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Probabilistic Design of Helical Coil Spring for Longitudinal Invariance by Using Finite Element Method

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ABSTRACT
The study represents new approach to design helical coil spring. Response surface modeling and analysis of open coiled helical spring by considering longitudinal and invariance have been carried out. Design parameters are wire diameter, spring diameter, height, number of turns elastic modulus in X and Z direction, poissions ratio, force. Simple equations is proposed which gives value of compressive stress of helical coil spring by carrying out regression analysis. It is observed that force and material property are significant parameters which affect compressive stress because their P value is 1. Relationship among design parameters and compressive stress has been obtained.
***Key words*:-** Simulation, open coiled spring by FEA and Response surface modeling

I. INTRODUCTION

Spring act as a flexible joint in between two parts or bodies. Spring is the energy storing and releasing element whenever required. This paper demonstrates by taking the combination of steel and composite material for design of helical compression spring. In this case instead of steel is used combination of steel and composite material Glass fiber/Epoxy because of low stiffness of single composite spring, which limits its application to light weight vehicle only. Composite material is light weight and corrosion resistance, it can withstand high temperature. It increase efficiency of vehicle and overcome the cost. He had concluded combination of steel and composite material can increase the stiffness which is the major requirement of regular vehicle due to higher weight this done by using the FEA.[1].This study investigates static behavior of helical structure under axial loads. In this paper, authors have taken two helical structure first one is single wire on which homogeneous theory applied and second is axial elastic properties of seven wire strand are computed. This approach, based on asymptotic expansion, gives the first-order approximation of the 3D elasticity problem from the solution of a 2D microscopic problem posed on the cross-section and a 1D macroscopic problem, which turns out to be a Navier–Bernoulli–Saint-Venant beam problem and result compared with reference results.**[**2]This paper researchers taken four composite material (structure)these are unidirectional laminates (AU), rubber core unidirectional laminates (UR), Unidirectional laminates with braided outer layer (BU), and rubber core unidirectional laminates with braided outer layer (BUR). They investigated effect of rubber core and braided outer layer on the mechanical properties of the above mentioned helical springs. According to the experimental results, the helical composite spring with a rubber core can increase its failure load in compression by about 12%; while the spring with a braided outer layer cannot only increase its failure load in compression by about 18%, but also improve the spring constant by approximately 16%.[3]This study deals with the stress analysis of a helical coil compression spring, which is employed in three wheeler's auto-rickshaw belonging to the medium segment of the Indian automotive market. This spring has to face very high working stresses, so in this design of the spring both the elastic characteristics and the fatigue strength have to be considered as significant aspects. This done by using finite element analysis. These springs have to face very high working stresses. The structural reliability of the spring must therefore be ensured. [4]. The linear zed disturbance equations governing the resonant frequencies of a helical spring subjected to a static axial compressive load are solved numerically using the transfer matrix method for clamped ends and circular cross-section to produce frequency design charts.This paper summarize the behavior of the lowest resonant frequency obtained from the model of a helical compression spring with an initial number of turns.[5]In this paper, long term fatigue test on shot peened compression spring were conducted by means of special spring fatigue testing machine at 40 Hz. Three different types of material is taken.

The influence of different shot peening conditions were investigated. In this paper fractured test spring were examined under scanning electron microscope, optical microscope and by means of metallographic micro section in order to analyze the fracture behavior and the failure mechanisms [6].
It is observed from literature review that probabilistic approach for the design of helical coil spring by using FEA is not taken into consideration. Also probabilistic design by considering longitudinal invariance, Translational and combined translation plus longitudinal invariance is necessary to consider for design under dynamic loading condition. Validation of the analysis will be done by analytical techniques in finite element method or solid mechanics. Also results of probabilistic design are to be optimized. Results will provide new approach and key to improve design of helical coil spring.

II. SIMULATION

Finite element analysis of helical coil spring

Analysis has been carried out in ANSYS work bench. Constrained geometry of the spring is as shown in figure 1.1.

