# COMPARISON BETWEEN CONCENTRIC SPRINGS & HELICAL COIL SPRINGS: APPLICATION IN LOCOMOTIVE PRIMARY SUSPENSION

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***Abstract :*** Spring is a mechanical element which is used to reduce the shocks and vibrations in any vehicle. In Railways we have two different types of suspensions which absorb the shocks and vibrations and balance the entire system under dynamic conditions. The springs both primary and secondary suspensions which have been using for the passenger railway trains are single coil helical suspension springs. Here in this paper the railway primary suspension spring is considered for the study. The concentric springs which have more than one spring with same central axis can able to bear the loads and withstand to the stresses and deformations better compared to the single helical coil springs. So, here in this present study the locomotive primary suspension is replaced with the concentric springs which have two springs with same axis one inside of the other spring. Chromium vanadium steel material is taken for the analyses of both the concentric and helical coil springs. The both concentric spring and helical coil springs are designed in Solidworks modeling software. Static, modal analyses are conducted in finite element analysis commercial tool ANSYS 15.0. The stress distributions, displacements are analyzed in Static analysis. The natural Frequencies and mode shapes are analyzed in Modal analysis. Comparison of stresses, deformations and natural frequencies for both the single helical coil primary suspension spring and replaced concentric springs are studied to determine better spring.

***IndexTerms* – Concentric springs, Helical coil spring, Stresses, Deformations, Natural frequencies, ANSYS 15.0.**

## I. INTRODUCTION

Springs plays a vital role in railways. We have two spring suspensions one is primary suspension and other one is secondary suspension. Primary suspension is at the axle and secondary suspension is at the bolster. There are eight primary suspension springs and four secondary suspension springs for one bogie. These two suspension springs are made of chromium vanadium steel or chromium molybdenum steel. These suspension springs absorb the shocks and vibrations and reduces these dynamic vibrations during speed running of the vehicle which helps to balance the entire system. K.Pavan kumar [1] has conducted the static analysis for the primary suspension spring of locomotive and he proposed the new material which is 60Si2MnA steel material and replaced the chromium vanadium steel material and concluded 60Si2MnA steel material is better compared to chrome vanadium steel as its maintenance and cost is very less and got the lesser stresses. K. pavan kumar [2] has conducted the buckling analysis on primary spring of locomotive and he proposed the 20NiCrMo2 steel material by replacing the chrome vanadium steel material. From the analysis he concluded that 20NiCrMo2 steel material can bear more loads than chrome vanadium material and the maintenance and cost of 20NiCrMo2 steel material is less in India. Mehdi bakshesh [3] he has conducted the analysis for the car suspension spring by replacing the steel material with Kevlar epoxy, glass fiber epoxy, carbon epoxy. He has compared the numerical results with analytical results and concluded that the valves are in good agreement with each other and concluded Compared to steel spring composite spring has got the lesser stresses and he verified the various spring parameters like weight of the spring and optimized the parameters. Investigations and case studies on premature failures of locomotive coil spring [4, 5, 6, 7, 8, and 9]. Analyses are conducted by considering the composite material of combination steel and copper and magnesium for the better results [10]. Experimental and harmonic analysis is conducted for the loco spring when loco is at the uphill and when it is at the straight path numerically and experimentally by using strain gauges [11]. Optimization of helical spring by using genetic algorithm and particle swarm algorithm to optimize the spring parameters [12, 13]. A review on primary suspension of ICF bogie [14]. Weight optimization of the helical spring by replacing the solid spring with hollow spring and conducted the analysis and concluded that weight can be reduced by considering the hollow spring which can be able with stand the more stresses [15]. The contribution of this paper was to investigate the feasibility of composites which are carbon epoxy and aluminium silicon carbide materials applied for the primary locomotive spring other than chromium vanadium steel.

In the second section we introduce the spring dimensions which are required for the modeling using solid works and the material properties which are used for the analysis in ANSYS 15.0 and analytical calculations for the concentric and helical coil springs. In the third section we introduce 3D modeling procedure to design the springs and the analyses in ANSYS work bench. In the fourth section we have the results and discussion. In the fifth section we have the conclusions.

