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Finite Element Analysis of Locomotive Primary Suspension by Using Composite Materials

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ABSTRACT

Springs Are The Elastic Components Which Are Used To Absorb The Shocks And Vibrations During The Dynamic Motion Of The Locomotive. These Springs Helps To Stabilize The Motion Of The Train On The Track By Reducing Vibrations And Deflections. We Have Primary And Secondary Suspension Springs In The Locomotive So As To Balance The Entire System. Chromium Vanadium Steel Has Been Using As The Railway Spring Material. But The Present Generation Needs Everything Sleek And Light In Weight. Due To The Rapid Development In Material Science And Manufacturing Technology The Usage Of Composites Become Usual In Each And Every Field To Make Everything Light In Weight. Here In This The Railway Primary Suspension Spring Is Considered For The Study By Applying The Composites. Carbon Epoxy and Aluminium Silicon Carbide Composite Materials Are Taken For the Analysis Other Than Chromium Vanadium Steel. The Spring Is Modeled 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 The Primary Spring Are Studied To Determine Better Material.

***Keywords* –** ANSYS 15.0, Deformations, Natural Frequencies, Primary Helical Coil Spring, Stresses.

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I. INTRODUCTION

Railways Are Using Steel Material For Suspension Spring Materials. In Present Scenario The Usage Of Composite Materials In Every Sector Has Been Increasing Day By Day Due To The Rapid Changes In The Evolution Of The Materials And Manufacturing Methods. Steel Has Been Using As The Spring Material For Decades Due To Its Elastic Properties Which Can Able To Reduce The Shocks And Vibrations And Regain Its Original Position. 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 Spring. In The Third Section We Introduce 3D Modeling Procedure To Design The Spring 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 Dimensions:

TABLE 1: 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

2.2 Analytical Calculations For The Helical Spring:

Maximum Shear Stress = $K\,(8WD/\Pi d^{3})$
K= Wahl's Stress Factor (4C-1/4C-4) + (0.615/C)
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)/ (Π X 33.5^3)
Maximum Shear Stress T = 344.2486 Mpa

Deflection of the spring $\delta = 8WD^3N/Gd^4$
= 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 Material Properties:

Chromium Vanadium Steel Is The Actual Material Using For The Spring By Railways. Here We Considered Carbon Epoxy and Aluminium Silicon Carbide Composite Materials for the Analysis. Chromium Vanadium Steel And Aluminium Silicon Carbide Materials Consist Of Isotropic Properties While Carbon Epoxy Consists Of Orthotropic And Transverse Isotropic Material Properties.

TABLE 2: Material Properties of Carbon Epoxy (N=Notations)

Material property	N	Units	Carbon epoxy
Density	ρ	Kg/m^3	1.6e3
Young's modulus	E_1	Gpa	140.4
Young's modulus	E_2, E_3	Gpa	10.344
Poisson's ratio	υ_{12}, υ_{13}	---	0.28
Poisson's ratio	υ_{23}	---	0.469
Shear modulus	G_{12}, G_{13}	Gpa	5.183
Shear modulus	G_{23}	Gpa	3.520
CTE	α_1	/k	6.32e-7
CTE	α_2, α_3	/k	4.06235e-4
Longitudinal Thermal conductivity	K_1	w/mk	14.44
Transverse Thermal conductivity	K_2,K_3	w/mk	0.24844
Specific heat	C	J/kg-k	1200

TABLE 3: Material Properties of Chromium Vanadium Steel and Aluminium Silicon Carbide (N=Notations)

Material property	N	Units	Chromium vanadium steel	Aluminium silicon carbide
Density	ρ	Kg/m^3	7860	2800
Young’s modulus	E	Gpa	207	115
Poisson’s ratio	υ	---	0.37	0.3
Shear modulus	G	Gpa	80	44.23
Ultimate tensile strength	σ_{uts}	Mpa	1200	700
Yield Strength	σ_{ys}	Mpa	1160	464
Hardness	BHN	Mpa	350	210

III. MODELING AND ANALYSES OF HELICAL COIL SPRING

3.1 Modeling of Helical Coil Spring in Solidworks:

The Spring Is Designed In Solid Works With The Dimensions In The Table 1. 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 Figure Is the 3d Model of the Helical Coil Spring.

