Finally, a continuous relation has been derived for a nonlinear conical spring by Rodrigues et al., [7]. They illustrated that the conical compression spring behaviour has a linear phase but can also have a nonlinear phase. The rate of the linear phase can easily be calculated but no analytical model exists to describe the nonlinear phase precisely. This nonlinear phase can only be determined by a discretizing algorithm. They presented analytical continuous expressions of length as a function of load and vice versa for a constant pitch conical compression spring in the nonlinear phase. Validation of new conical spring models in comparison with experimental data is performed. The behaviour law of a conical compression spring can now be analytically determined Becker et al., [6][8], partial differential equations governing the buckling behaviour of helical compression springs were developed and solved for both end fixed and circular cross-section using transfer matrix method and produced buckling design charts. And the equations governing resonant frequencies of a helical spring subjected to a static axial compressive load are solved numerically using transfer matrix method for clamped ends. H. Wang et al., [9], has developed load-deflection relationships by using the strain-energy method and nonlinear effects due to compression of the large diameter coils have been discussed. M.H.Wu et al., [10], has proposed a model to calculate the load-deflection relation of the conical spring and verified experimentally with static data. It shows that the maximum error between simulation and experimental results was 4.6 %. V. Yildirim [2][11], has developed free vibration equations for cylindrical isotropic helical springs loaded axially and solved numerically based on the transfer matrix method to perform dynamically buckling analysis. The axial and shear deformation effects together with rotator inertia effects are all considered based on the first-order shear deformation theory. However, Wolansky.E.B [5], has derived the buckling –deflection equation of conical spring for both simply-supported and fixed ends. The deflection due to shear load is omitted, and only energy from torsional and flexural stresses was considered.
Based on the literature reviewed, it was found that very less work is reported on the variation in performance based on the geometric design of the coil spring. Hence, this paper deals with the selection of the suitable geometric representation of a coil spring for enhanced factor of safety and load capacity.

3. METHODOLOGY

In this section, various geometrical design of coil spring is generated for the application of passenger vehicles. The parameters selected for the design of coil spring is shown in table-3.1.

Table-3.1 Coil Spring Design Parameter

Wire Diameter (d)	9.49×10^{-3} m
Coil Outer Diameter (D)	56.94×10^{-3} m
Coil Free Height (H)	152×10^{-3} m
No. of Active Coil (N)	11
Pitch (P)	13.8×10^{-3} m
Test Load (F)	2750 N



(a) Open-end Cylindrical Coil Spring (b) Open-end conical Coil Spring (c) Open-end variable outer diameter coil spring

Fig. 3.1 Various Geometrical Design of Coil Spring

The possible geometrical designs are explored by keeping these parameters constant and the model is developed in CATIA V5® as shown in FIG.3.1. FIG.3.1(a) has a cylindrical shape of the coil spring whereas FIG.3.1(b) represents the conical geometry of the coil spring. The cone angle is selected in such a way that the smaller coil outer diameter should not be less than 20% of the maximum outer diameter. Therefore, the selected cone angle is 2°. However, under higher load, the consecutive coils may touch each other and cause wear of the coil sometimes failure of these coils therefore, these coils should have different outer diameter. This variation of the outer diameter is calculated using Eq. (1), and coil spring is generated as shown in FIG.3.1(c).