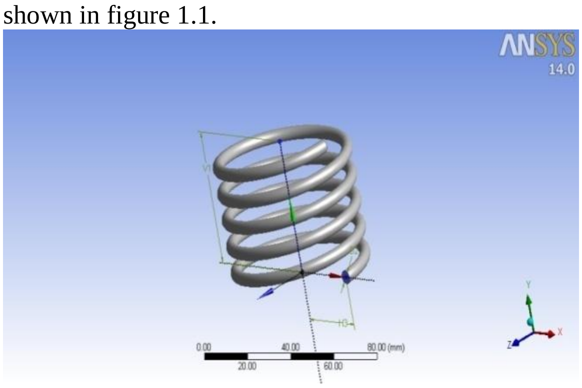

Fig.1.1 Geometry of the spring in ANSYS

In table No. 1.1 Simulation of helical coil spring is done by using response surface modeling in ANSYS workbench (FEA). Geometry is meshed by using brick element. Total number of nodes 25620 and elements 4850 are generated after meshing. One end of the spring is fixed in all direction while load is applied in negative Y direction at another end. It is shown in figure 1.2

In the table No. 1.2, material properties and their values in x, y, z direction is quoted.

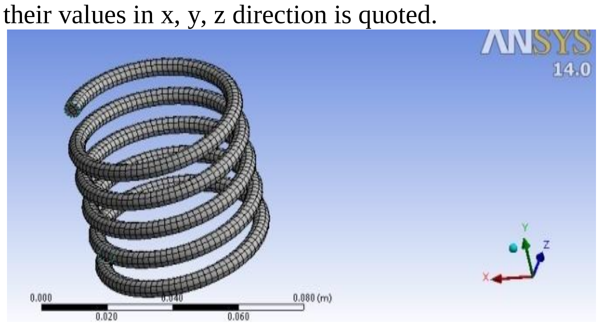

Fig.1.2 Meshed model of helical coil spring

Table 1.1Material properties of spring for analysis

Sr.No.	Material Property	Value
1	Young's modulus (EX), MPa	200e3
2	Young's modulus ((EY) MPa	210e3
3	Young's modulus (EZ) MPa	220e3
4	Shear modulus along XY-direction (Gxy), MPa	2433
5	Shear modulus along XY-direction (Gyz), MPa	1698
6	Shear modulus along XY-direction (Gzx), MPa	2433
7	Force on x direction, N	1000
8	Poisson ratio along XY-direction (NUxy)	0.3
9	Poisson ratio along YZ-direction (NUyz	0.27
10	Poisson ratio along ZX-direction (NUzx)	0.24

Table 1.2 Limits of input parameter

Sr. No.	Parameters	Lower Limits	Higher Limits
1	Height(mm)	50	55
2	Wire diameter(mm)	4	5
3	Turns(mm)	4	5
4	Coil diameter(mm)	27	32
5	Ez (MPa)	190e3	220e3
6	Ex (MPa)	180e3	210e3
7	Force Y Component (N)	1000	1500

Table 1.1 shows material properties in X, Y and Z directions which are used for analysis. In table 1.2, lower and upper limit of input parameters are specified for uniform distribution
Simulation of helical coil spring is done by using response surface modeling in ANSYS workbench (FEA).

Table 1.3 shows corresponding parameters according to RSM. In this table,
P1 - Height, P2 – Wire diameter , P3 - Turns, P4 – Coil diameter, P5 - Young's Modulus Z direction (Pa) , P6 - Young's Modulus X direction (Pa),P7 - Force Y Component (N) ,P8 - Equivalent Stress Maximum (Pa), P9 - Total Deformation Maximum (mm).

Table No.1.3 Corresponding parameters according to RSM (Response Surface Modelling)