## II. SPRING DIMENSIONS, MATERIAL PROPERTIES AND ANALYTICAL CALCULATIONS:

### 2.1 Spring Material properties:

**Table 1:** Material properties of helical spring.

| Material property | Notations | Units | Chromium vanadium steel |
|---|---|---|---|
| Density | ρ | $Kg/m^3$ | 7860 |
| Young's modulus | E | Gpa | 207 |
| Poisson's ratio | υ | --- | 0.37 |
| Shear modulus | G | Gpa | 80.55 |
| Ultimate tensile strength | $\sigma_{uts}$ | Mpa | 1200 |
| Yield Strength | $\sigma_{ys}$ | Mpa | 1160 |
| Hardness | BHN | Mpa | 350 |

### 2.2 Dimensions for single coil helical spring and concentric spring:

**Table 2:** Dimensions of Railway concentric helical spring.

| Dimensions of Concentric helical spring | |
|---|---|
| **Description** | **Dimension valve** |
| Outer Wire diameter($d_1$) | 33.5mm |
| Outer Mean diameter($D_1$) | 208.5mm |
| Outer spring Total no of coils$(N_t)_1$ | 6.75 |
| Outer spring No of active coils($N_1$) | 5.25 |
| Inner Wire diameter($d_2$) | 22.733mm |
| Inner Mean diameter($D_2$) | 141.4705mm |
| Inner spring Total no of coils$(N_t)_2$ | 9.9469933658 |
| Inner spring No of active coils($N_2$) | 7.736550389 |
| Total Load acting (w) | 19.62KN |
| Free height (H) | 360mm |

**Table 3:** Dimensions of Railway primary helical spring.

| Dimensions of helical spring | |
|---|---|
| **Description** | **Dimension valve** |
| Wire diameter(d) | 33.5mm |
| Mean diameter(D) | 208.5mm |
| Total no of coils($N_t$) | 6.75 |
| No of active coils(N) | 5.25 |
| Load acting on each spring(W) | 19.62KN |
| Free height (H) | 360mm |

**2.3 Analytical calculations for the concentric and single helical coil springs:**
**2.3.1 Analytical calculations for the single primary helical coil spring:**

Maximum shear stress T= $k\,(8WD/\pi d^{\,3})$ (1)

K= Wahl's stress factor (4C-1/4C-4) + (0.615/C) (2)

Where $C$ = D/d = spring index= 208.5/33.5 = 6.2238

Now $k$ = 1.2424

$T$ = 1.2424 x (8 x 19.62 x 1000 x 208.5)/ ($\pi$ x $33.5^3$)

Maximum shear stress $T$ = 344.2486 MPa

Deflection of the spring = $\delta = 8WD^3N/Gd^4$ (3)

= 8 x 19.62 x 1000 x 6.75 x $208.5^3$ /80,000.55 x $33.5^4$= 74.13 mm.

**2.3.2 Analytical calculations for the concentric helical coil spring:**

Outer Wire diameter ($d_1$) = 33.5mm
Outer Mean diameter ($D_1$) = 208.5mm
Outer spring Total no of coils $(N_t)_1$ = 6.75
Outer spring No of active coils ($N_1$) = 5.25
$d_1 / d_2$ = (C/C-2) (1)
Where C = spring index
$D_1/d_1 = D_2/d_2 = C$ (2)
$D_1/d_1$ = C = (208.5/33/5) = 6.223
Therefore, $d_1/d_2$ = 1.4734
$d_2$ = (33.5/1.4734) = 22.733mm
$D_2 = d_2 * C$ = 6.223*22.733 = 141.4705 mm
$(N_t)_1\, d_1 = (N_t)_2\, d_2$ (3)
$(N_t)_2$ = (6.75*33.5/22.733) = 9.946993358
$N_1\, d_1 = N_2\, d_2$ (4)
(5.25)(33.5) = $N_2\, d_2$
$N_2$ = (5.25*33.5/22.733) = 7.736550389
Therefore, Inner Wire diameter ($d_2$) = 22.733 mm
Inner Mean diameter ($D_2$) = 141.4705 mm
Inner spring Total no of coils $(N_t)_2$ = 9.946993358
Inner spring No of active coils ($N_2$) = 7.736550389

Total load = W = $W_1 + W_2$ = 19.62 KN
$W_1/W_2 = (d_1/d_2)^2$
$W_1/W_2$ = 2.17158
$W_1$ = 2.17158 $W_2$

$2.17158\ W_2 + W_2 = 19.62KN$
$W_2 = 6.18619$ KN = Axial force transmitted by inner spring
$W_1 = 13.43380889$ KN= Axial force transmitted by outer spring
K= Wahl's stress factor (4C-1/4C-4) + (0.615/C) (5)
K = 1.242422
$T_1 = k\ (8W_1C/\ \pi d_1^2)$ (6)
$T_1 = 235.677\ N/mm^2$
$T_2 = k\ (8W_2C/\ \pi d_2^2)$ (7)
$T_2 = 235.6778\ N/mm^2$
Therefore, $T_1 = T_2$
Where $T_1$ and $T_2$ = Maximum shear stresses for inner and outer springs

Deflection of outer spring = $\delta_1 = (8W_1\ D_1^3\ N_1\ /Gd_1^4)$ (8)