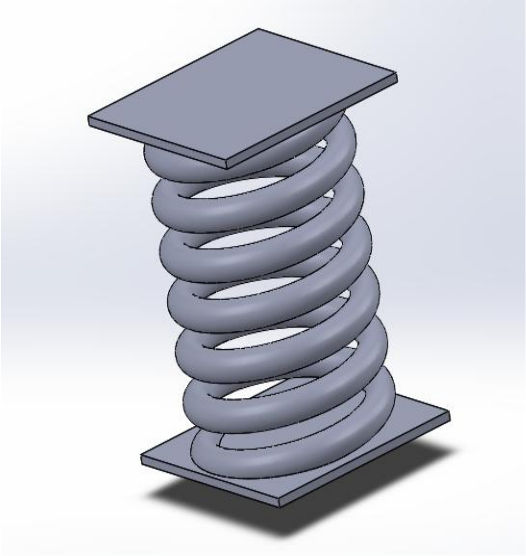

Figure 1: 3D Model of the Helical Coil Spring

3.2 Analyses and Boundary Conditions:

The Part Model Which Was 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 Design By Giving Proper Boundary Conditions For Various Materials By Providing The Material Properties. Below Is The Finite Element Model Of The Primary Helical Coil Spring.

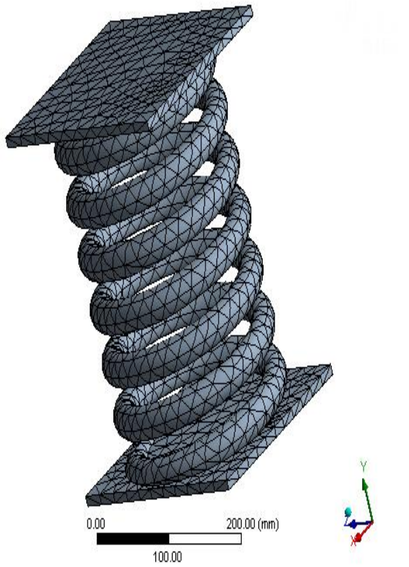

Figure 2: Finite Element Meshing Model of Primary Helical Spring

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 Is The Figure For The Boundary Conditions Applied On The Spring For Conducting The Static Analysis.

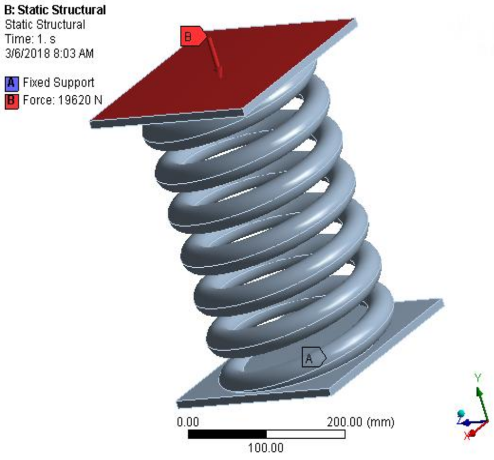

Figure 3: Boundary and Loading Conditions Acting On the spring in Static Position.

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 Ω_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 Is The Figure Gives The Boundary Conditions Applied In Modal Analysis.

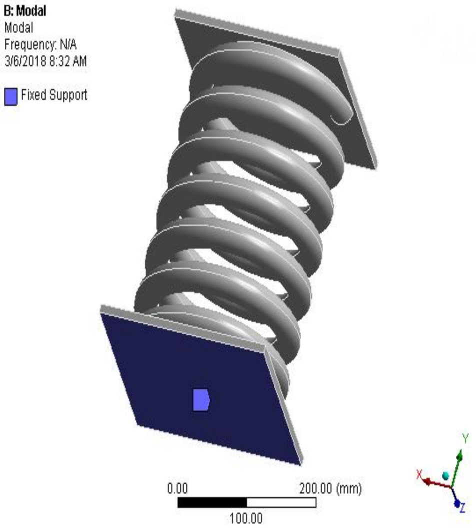

Figure 4: Boundary Conditions for Modal Analysis.

IV. RESULTS AND DISCUSSION

Static And Modal Analyses Are Carried Out For All The Three Materials To Obtain The Better Material For The Primary Helical Coil Spring. In Static Analysis Graphs Are Drawn Between the Vonmises Stresses, Deformations vs. Materials. In Modal Analysis Graphs Are Drawn Between the Natural Frequencies, Deformations vs. Materials.