Sr.No.	P1	P2	P3	P4	P5	P6	P7	P8	P9
1	50	5	5	30	211000	200000	-1000	4737845097	0.37953
2	45	5	5	30	211000	200000	-1000	4735321402	0.37454
3	55	5	5	30	211000	200000	-1000	4737660972	0.38499
4	50	4.5	5	30	211000	200000	-1000	6795865785	0.57608
5	50	5.5	5	30	211000	200000	-1000	3604871584	0.26014
6	50	5	4.5	30	211000	200000	-1000	5054538189	0.34210
7	50	5	5.5	30	211000	200000	-1000	4991907953	0.41728
8	50	5	5	27	211000	200000	-1000	4304231724	0.28213
9	50	5	5	33	211000	200000	-1000	5172052972	0.49755
10	50	5	5	30	189900	200000	-1000	4737845097	0.37953
11	50	5	5	30	232100	200000	-1000	4737845097	0.37953
12	50	5	5	30	211000	180000	-1000	4737845097	0.37953
13	50	5	5	30	211000	220000	-1000	4737845097	0.37953
14	50	5	5	30	211000	200000	-1100	5211629607	0.41748
15	50	5	5	30	211000	200000	-900	4264060587	0.34157
16	47.3546	4.7355	4.7355	28.4127	199836.2096	189418.2081	-947.0910	5004640196	0.37429
17	52.6454	4.7355	4.7355	28.4127	199836.2096	189418.2081	-1052.9090	5566299912	0.42324
18	47.3546	5.2645	4.7355	28.4127	199836.2096	189418.2081	-1052.9090	4091668192	0.27328
19	52.6454	5.2645	4.7355	28.4127	199836.2096	189418.2081	-947.0910	3682079657	0.25001
20	47.3546	4.7355	5.2645	28.4127	199836.2096	189418.2081	-1052.9090	5570176371	0.42749
21	52.6454	4.7355	5.2645	28.4127	199836.2096	189418.2081	-947.0910	5011795224	0.39027
22	47.3546	5.2645	5.2645	28.4127	199836.2096	189418.2081	-947.0910	3678421953	0.25266
23	52.6454	5.2645	5.2645	28.4127	199836.2096	189418.2081	-1052.9090	4091586505	0.28508
24	47.3546	4.7355	4.7355	31.5873	199836.2096	189418.2081	-1052.9090	6137490974	0.56183
25	52.6454	4.7355	4.7355	31.5873	199836.2096	189418.2081	-947.0910	5527656778	0.51235
26	47.3546	5.2645	4.7355	31.5873	199836.2096	189418.2081	-947.0910	4048357399	0.33194
27	52.6454	5.2645	4.7355	31.5873	199836.2096	189418.2081	-1052.9090	4502311707	0.37429
28	47.3546	4.7355	5.2645	31.5873	199836.2096	189418.2081	-947.0910	5524162900	0.52009
29	52.6454	4.7355	5.2645	31.5873	199836.2096	189418.2081	-1052.9090	6162062321	0.58576
30	47.3546	5.2645	5.2645	31.5873	199836.2096	189418.2081	-1052.9090	4505197410	0.37981
31	52.6454	5.2645	5.2645	31.5873	199836.2096	189418.2081	-947.0910	4053577500	0.34588
32	47.3546	4.7355	4.7355	28.4127	222163.7904	189418.2081	-1052.9090	5563805484	0.41611
33	52.6454	4.7355	4.7355	28.4127	222163.7904	189418.2081	-947.0910	5006883760	0.38070
34	47.3546	5.2645	4.7355	28.4127	222163.7904	189418.2081	-947.0910	3680453400	0.24581
35	52.6454	5.2645	4.7355	28.4127	222163.7904	189418.2081	-1052.9090	4093476174	0.27794
36	47.3546	4.7355	5.2645	28.4127	222163.7904	189418.2081	-947.0910	5010370704	0.38452
37	52.6454	4.7355	5.2645	28.4127	222163.7904	189418.2081	-1052.9090	5571760200	0.43388
38	47.3546	5.2645	5.2645	28.4127	222163.7904	189418.2081	-1052.9090	4089409783	0.28089
39	52.6454	5.2645	5.2645	28.4127	222163.7904	189418.2081	-947.0910	3680379765	0.25643
40	47.3546	4.7355	4.7355	31.5873	222163.7904	189418.2081	-947.0910	5520669811	0.50537
41	52.6454	4.7355	4.7355	31.5873	222163.7904	189418.2081	-1052.9090	6145258487	0.56959
42	47.3546	5.2645	4.7355	31.5873	222163.7904	189418.2081	-1052.9090	4500677927	0.36902
43	52.6454	5.2645	4.7355	31.5873	222163.7904	189418.2081	-947.0910	4049826914	0.33667
44	47.3546	4.7355	5.2645	31.5873	222163.7904	189418.2081	-1052.9090	6141374347	0.57820
45	52.6454	4.7355	5.2645	31.5873	222163.7904	189418.2081	-947.0910	5542771793	0.52689
46	47.3546	5.2645	5.2645	31.5873	222163.7904	189418.2081	-947.0910	4052422635	0.34164
47	52.6454	5.2645	5.2645	31.5873	222163.7904	189418.2081	-1052.9090	4506481409	0.38452
48	47.3546	4.7355	4.7355	28.4127	199836.2096	210581.7919	-1052.9090	5563805484	0.41611
49	52.6454	4.7355	4.7355	28.4127	199836.2096	210581.7919	-947.0910	5006883760	0.38070
50	47.3546	5.2645	4.7355	28.4127	199836.2096	210581.7919	-947.0910	3680453400	0.24581
51	52.6454	5.2645	4.7355	28.4127	199836.2096	210581.7919	-1052.9090	4093476174	0.27794
52	47.3546	4.7355	5.2645	28.4127	199836.2096	210581.7919	-947.0910	5010370704	0.38452
53	52.6454	4.7355	5.2645	28.4127	199836.2096	210581.7919	-1052.9090	5571760200	0.43388