$\delta_1 = 50.75mm$

Deflection of inner spring = $\delta_2 = (8W_2\ D_2^3\ N_1\ /Gd_2^4)$ (9)

$\delta_2 = 50.75$ mm

Therefore, $\delta_1 = \delta_2$

## III. MODELING AND ANALYSES OF CONCENTRIC & SINGLE HELICAL COIL SPRINGS:

### 3.1 Modeling of concentric and helical coil primary suspension springs in solidworks:

The springs are designed in solid works with the dimensions in the Table 2 and Table 3. Draw the wire diameter, mean diameter in sketcher. After that select the helix option then give the free height, total number of coils and by choosing clockwise or anti clockwise direction and Select the constant pitch option in the helix option then exit the sketcher then Take the sweep option by exiting in to the part features select the wire diameter then will get the helical spring with the required dimensions. The below figures 1 and 2 are the 3d models of the single and concentric helical coil springs.

**Figure 1:** 3D model of the single helical coil spring

**Figure 2:** 3D model of the concentric helical coil spring

**3.2 Analyses and boundary conditions:**

The part models which are drawn in the solid works has to import to the ANSYS work bench 15.0 in IGES format so as to conduct the different analyses after meshing the imported part designs by giving proper boundary conditions by providing the material properties of chromium vanadium steel. Below figures 3 and 4 are the finite element models of the concentric and single primary helical coil springs.

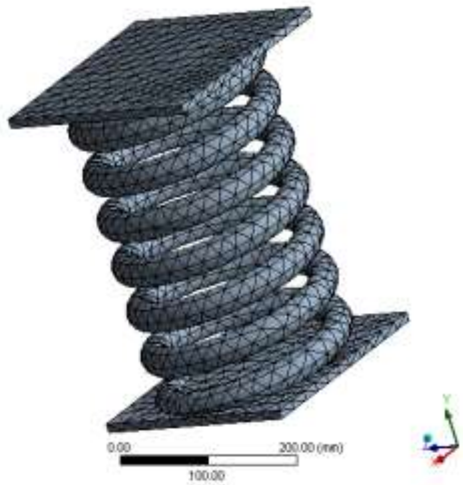


**Figure 3:** Finite element meshing model of single helical spring


**Figure 4:** Finite element meshing model of concentric helical Spring

**3.2.1 Static Analysis:**

Static analysis performs the calculations for the static loads which we applied on the component at the static position. It doesn't include an inertial effect (mass and damping).Doesn't consider a time varying force. In static analysis we can, however include steady inertia loads and time varying loads that can be considered as static equivalent loads. From static analysis we can attain the deformations, different types of stresses in static position without applying any external forces and inertial effects and damping effects. We don't apply the dynamic loads in static analysis.

**Boundary conditions in static analysis:**

1. One end of the spring is fixed.
2. Apply 19.62KN axially downwards on top of the spring.

Below are the figures for the boundary conditions applied on the concentric and single helical springs for conducting the static analysis.