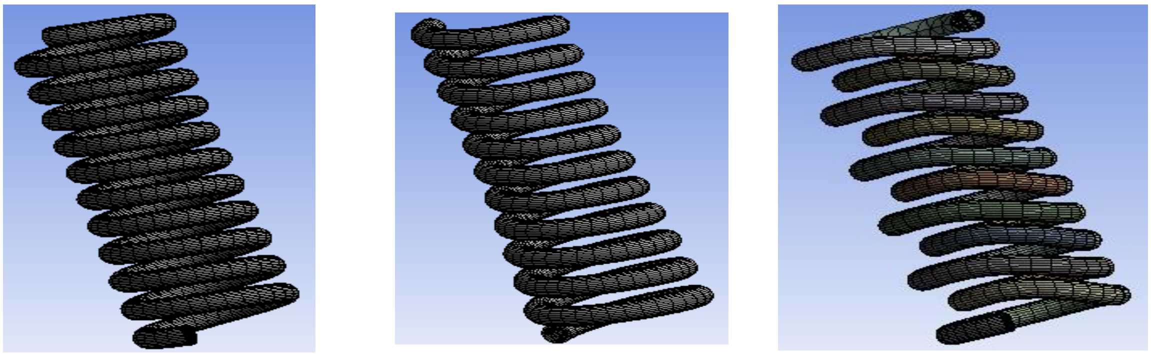
$$D_{SO} = D - 2 \times d \qquad (1)$$

The performance like deflection, Stress induced in these spring geometries has analysed through FEM Approach using ANSYS® for the load of 2750 N. The material of all designed springs is considered to be chromium-vanadium alloy. The properties of chromium-vanadium alloy are shown in TABLE-3.2. The designed geometry is discretized into fine Quad element because it predicts more accurate results and computation time is also less compared to the triangular element.

The number of nodes and elements generated on the geometry is shown in TABLE-3.3 and the meshed geometry is shown in FIG.3.2.

Table-3.2 Mechanical Properties of Chromium-Vanadium Alloy

Young’s Modulus	210 GPa
Poisson’s Ratio	0.27
Ultimate Tensile Strength	1740 MPa
Density	7860 Kg/m^3



(a) Open-end Cylindrical Coil Spring (b) Open-end conical Coil Spring (c) Open-end variable outer diameter coil spring

Fig. 3.2 Mesh Structure on Coil Spring Geometries

Table-3.3 Number of Nodes and Elements Generated on the Geometries

Geometries of Coil Spring	Number of Nodes	Number of Elements
Open-end Cylindrical Coil Spring	66324	13377
Open-end conical Coil Spring	58732	11844
Open-end variable outer diameter coil spring	40743	7983

One end of the spring is kept fixed and load is applied axially downward on the other end as shown in FIG.3.3. The spring geometry is then analysed for directional deformation along Z-axis along and for the total deformation as shown in Fig. 3.4. The geometries are also analysed for Von-mises stress and maximum principal stress as shown in Fig. 3.5.

