Analysis of Helical Conical Spring by F.E.M and Analytical method

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***Abstract*— Spring is a mechanical component which is used in automobile industries and many other applications like as in some types of pen mechanism for writing. In the present study the finite element analysis of helical conical spring is carried out using ANSYS 15 and the material is spring steel according to specification of IS 4454 Grade 3. Conical Compression Springs are cone shaped springs designed to provide a near constant spring rate and a solid height lower than a normal spring The simulated results of the present study are compared with the available experimental data from a spring industry. The numerical simulation results for deformation and analytical stress are calculated under various loading conditions. It was found that that the simulated results for deformation and stress shows the good agreement with the available experimental data. In addition to the above analysis a fatigue analysis is also done using analytical method. The spring component which we used for analysis has 500,000 cycle duration. So for safety of spring we will ensure during analysis through analytical method that maximum stress generation in spring should be less than the spring fatigue strength corresponding to their generation cycle**

***Keywords*— Helical spring, FEM analysis, Stress analysis, fatique strength**

I. INTRODUCTION

A coil spring, also known as a helical spring, is a mechanical device which is typically used to store energy and subsequently release it, to absorb shock, or to maintain a force between contacting surfaces. They are made of an elastic material formed into the shape of a helix which returns to its natural length when unloaded. A.M Whal stated about mechanical spring that it is a kind of elastic body which distorted it's shape or deflected under a load condition (to absorb energy) and after removing the load condition it regain its original shape [1]. Further he goes to classify the main functions of spring as one of the four things which was to apply force, to provide load control, to support the structure, to absorb the shock. A coil spring may also be used as a torsion spring: in this case the spring as a whole is subjected to torsion about its helical axis. The material of the spring is thereby subjected to a bending moment, either reducing or increasing the helical radius. In this mode, it is the Young's Modulus of the material that determines the spring characteristics, Lath martensitic structures usually have a higher strength, and improving toughness [11]. Coil springs are commonly used in vehicle suspension. These springs are compression springs and can differ greatly in strength and in size depending on application. A coil spring suspension can be stiff to soft depending on the vehicle it is used on. Coil spring can be either mounted with a shock absorber or mounted separately. Concomitantly, work hardening takes place. Also, the accompanying surface roughness may initiate undesirable cracking which may be countered by the residual compressive stresses. However, these stresses can fade during cycling with the surface stress concentrations becoming more dominant than the residual stress field, allowing the fatigue cracks to initiate and subsequently propagate.[12][13][14][15].The surface coating on component is also used to increase the fatigue strength like Coating materials deposited onto various substrates have been extensively used in the aerospace, automotive and petrochemical fields, in recent years. Basically, micro cracks density in the material of component is related to the high tensile residual internal stresses, hardness and corrosion resistance.

II. MATERIAL

The material taken for the front axle is structural steel. This material has following properties

1. *MECHANICAL PROPERTIES:*

Table.1 Mechanical properties of spring material

Young's Modulus	210790 MPa
Poisson's Ratio	0.29526
Bulk Modulus	171590 MPa
Shear Modulus	81370 MPa
Tensile Ultimate Strength	1430 MPa

2. *Chemical properties:*

Table.2 Chemical properties of Spring material

Carbon percent	0.75 - 1.0
Silicon percent	0.15 – 0.35
Manganese Max percent	0.8
Sulphur, Max percent	0.030
Phosphorus, Max percent	0.030
Sulphur + Phosphorus, Max percent	0.050
Copper, Max percent	0.12

III. EXPERIMENTAL DETAIL

The test of industrial spring deflection and fatigue life is carried out in a computerized spring endurance testing machine. The details of machine and component are below.

Fig.1 computerized spring endurance testing machine

1. *Machine specification:*

STROKE : 93.60
RPM : 180
The data detail is according to IS4454 grade 3.

Table.3 Spring design specification

CHARACTERISTICS	SPECIFIED
Wire Diameter	7.5 mm
I.D 1 (lower internal diameter of one side of spring)	33.5 + 0.5mm
I.D 2 (higher internal diameter of other side of	40.5 + 0.5mm

spring)	
O.D (outer diameter of spring)	56.5mm MAX
Free length	238.5±2.0mm
Coil direction	R.H (Right hand)
Ends	Squared and ground ends (270^0)
Total coils	17.6
Solid length	133.7mm MAX

The experimental results obtained on computerized endurence testing machine corresponding to various load condition.