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Continued

54	47.3546	5.2645	5.2645	28.4127	199836.2096	210581.7919	-1052.9090	4089409783	0.28089
55	52.6454	5.2645	5.2645	28.4127	199836.2096	210581.7919	-947.0910	3680379765	0.25643
56	47.3546	4.7355	4.7355	31.5873	199836.2096	210581.7919	-947.0910	5520669811	0.50537
57	52.6454	4.7355	4.7355	31.5873	199836.2096	210581.7919	-1052.9090	6145258487	0.56959
58	47.3546	5.2645	4.7355	31.5873	199836.2096	210581.7919	-1052.9090	4500677927	0.36902
59	52.6454	5.2645	4.7355	31.5873	199836.2096	210581.7919	-947.0910	4049826914	0.33667
60	47.3546	4.7355	5.2645	31.5873	199836.2096	210581.7919	-1052.9090	6141374347	0.57820
61	52.6454	4.7355	5.2645	31.5873	199836.2096	210581.7919	-947.0910	5542771793	0.52689
62	47.3546	5.2645	5.2645	31.5873	199836.2096	210581.7919	-947.0910	4052422635	0.34164
63	52.6454	5.2645	5.2645	31.5873	199836.2096	210581.7919	-1052.9090	4506481409	0.38452
64	47.3546	4.7355	4.7355	28.4127	222163.7904	210581.7919	-947.0910	5004640196	0.37429
65	52.6454	4.7355	4.7355	28.4127	222163.7904	210581.7919	-1052.9090	5566299912	0.42324
66	47.3546	5.2645	4.7355	28.4127	222163.7904	210581.7919	-1052.9090	4091668192	0.27328
67	52.6454	5.2645	4.7355	28.4127	222163.7904	210581.7919	-947.0910	3682079657	0.25001
68	47.3546	4.7355	5.2645	28.4127	222163.7904	210581.7919	-1052.9090	5570176371	0.42749
69	52.6454	4.7355	5.2645	28.4127	222163.7904	210581.7919	-947.0910	5011795224	0.39027
70	47.3546	5.2645	5.2645	28.4127	222163.7904	210581.7919	-947.0910	3678421953	0.25266
71	52.6454	5.2645	5.2645	28.4127	222163.7904	210581.7919	-1052.9090	4091586505	0.28508
72	47.3546	4.7355	4.7355	31.5873	222163.7904	210581.7919	-1052.9090	6137490974	0.56183
73	52.6454	4.7355	4.7355	31.5873	222163.7904	210581.7919	-947.0910	5527656778	0.51235
74	47.3546	5.2645	4.7355	31.5873	222163.7904	210581.7919	-947.0910	4048357399	0.33194
75	52.6454	5.2645	4.7355	31.5873	222163.7904	210581.7919	-1052.9090	4502311707	0.37429
76	47.3546	4.7355	5.2645	31.5873	222163.7904	210581.7919	-947.0910	5524162900	0.52009
77	52.6454	4.7355	5.2645	31.5873	222163.7904	210581.7919	-1052.9090	6162062321	0.58576
78	47.3546	5.2645	5.2645	31.5873	222163.7904	210581.7919	-1052.9090	4505197410	0.37981

As shown in the table No.3.4. Regression analysis of helical coil spring is carried out by using M S excels 2014 for obtaining regression equation. Regression analysis of helical coil spring has been done by using M S excel and following equation of regression is obtained.

P8 = 9726699830+ (P1) 819521.8308+ (P2) (-2839451970)+ (P3) 1190032.296+ (P4) 147833012.7 + (P5) 1.36331E-12+ (P6) (-1.58666E-12)+(P7) (-4813812.772)
…... [1.1]

III. RESULTS AND DISCUSSION

In this chapter, analysis of helical coil spring by using the response surface modeling has been discussed. This analysis provides the resulting graphs of design parameters Vs compressive stress. Under the loading condition, compression strength of helical coil spring is obtained. Stress distribution of helical coil spring is as shown below in figure 1.3.In this case, static analysis is done by using the finite element method, in the figure blue color indicates the minimum stresses 4.8343E6 acting on the turns and Red color indicates maximum stresses 4.7378E9. The force applied in y direction .Material properties in Y direction are kept constants i.e. longitudinal invariance while material properties in other two directions are varied within range 190e3 to 220e3.