4.1 Static Analysis Results:

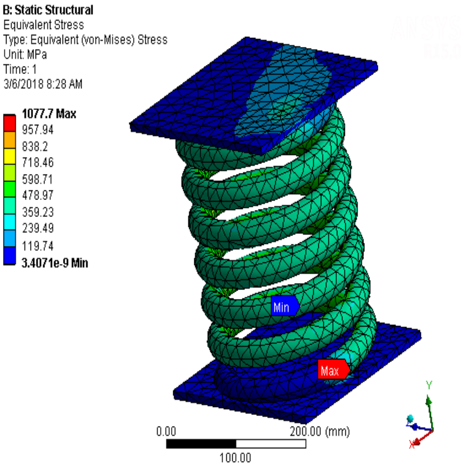

Figure 5: Vonmises Stress Distribution for Chromium Vanadium Steel

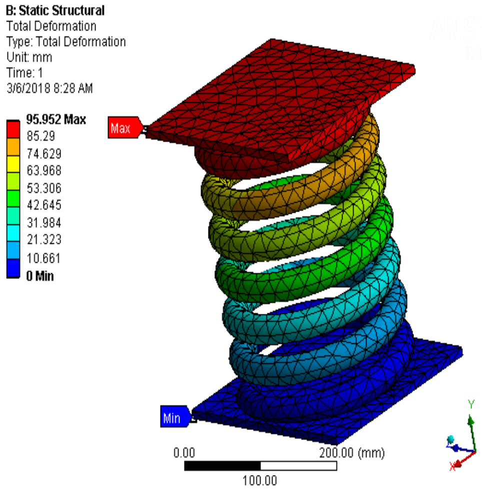

Figure 6: Deformations for Chromium Vanadium Steel.

Fig.5 And Fig.6 Depicts The Maximum Vonmises Stress Of Primary Helical Spring For AAR Chromium Vanadium Steel Material 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.

The Maximum Equivalent Vonmises Stresses and Maximum Deflections for the Remaining Two Materials Carbon Epoxy and Aluminum Silicon Carbide Materials Are Shown In the Below Fig.7 and Fig. 8 Graphs.

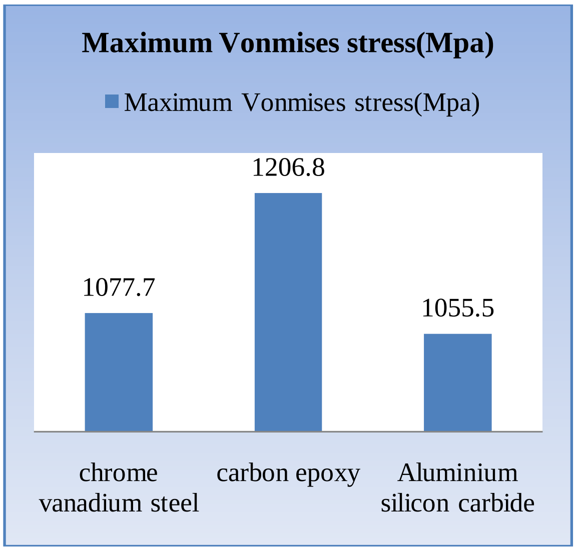

Figure 7: Maximum Vonmises Stresses for Various Materials.

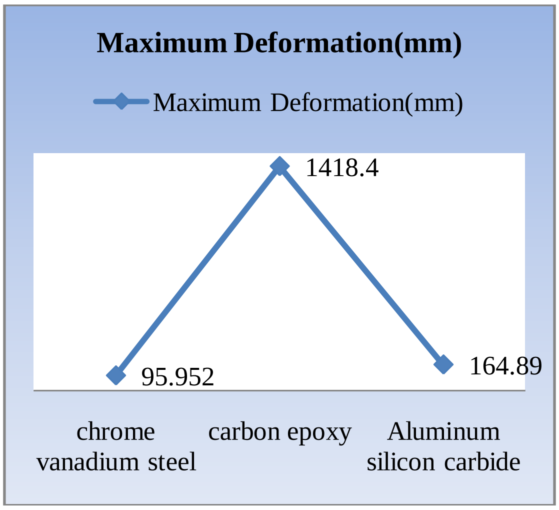

Figure 8: Maximum Deformations for Various Materials.