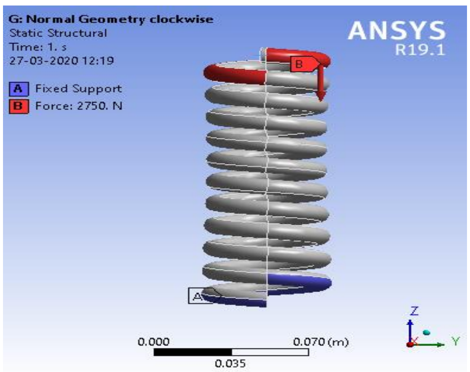
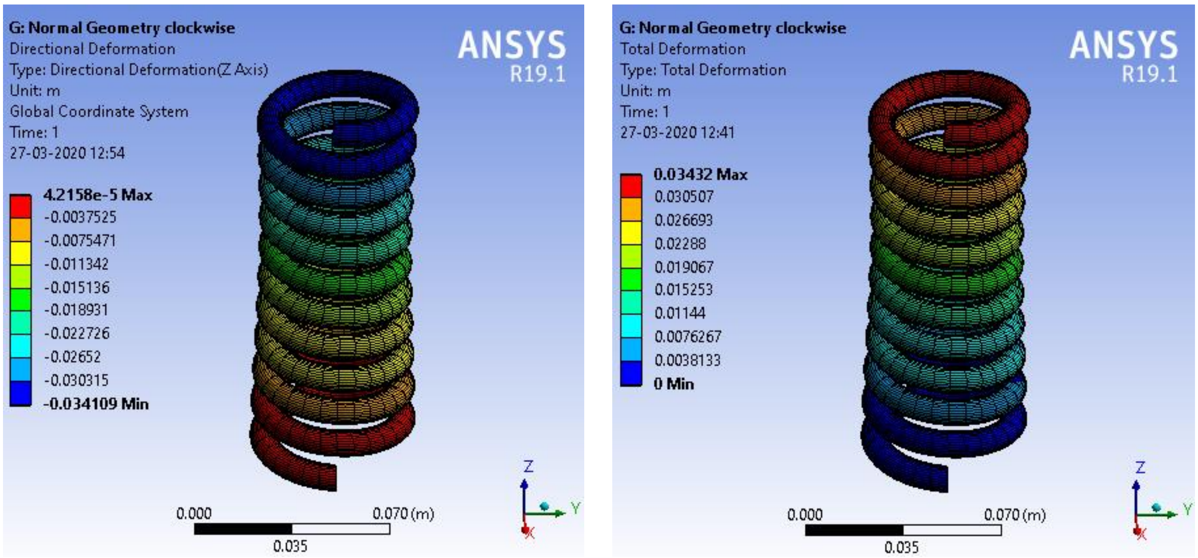
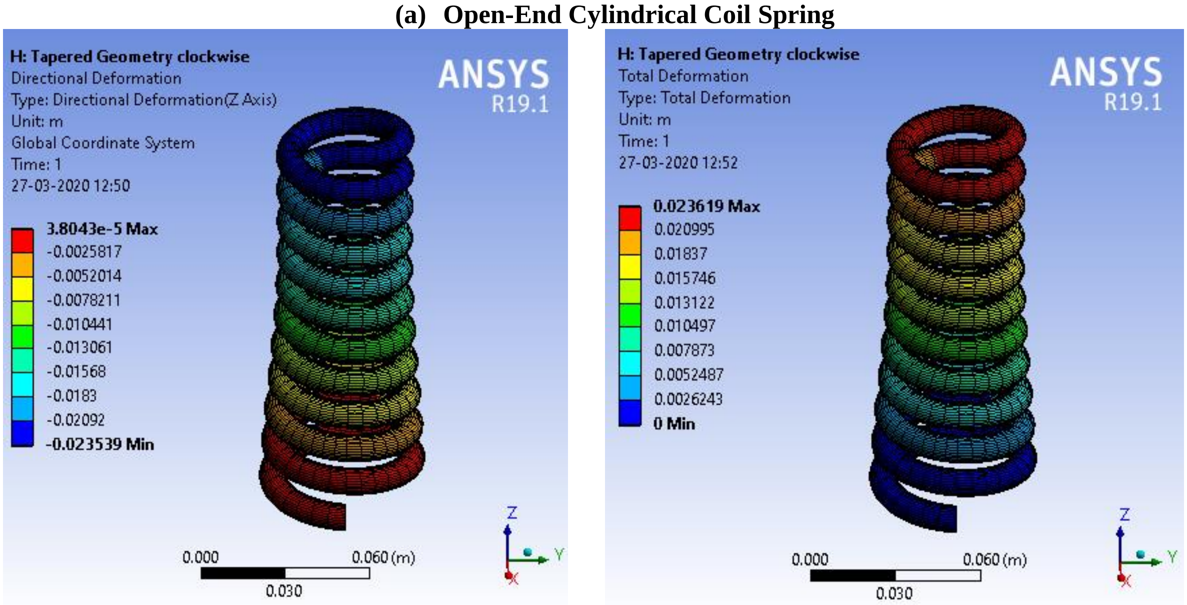