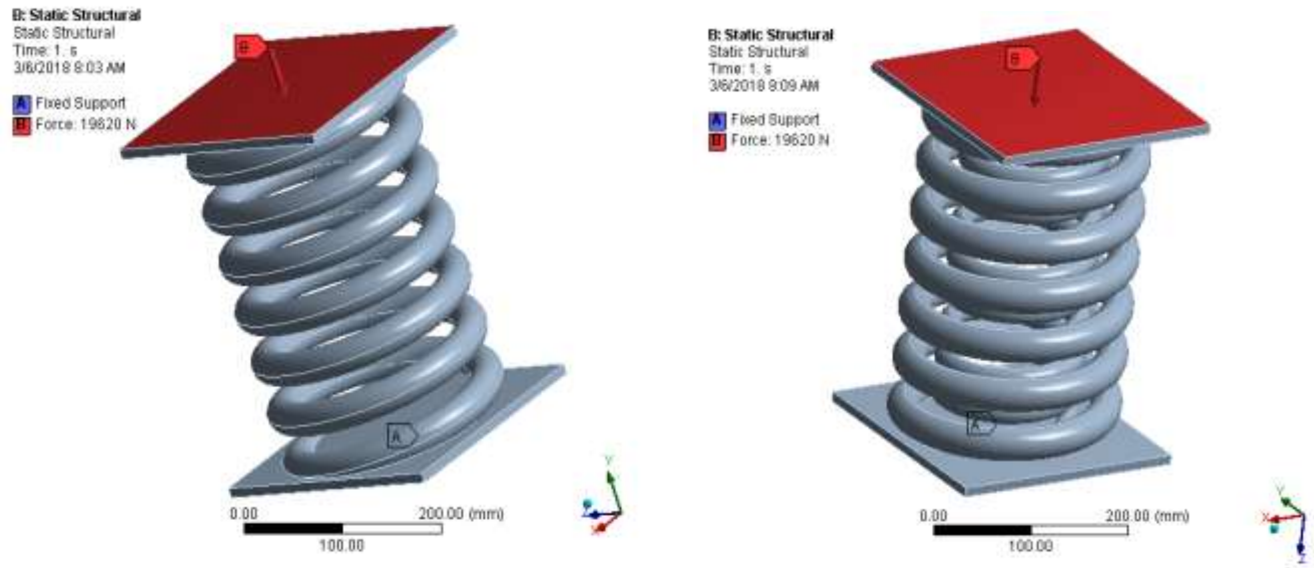


**Figure 5:** Boundary and loading conditions acting on the concentric and single helical primary suspension springs in static position.

### 3.2.2 Modal analysis:

It is the basic dynamic analysis. In this we can determine the different mode shapes at different natural frequencies of an object or structure during free vibration. Where we can obtain the deformations of objects at different natural frequencies for a particular mode shape. We also can obtain the configurations of the mode shapes for a particular deformation and natural frequency. Mode shapes describe the configurations in to which a structure will naturally displace. The number of modes is independent of the material properties and boundary conditions of the applied on the component. Each mode is defined by a natural frequency, Modal damping, and a mode shape. If either the material properties or the boundary conditions of a structure change its mode shapes will change. The observed displacement at angular frequency $\omega_n$ is called operating deflection shapes also called as mode shapes. The modal analysis depends on the mass and stiffness of the body not on the forces acting on it i.e. $(K-M\omega^2)=0$.

**Boundary conditions in modal analysis:**

1. Apply fixed support on one end of the spring

Below are the figures gives the boundary conditions applied in modal analysis.

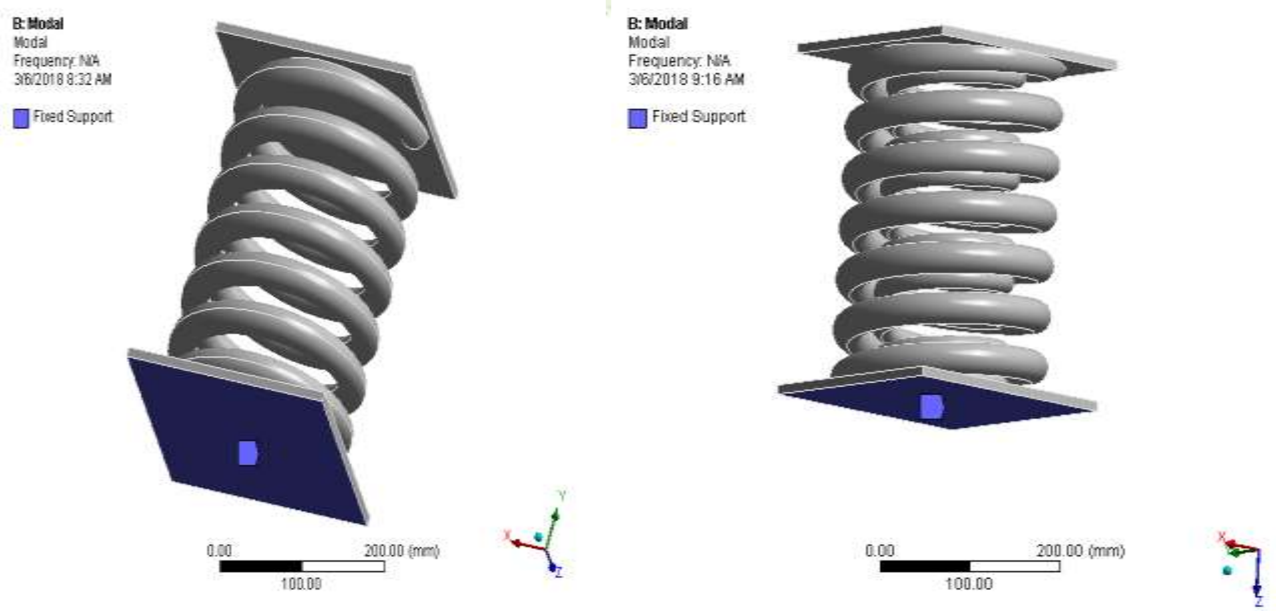


**Figure 6:** Boundary conditions for single helical coil and concentric springs in modal analysis

## IV. RESULTS AND DISCUSSION:

Static and modal analyses are carried out for the both single and concentric helical coil springs to obtain the better suspension spring by using chromium vanadium steel material for both the springs. In static analysis graphs are drawn between the vonmises stresses, deformations vs. existing single helical coil spring and new modified concentric spring. In modal analysis graphs are drawn between the natural frequencies, deformations vs. existing single helical coil spring and new modified concentric spring.