4.2 Modal Analysis Results:

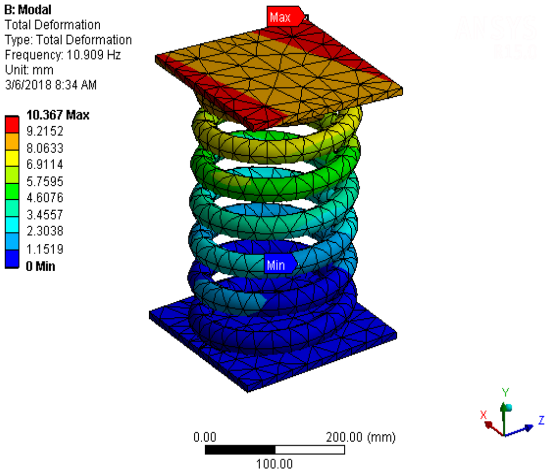

Figure 9: Mode Shape 1 for Chromium Vanadium Steel

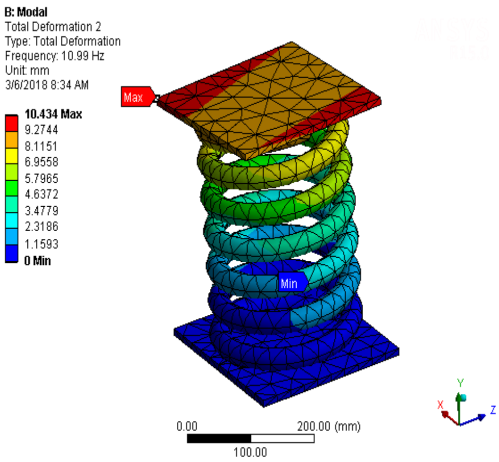

Figure 10: Mode Shape 2 for Chromium Vanadium Steel.

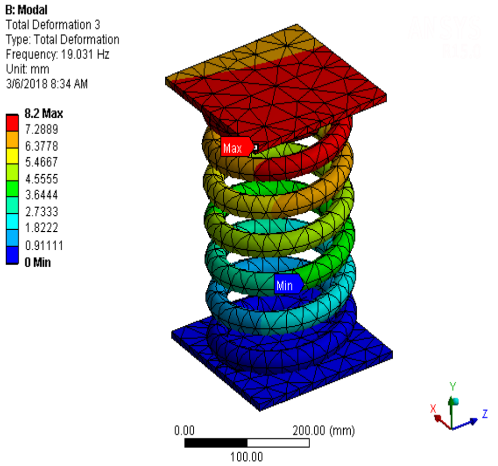

Figure 11: Mode Shape 3 for Chromium Vanadium Steel.

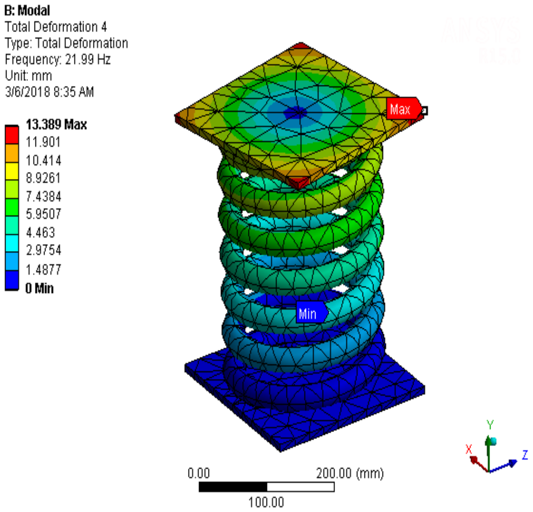

Figure 12: Mode Shape 4 for Chromium Vanadium Steel.

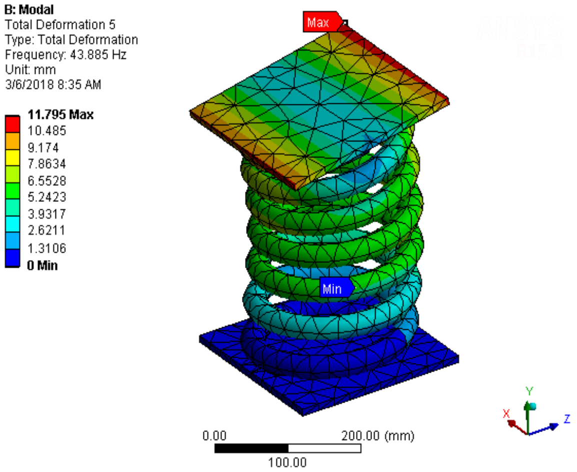

Figure 13: Mode Shape 5 for Chromium Vanadium Steel.

The Five Number Of Mode Shapes Are Extracted In Modal Analysis. Fig.9 To Fig.13 Depicts The Natural Frequencies And Deformations For All The Five Modes And Their Mode Shapes And Their Deformations.

The Mode Shapes and Deformations for Carbon Epoxy and Aluminum Silicon Carbide Materials Are Shown In the Below Fig.14 and Fig.15 Graphs.