Table.4. Experimental detail of Load vs Deflection

LOAD IN Kgf	LOAD (N) in Newton(after multiplication of Kgf by 9.8)	DEFLECTION (MM)
38	372.4	20
76	744.8	40
132.9	1302.42	67
149.1	1461.18	73
186	1822.8	85
222	2175.6	95

The duration of cycle (specified fatigue cycle for component) is : 5,00,000 Cycles.

IV. METHODOLOGY AND MESH GENERATION

To analysis the results firstly we have to make the modeling of the spring. In our work the modeling is done in the SOLIDWORKS 2016 x 64 edition software. For analysis purpose we have to distribute load uniformly on spring. So for it we have to make seat as base on both side of spring.Now spring will be look like.

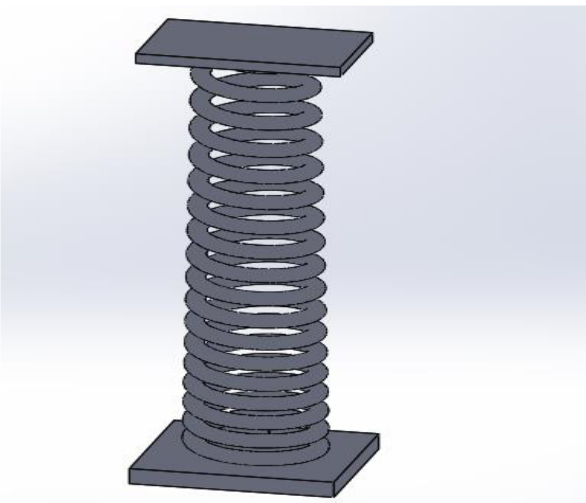

Fig.2 3D CAD model of helical conical spring with seats

Now for analyzing the spring in ANSYS we will convert it into IGES format and then analysis on spring is done in static structural system of ANSYS 15 edition.Under this, the fine mesh generation is selected and then spring will be look like

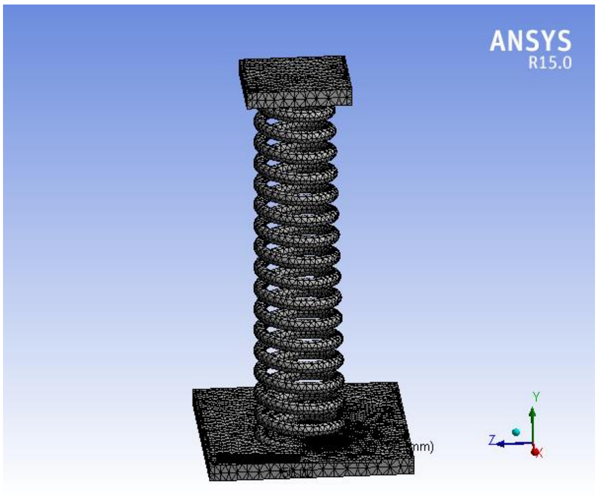

Fig.3. Fine size meshing of Spring

The number of nodes in the meshing of spring modeling is 54419 and the number of elements generation are 29093.
The boundary conditions are that force application will be on top seat of spring modeling and the other is that the bottom seat will be fixed

V. SIMULATION

Under the load of 372.4 N and 744.8 N, The maximum deflection is found to be 18.521 and 37.043 as shown in figure