### 4.1 Static analysis results:

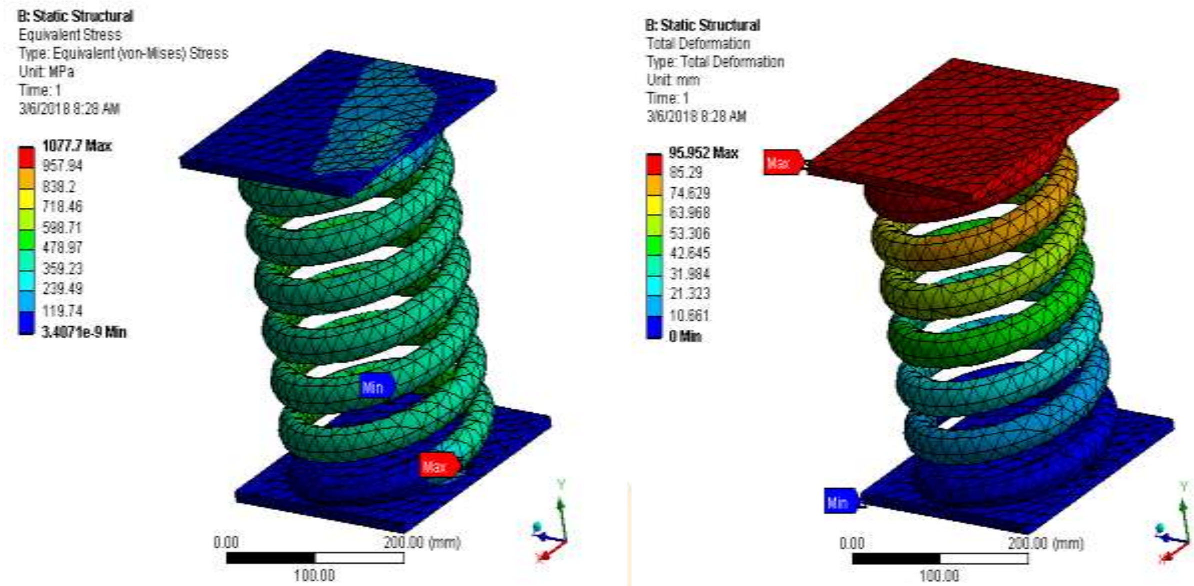


**Figure 7:** Vonmises stress distribution and deformation for locomotive primary single helical coil suspension spring

Figure 7 depicts the Vonmises stress distribution and deformation for locomotive primary single helical coil suspension spring is 1077.77 Mpa at inner side of the coils and maximum deformation is 95.952 mm at top of the spring coil where load is applied.

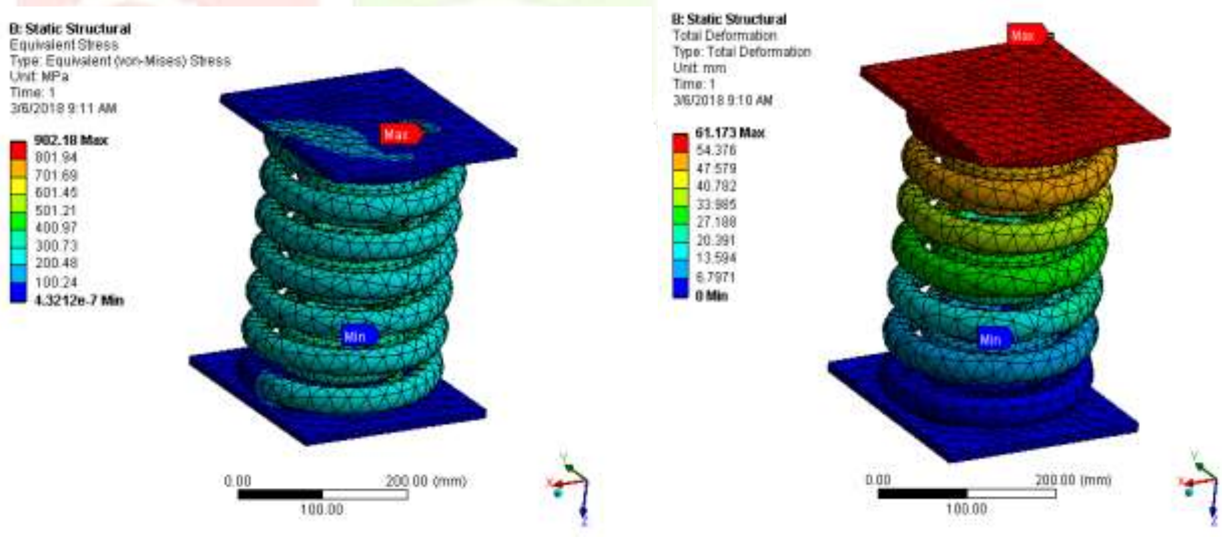


**Figure 8:** Vonmises stress distribution and deformation for locomotive concentric helical coil suspension spring

Figure 8 depicts the Vonmises stress distribution and deformation for concentric helical coil suspension spring is 902.18 Mpa at inner side of the coils and maximum deformation is 61.173 mm at top of the spring coil where load is applied.