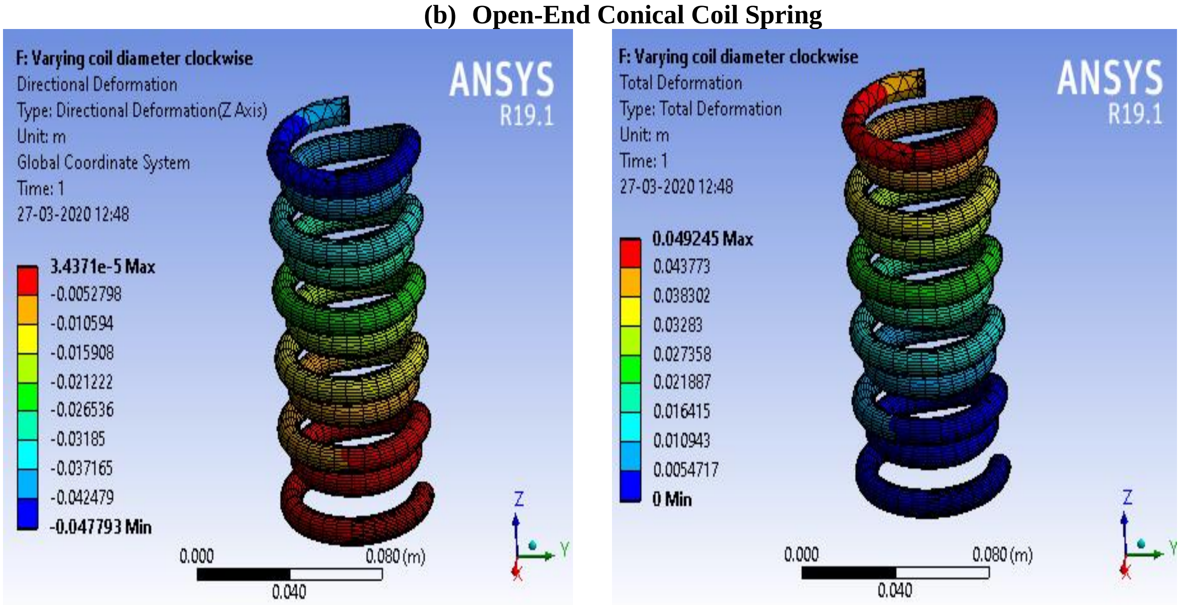
Fig. 3.3 Boundary Condition on the Coil Spring for the Analysis