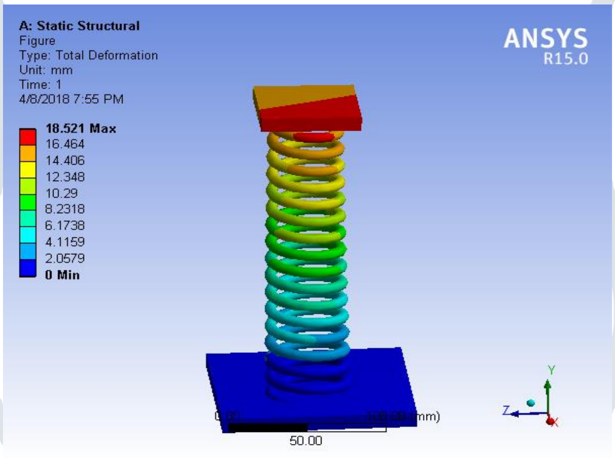

Fig. 4 Deflection of Spring at 372.4 N

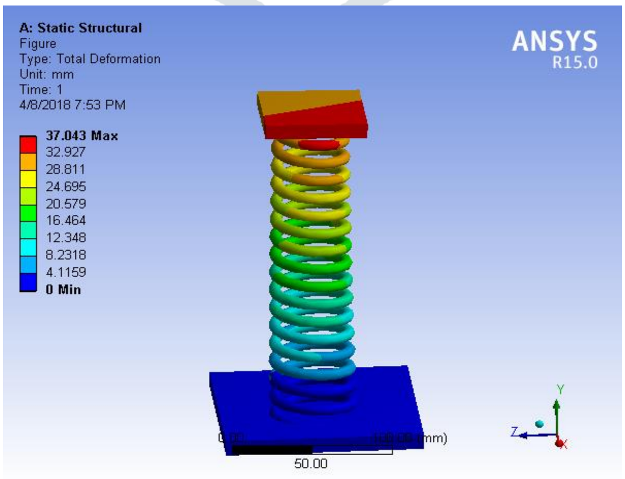

Fig.5 Deflection of Spring at 744.8 N

Under the load of 1302.42Newton, the maximum deflection is 64.776mm as shown in figure

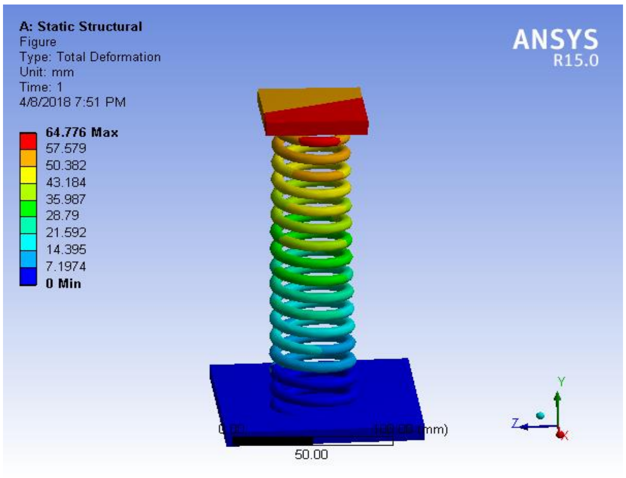

Fig.6 Deflection of spring at 1302.42N

The maximum deflection at 1461.18 Newton is 72.67mm by analysis the spring

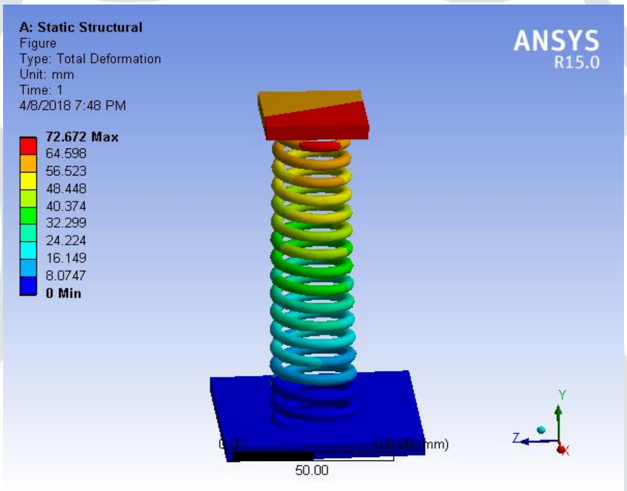

Fig.7 Deflection of spring at 1461.18N

The maximum deflection at 1822.8 Newton is 90.658mm as shown in figure

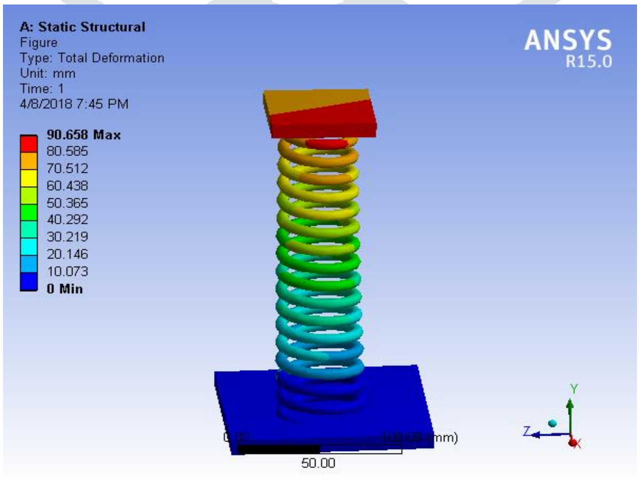

Fig.8 Deflection of Spring at 1822.8N

The deflection at final load condition of 2175.6Newton is 108.2mm as shown in figure 4.6