The maximum equivalent vonmises stresses and maximum deflections for the two springs are shown in the below Figure 9 and Figure 10 graphs.

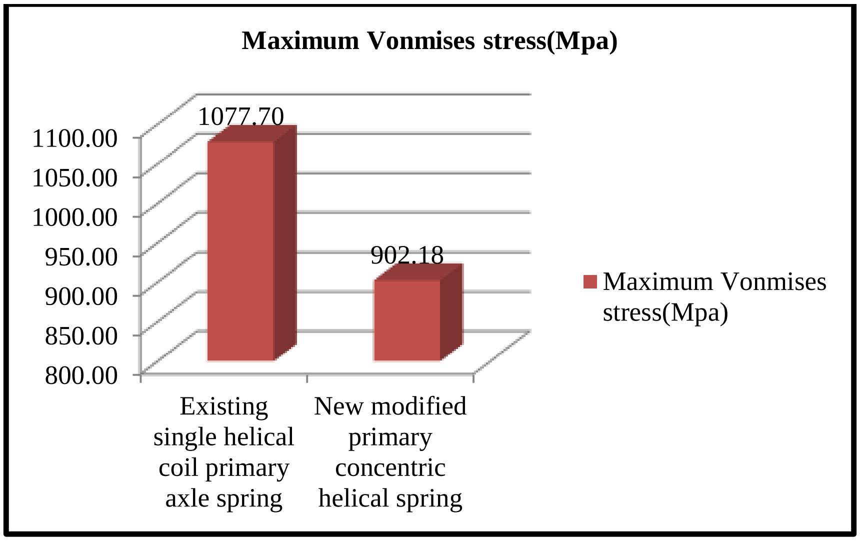


**Figure 9:** Maximum vonmises stresses for single helical coil and concentric springs

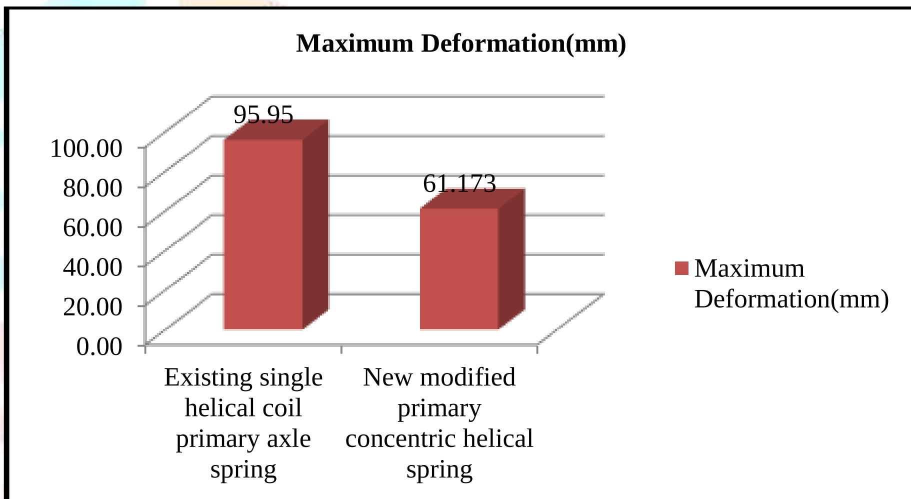


**Figure 10:** Maximum deformations for single helical coil and concentric springs

**4.2 Modal analysis results:**

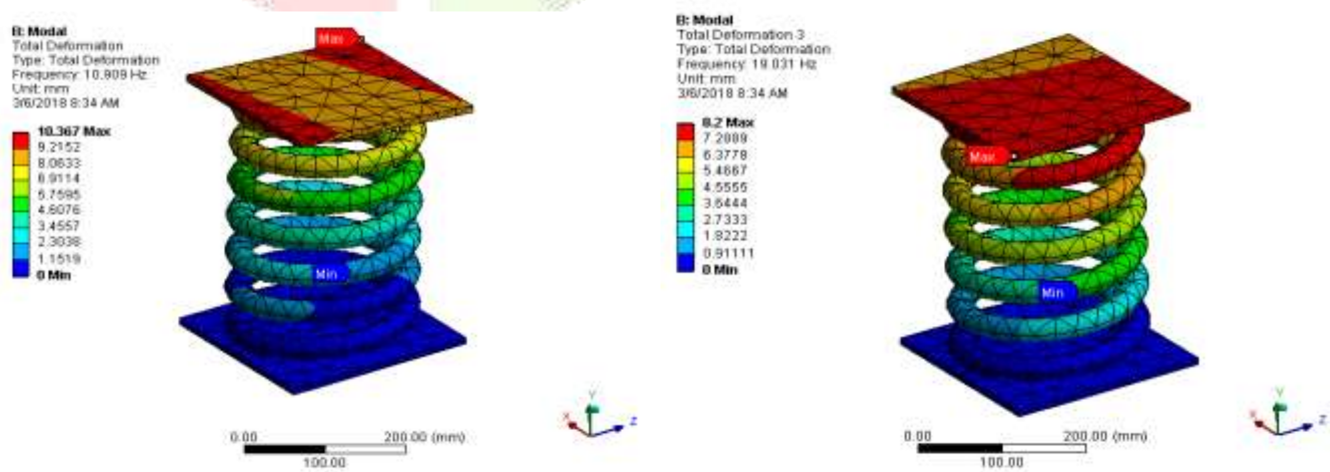


**Figure 11:** Mode shapes for locomotive primary single helical coil suspension spring

The five number of mode shapes are extracted in