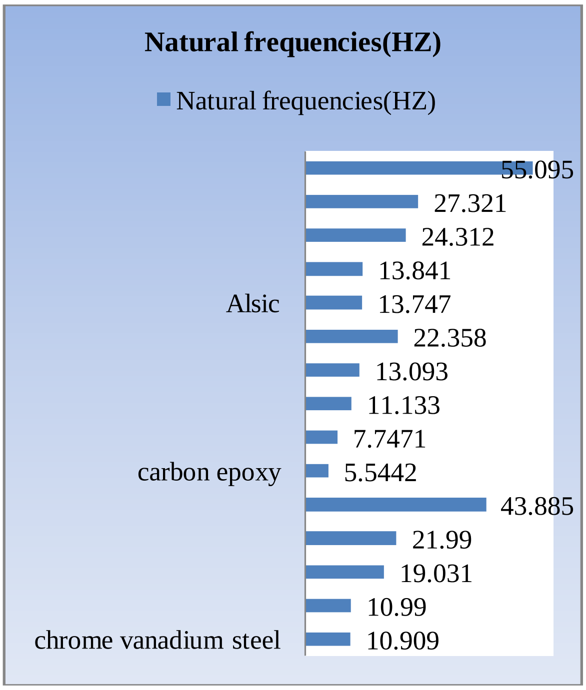

Figure 14: Natural Frequencies for Various Materials of Primary Helical Spring for 5 Modes. [Alsic = Aluminium Silicon Carbide]

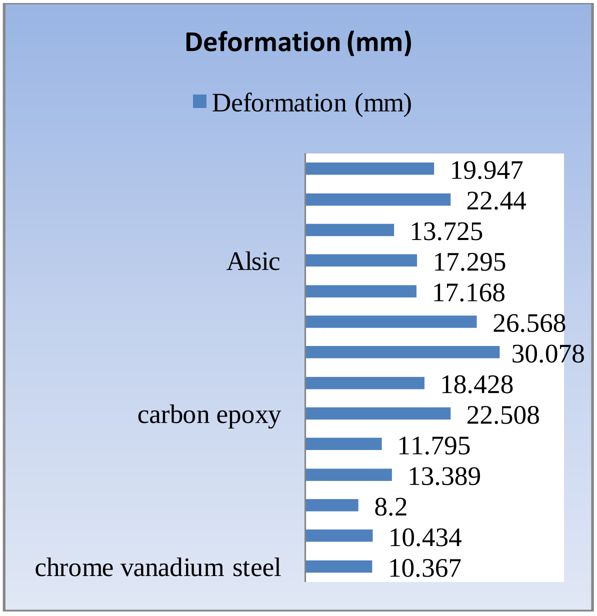

Figure 15: Maximum Deformations for Various Materials of Primary Helical Spring for 5 Modes. [Alsic = Aluminium Silicon Carbide]

V. CONCLUSIONS

- In This Study The Analysis Is Carried Out For The Primary Helical Coil Spring Of Locomotive 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 All The Materials.
- Chromium Vanadium Steel Has Got The Lesser Vonmises Stresses Than Carbon Epoxy And Aluminium Silicon Carbide Has Got The Lesser Stresses Than Chromium Vanadium Steel In Static Analysis.
- Chromium Vanadium Steel Has Got The Lesser Deformations Than Carbon Epoxy And Aluminium Silicon Carbide In Static Analysis.
- Chromium Vanadium Steel Has Got The Lesser Deformations And Better Natural Frequencies Than Carbon Epoxy And Aluminium Silicon Carbide In Modal Analysis.
- Chromium Vanadium Steel Is The Better Material Than Carbon Epoxy And Aluminium Silicon Carbide Even Though Alsic Has Got The Lesser Stresses In Static Analysis But Due To Its Less Young's Modulus And Less Stiffness Nature The Deformations Are Very High.

Table 4: Analyses Results.

Analyses results			**Chromium vanadium steel**	**Carbon epoxy**	**Aluminium silicon carbide**
Primary helical coil spring					
Static analysis	a)	Maximum vonmises stress(Mpa)	1077.77	1206.8	1055.5
	b)	Maximum deformation (mm)	95.952	1418.4	164.89
Modal analysis	a)	Natural frequency for Mode shape 1 (Hz)	10.909	5.5442	13.747
	b)	Maximum deformation for Mode shape 1(mm)	10.367	22.508	17.168
	c)	Natural frequency for Mode shape 2 (Hz)	10.99	7.7471	13.841
	d)	Maximum deformation for Mode shape 2(mm)	10.434	18.428	17.295
	e)	Natural frequency for Mode shape 3 (Hz)	19.031	11.133	24.312
	f)	Maximum deformation for Mode shape 3(mm)	8.2	30.078	13.725

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