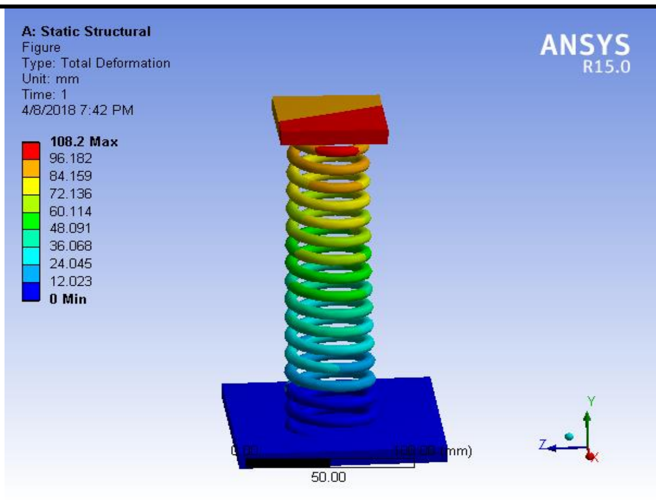

Fig.9 Deflection of Spring at 2175.6N

IV. RESULT AND DISCUSSION

So by analysis of spring through ANSYS we get results as above mention, here we write these results corresponding to their load condition in below given table:

Table.5 Details of Load Vs Deflection

LOAD (N)	DEFLECTION(mm) by ANYS (FEM method)
372.4	18.521
744.8	37.043
1302.42	64.776
1461.18	72.67
1822.8	90.658
2175.6	108.2

If we plot the variation of deflection results corresponding to their load condition ,the plotting graph will be look like

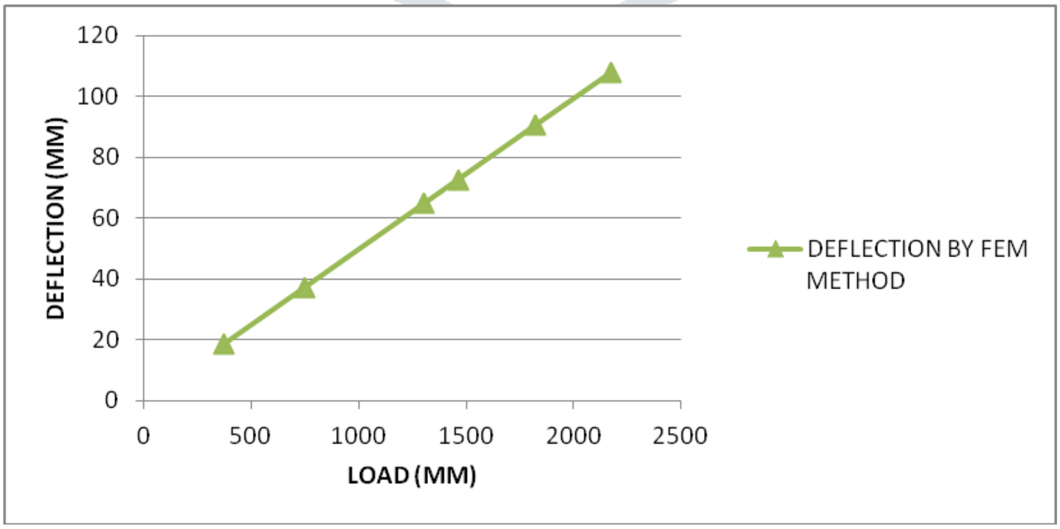

Fig.10 Load Vs Deflection by FEM technique

Now we find the deflection result by analytical method with the help of deflection formula of conical spring:[2]

$$\delta = \frac{2wn(D_1^2+D_2^2)(D_1+D_2)}{Gd^4}$$

D_1 = small mean coil diameter of spring and D_2 = large mean coil diameter of spring.

δ= deflection of conical spring

W= load applied

d= diameter of wire

n= number of active coil turns

Table.6 Parameter for estimation of Spring Deflection

D_1	41.5mm
D_2	48.5mm
d	7.5mm
G	81.370 $\times 10^9$ pa
n	16.9

With the help of formula the deflection results for various load conditions as mention in experimental data, is given in table:

Table.7 Detail of Load vs Deflection

LOAD(N)	DEFLECTION(mm) by analytical method
372.4	17.9
744.8	35.81
1302.42	62.62
1461.18	70.26
1822.8	87.65
2175.6	104.61

We can plot these variations of deflection results. The plotting graph of deflection results by analytical method will be look like as below:

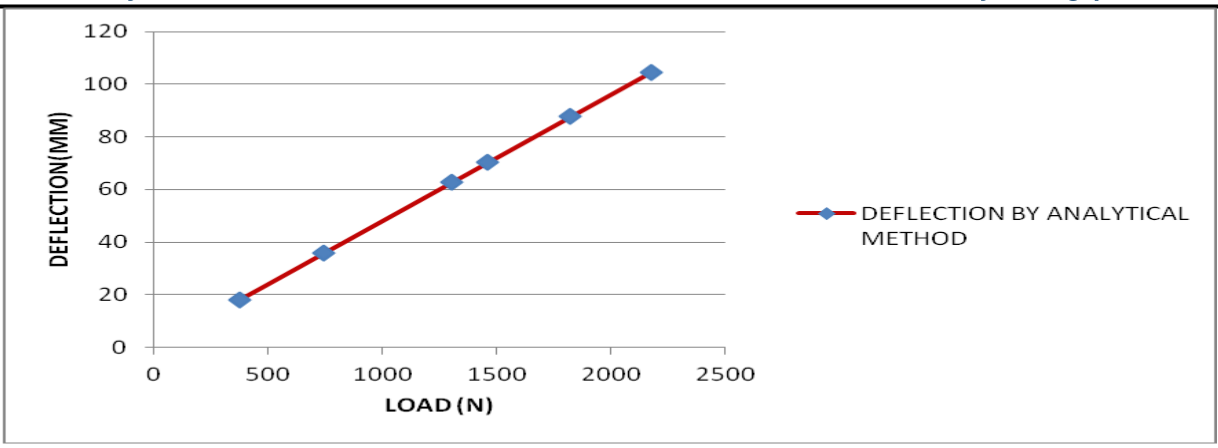

Fig.11 Load vs Deflection (by Analytical method)

There are different methods like

1. FEM method technique,
2. Analytical method technique and
3. Experimental method technique,

By these techniques methods we have found the deflection results and also plotted the graphs.

Now we will compare FEM method deflection results and Analytical method results with the experimental deflection results corresponding their load condition. This comparison will be in the form of percentage error

$$\% \text{ Error} = \frac{\text{Expected value} - \text{Experimental value}}{\text{Experimental value}} \times 100$$

Table.8 %Error in Deflection results by different techniques to the experimental result

LOAD(N)	DEFLECTION(MM) by experimental method	%ERROR (by FEM) to experimental results	%ERROR(by analytical method) to experimental results
372.4	20	7.395%	10.45%
744.8	40	7.392%	10.47%
1302.42	67	3.3%	6.5%
1461.8	73	0.41%	3.7%
1822.8	85	6%	3.1%
2175.6	95	13.8%	10.1%

We can also compare these results by merging all plotting graph to each other and after merging the plotting graphs between load and deflection result by different techniques it will be look like as below:

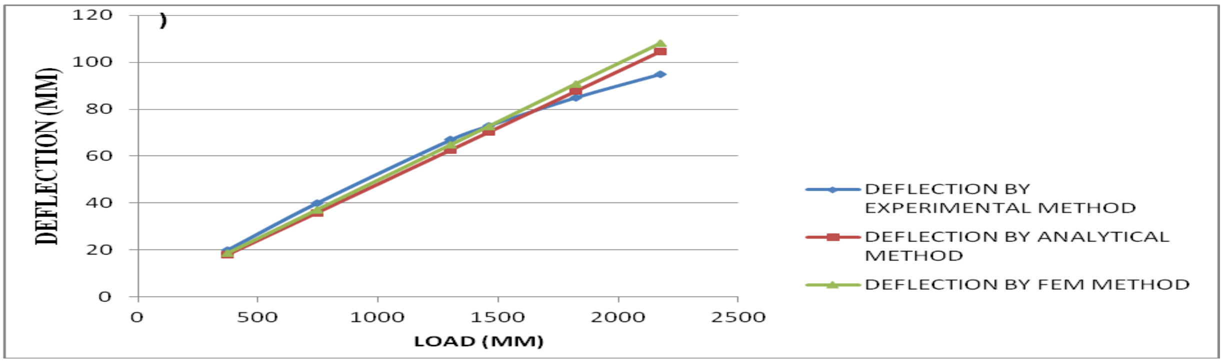

Fig.12 Load Vs Deflection (by different techniques)

We can find the maximum shear stress generation in spring by different load condition which is very important part to design a spring