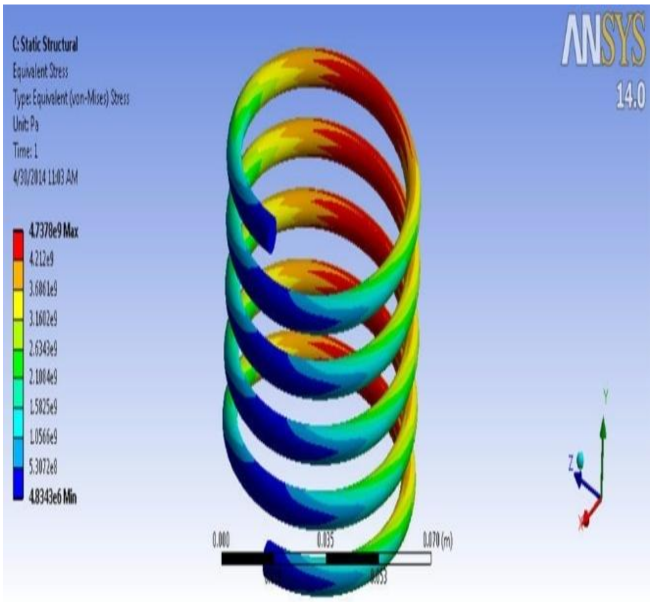

Fig.1.3. Equivalent stress of helical coil spring

a) Coil diameter Vs Compressive stress

Figure shows relationship between coil diameter Vs compressive stress has been obtained. In this fig showing that when mean diameter of spring increases compressive stress also goes on increasing upto 32mm. There compressive stress decreases because stress exceeds elastic limit.

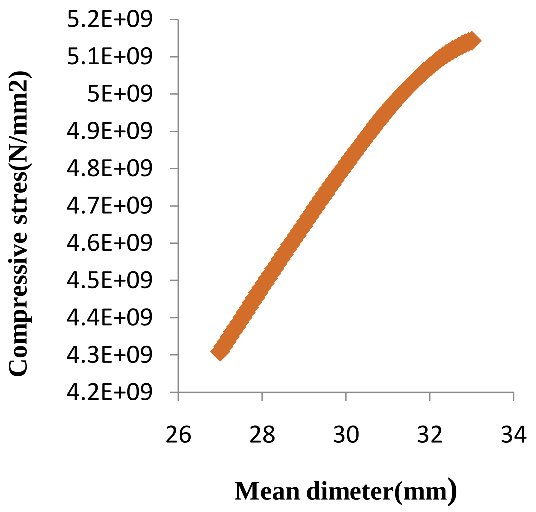

Fig.1.3. Mean diameter Vs Compressive stress

b) Young's modulus Vs Compressive stress

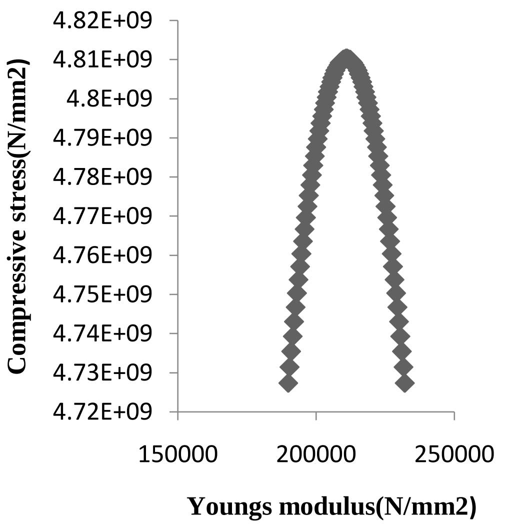

Fig.1.4. Young's modulus Vs Compressive stress

Figure shows young's modulus Vs compressive stress in this case, when young's modulus increase the compressive stress increases up to 210E3 after that compressive stress decrease up to upper limit i.e. 230E3 N/mm2. It happens due to high stiffness value ofspring.