(a) Open-End Cylindrical Coil Spring



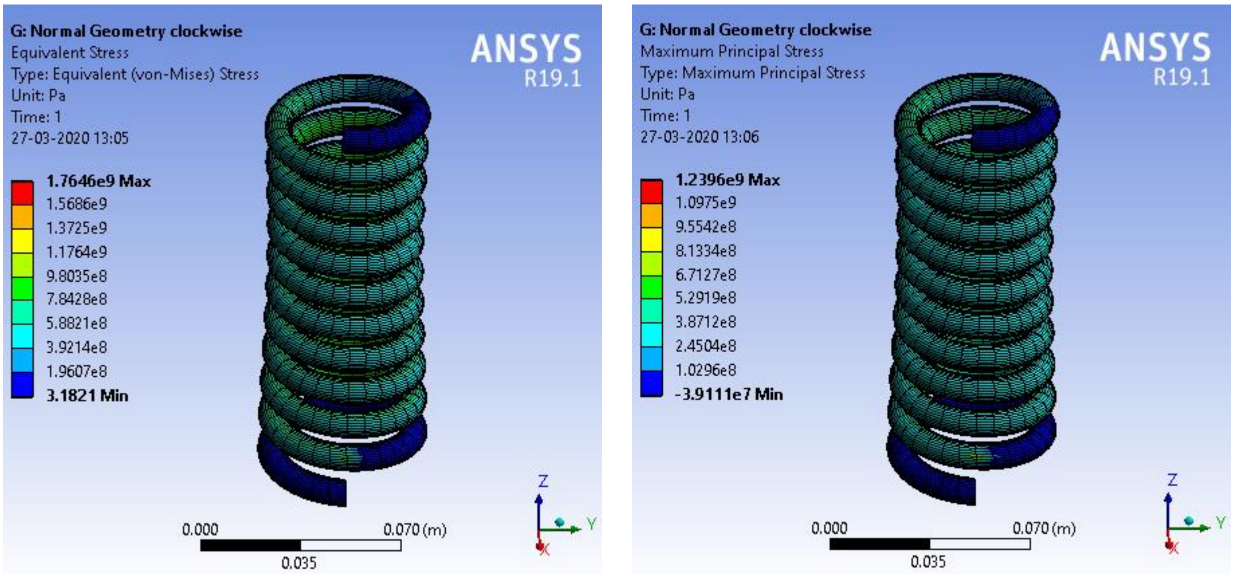
(b) Open-End Conical Coil Spring



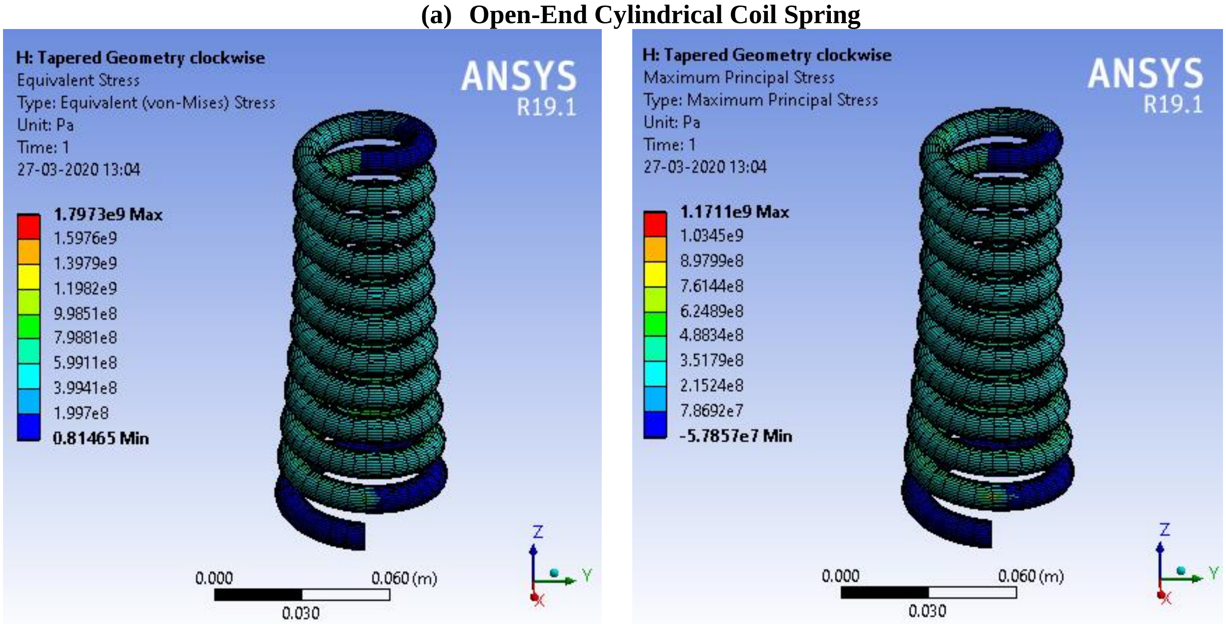
(C) Open End Variable Outer Diameter Coil Spring