The shear stress formula for spring is:

$$\tau = K\frac{8.W.C}{\pi d^2}$$

"K" is Wahl's stress factor which is :

$$K = \frac{4c-1}{4c-4} + \frac{0.615}{c}$$

$$C \text{ (spring index)} = \frac{D \text{ mean (larger)}}{d}$$

By solving: The values are C = 6.48 and K = 1.23

And the shear stress value for different load condition as mention in experimental data sheet is given in below table:

Table.9 Detail of Load Vs Shear stress

LOAD (N)	MAXIMUM SHEAR STRESS (MPa)
372.4	134.37
744.8	268.74
1302.42	469.94
1461.18	527.17
1822.8	657.71
2175.6	785.01

If we plot the variation of maximum shear stress value corresponding to their load conditions then the plotted graph will be look like as below:

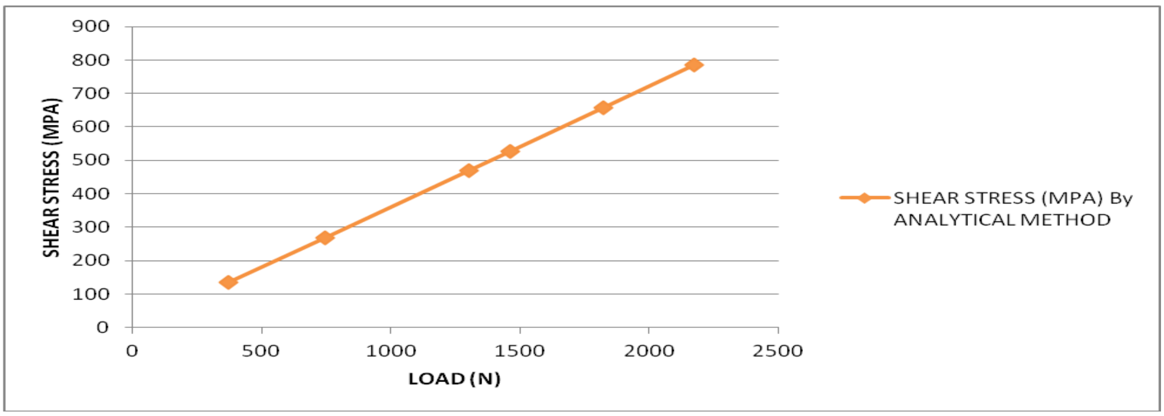

Fig.13 Load Vs Shear stress

We can analysis the spring for fatigue or endurance limit. It is main factor by which we can check the spring is in safety factor or not. This safety is related to that, maximum shear stress generation corresponding to their maximum load in spring should be less than the endurance strength of spring material.

The duration of cycle for spring in experimental testing is 500,000 cycle. So we will find the strength of spring corresponding their duration of cycle.

To estimate the S-N curve for steel the following power relation was found (Bannantine, 1990).[3]

$S= 10^c N^b$ (for $10^3 < N < 10^6$)

Where S is the cyclical stress and N the number of cycles. If Se and Su are the endurance and ultimate stresses and S_{1000} the stress after 1000 cycles:

$$b = \frac{1}{3} log_{10} \frac{S_{1000}}{S_e}$$

$$C= log_{10} \frac{(S_{1000})^2}{S_e}$$

If one makes the assumption that $S_{1000} \approx 0.9 S_u$ and $S_e \approx 0.5 S_u$ then the equation can be reduced to:

$S= 1.62 S_u N^{-0.085}$

For the spring the material is according to IS 4454 grade 3. So the ultimate tensile strength S_u = 1430 MPa .

N = 500,000 cycles

So at these conditions the strength value will be S= 870.664MPa. It is basically endurance limit for spring at the particular value of 500,000 cycles.

The maximum shear stress value in spring is 134.37MPa and it is lower than the endurance value 870.664MPa. so we can say by this analysis that our spring component is in safe mode.

IV. CONCLUSION

Under this work, there are following results are concluded:

- There is some error in result comparison of deflection by FEM and Analytical method to the experimental results. Which is approximately to 10%
- The %Error is going to decrease as input load increase up to the limit of 1461.8N by FEM and after it is increased
- The %Error is also going to decrease as input load increase but up to limit 1822.8N
- The FEM show closed result to experimental results as compare to Analytical results up to limit of deflection 73mm
- The Maximum shear stress in spring is 785.01Mpa, is the under limit of endurance strength of spring. Which shows that our design of spring is safe.

The overall work shows that our estimating results are closed to available experimental results with the under considering of safe design of spring.

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