modal analysis. Figure 11 depicts the natural frequencies and deformations for the modes 1 and 3 and their mode shapes and their deformations for single helical coil spring.

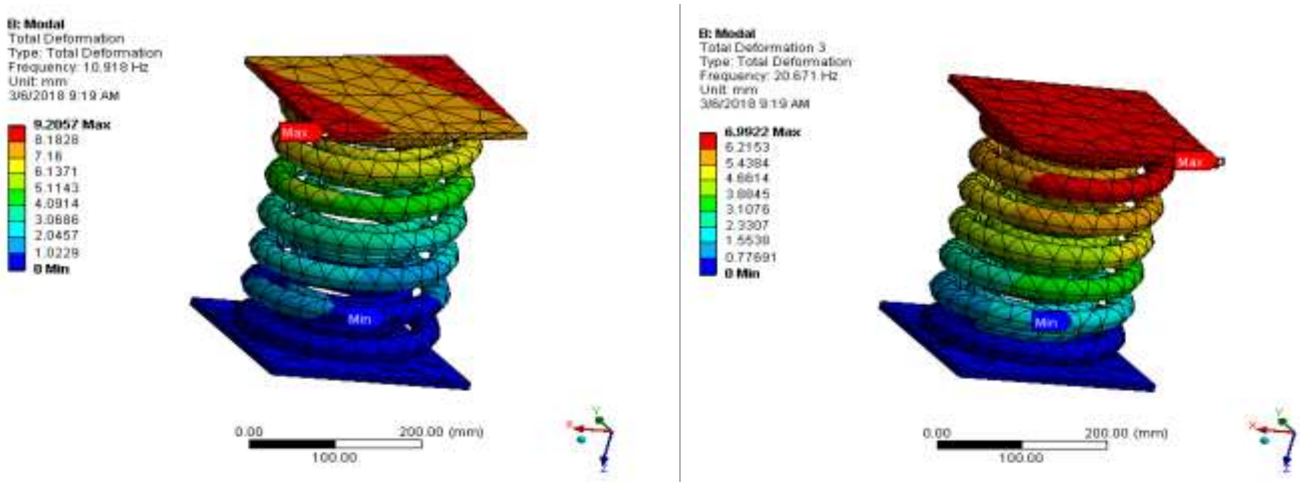


**Figure 12:** Mode shapes for concentric helical coil suspension spring

The five number of mode shapes are extracted in modal analysis. Figure 12 depicts the natural frequencies and deformations for the modes 1 and 3 and their mode shapes and their deformations for concentric spring.

Figure 13 and Figure 14 graphs depicts the natural frequencies and their deformations for the two springs