c) Wire diameter Vs Compressive stress

Figure shows the wire diameter Vs compressive stress. When wire diameter of spring is increases compressive stress decreases up to 5mm after these compressive stress increase force is transferred in helical direction to another end of spring. From fig. it is observed that 5mm is optimum wire diameter where compressive stress is 4.8N/mm2

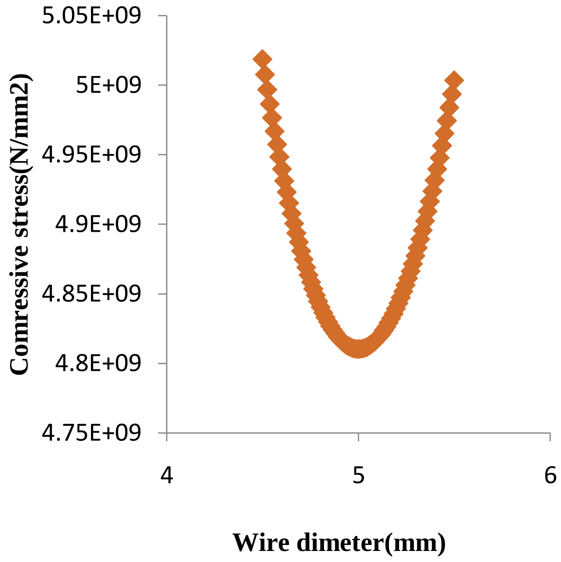

Fig.1.5. Wire diameter Vs Compressive stress

d) Force Vs Compressive stress

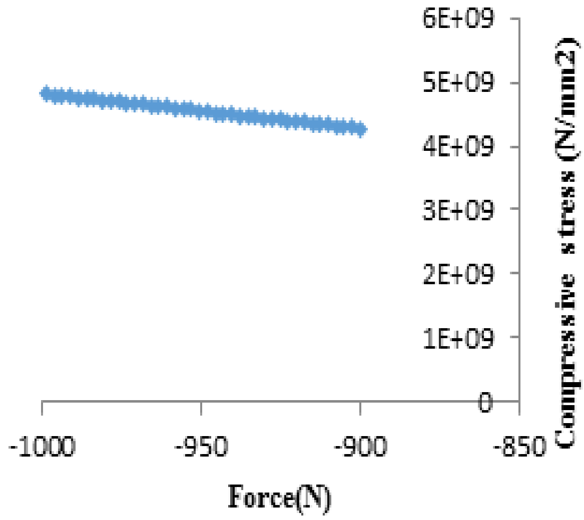

Fig.1.6. Force Vs Compressive stress

Figure shows graph of force Vs compressive stress. In this graph shown that when force increases compressive stress also increase, so compressive stress depend on applied force. From obtained regression model it is observed that force is one among significant parameter

e) Free length Vs compressive stress

Figure shows graph of free length VS compressive stress. graph obtained shows exactly reverse nature as that of wire diameter Vs compressive stress. As shown in the fig. free length increases up to 50mm there after compressive stress decrease up to free length 55mm because energy stored in spring is released.

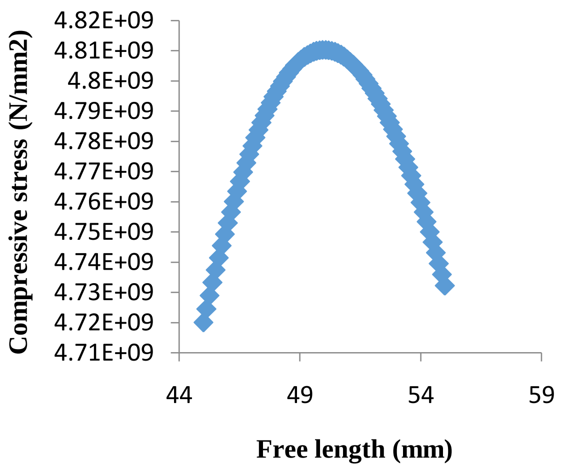

Fig.1.7. Free length Vs compressive stress

IV CONCLUSION

- Simple equations proposed which gives value of compressive stress of helical coil spring by carrying regression analysis
- It is observed that force and material property are significant parameters which affect compressive stress because their P value is 1.
- Finite element analysis of helical coil spring has been carried out.
- Response surface modeling of helical coil spring under longitudinal invariance has been carried out for compression stress.
- Relationship among design parameters and compressive stress has been obtained

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