Fig. 3.4 Axial and Total Deformation of Coil Spring Geometries

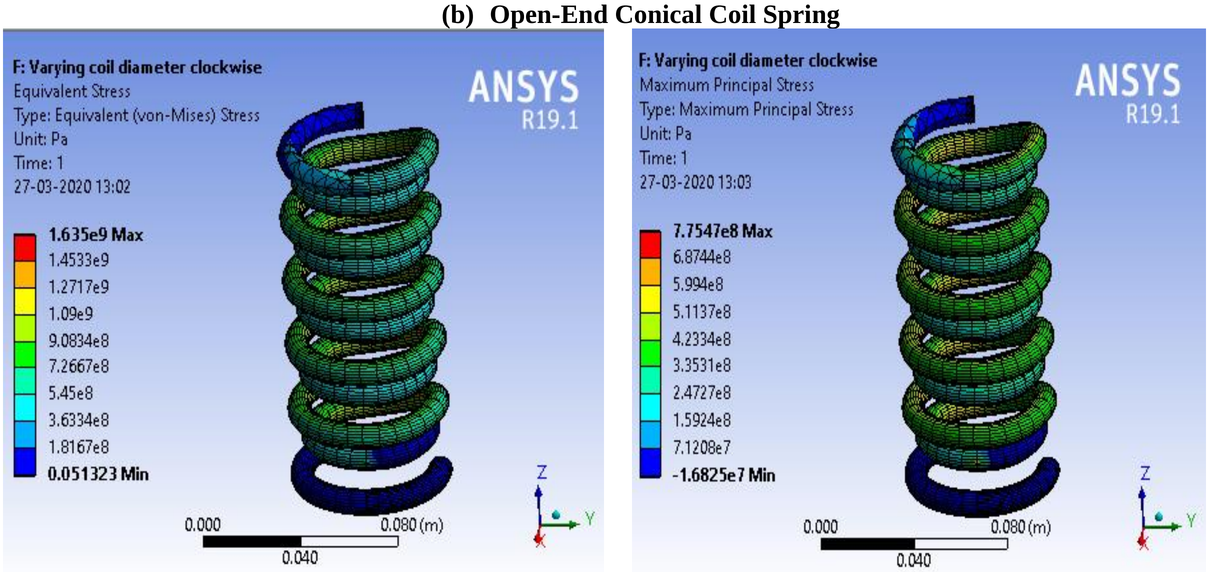
From Fig. 3.4 it is observed that conical spring is stiffer than the other two geometries whereas variable outer diameter coil spring is less stiff among all which allow more deflection in coils.



(a) Open-End Cylindrical Coil Spring



(b) Open-End Conical Coil Spring



(C) Open End Variable Outer Diameter Coil Spring

Fig. 3.5 Von-Mises and Maximum Principal Stress in Coil Spring Geometries

From Fig. 3.5 it is observed that stress generated in the variable outer diameter coil spring is lesser among all the geometries due to reduced stiffness.

Table-3.4. Comparison of All Three Geometries Based on Analysis

	(a) Open-end Cylindrical Coil Spring	(b) Open-end conical Coil Spring	(c) Open-end variable outer diameter coil spring
Total Deformation	34.32 mm	23.62 mm (-31.2%)	49.25 mm (+43.5%)
Directional Deformation	0.042 mm	0.038 mm (-9.5%)	0.034 mm (-19.0%)
Von-mises Stress	1764.6 MPa	1797.3 MPa (+1.9%)	1635 MPa (-7.4%)
Maximum Principal Stress	1239.6 MPa	1171.1 MPa (-5.5%)	775.5 MPa (-37.4%)
Factor of Safety (FOS)	0.889	0.873 (-1.7%)	0.960 (+8%)

The comparison of all the three geometries based on analysis is shown in TABLE-3.4. From the table, it is observed that the deformation of conical spring is 31.2% lower than the cylindrical spring because the applied load is at a smaller diametrical end. This reduced deflection increases the von-mises stress by 1.9 % therefore, the factor of safety is reduced by 1.7%. Whereas, the variable outer diameter coil spring reduces the von-mises stress by 7.4% and maximum principal stress by 37.4% and therefore increases the factor of safety by 8%.

CONCLUSION

The present work is focused to explore the various possible geometries of the helical coil spring and analysing the explored geometries of a suspension spring for motor vehicle subjected to the static condition of helical spring. In this work, three different geometries of the helical spring are generated and analysed for the maximum stress and deformation. Through the analysis, it is found that variable outer diameter coil spring has comparatively 7.4% and 37.4% low von-mises and maximum principal stress respectively. These reduced stresses in the spring increase the factor of safety by 8%, which indicates that the varying coil geometry is safer than the other two geometries.

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