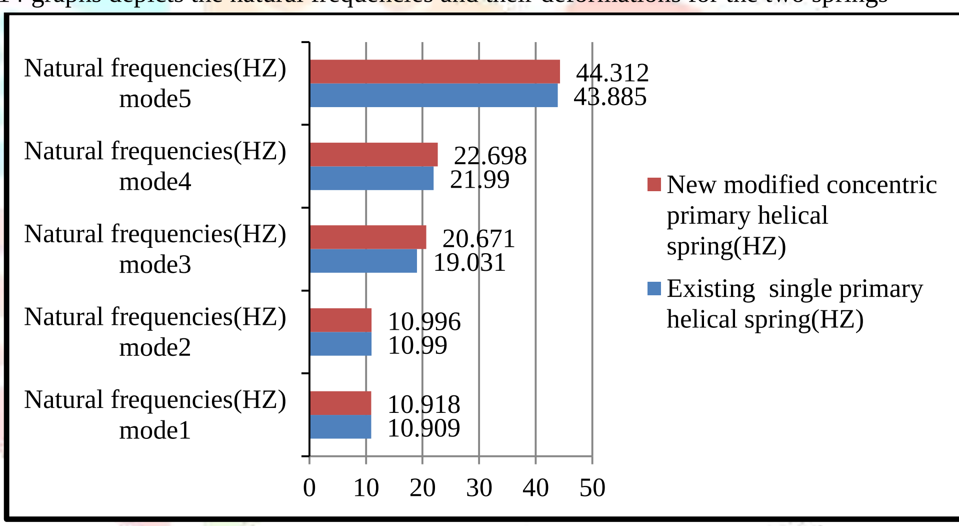


**Figure 13:** Natural frequencies for single helical coil and concentric springs

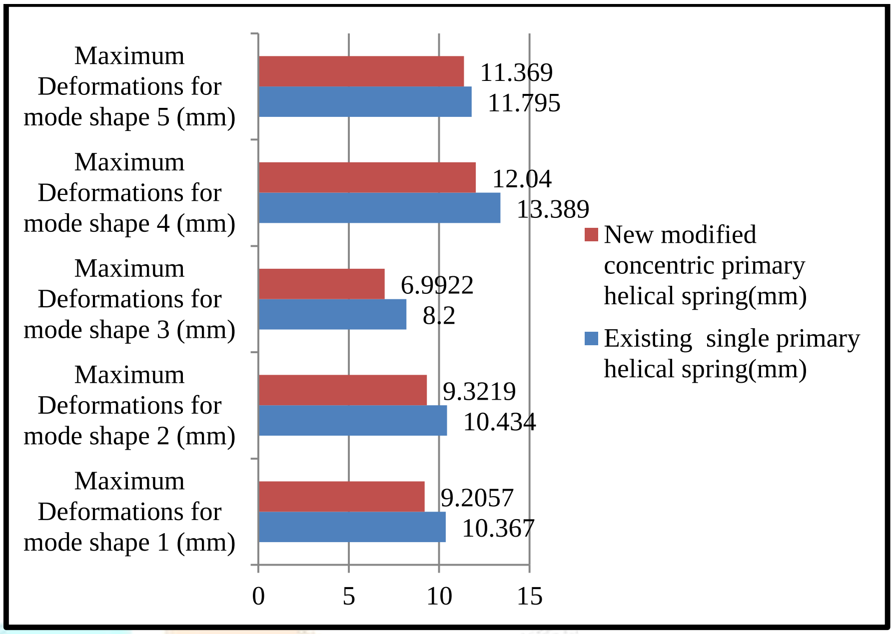


**Figure 14:** Maximum deformations for single helical coil and concentric springs with respect to their natural frequencies and mode shapes

## V. CONCLUSIONS

Table 4: Analyses results for existing single primary helical coil spring and new modified concentric helical spring

| Analyses results | | Existing single primary helical coil spring | New modified concentric helical spring |
|---|---|---|---|
| Static analysis | a) Maximum vonmises stress(Mpa) | 1077.70 | 902.18 |
| | b) Maximum deformation(mm) | 95.952 | 61.173 |
| Modal analysis | a) Natural frequency for Mode shape 1 (Hz) | 10.909 | 10.918 |
| | b) Maximum deformation for Mode shape 1(mm) | 10.367 | 9.2057 |
| | c) Natural frequency for Mode shape 2 (Hz) | 10.99 | 10.996 |
| | d) Maximum deformation for Mode shape 2(mm) | 10.434 | 9.3219 |
| | e) Natural frequency for Mode shape 3 (Hz) | 19.031 | 20.671 |
| | f) Maximum deformation for Mode shape 3(mm) | 8.2 | 6.9922 |

- In this study the analysis is carried out for the primary helical coil spring of locomotive and concentric springs for maximum vonmises stresses, deformations in static analysis, for natural frequencies in modal analysis and for maximum vonmises stresses, for various materials analyzed in ANSYS 15.0.
- It is observed that the maximum vonmises stresses occurred at the inner side of the coils and maximum deformation occurred at the outer part of the coil spring where maximum load is applied for both the springs.
- From the study it is observed that concentric springs have got less stresses and deformations compared to single helical spring in static analysis.
- It is also observed that the natural frequencies are better for concentric springs compared to single helical spring in modal analysis.
- It is also observed that the deformations which are deflections are better for concentric springs compared to single helical spring in modal analysis.
- Therefore concentric springs are better than single helical coil springs for locomotive suspension springs.

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