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A COMPARATIVE EVALUATION OF SPRING RATE OF CYLINDERICAL AND CONICAL HELICAL COMPRESSION SPRING MADE OF ASTM A227 MATERIAL

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Abstract-**This paper does a comparative evaluation of spring rate 'K' of cylindrical and conical helical compression spring. This paper analyses how tapering of a straight helical compression (cylindrical Vis-a-Vis conical spring) improves spring rate 'K'. The cylindrical and conical springs have been manufactured from hard drawn carbon steel ASTM A227 of wire diameter 3.5 mm and 4mm. The tests have been conducted on Universal Testing Machine (UTM) with the help of a fixture. The need of a fixture arises due to high slenderness ratio (L/D > 4) so as to restrict the lateral deflection of spring under compression load during testing.**

Index Terms- **buckling, critical frequency, deflection, fixture, peak load, spring rate**

I. INTRODUCTION

Helical compressions springs function as an energy absorbing machine element. They absorb vibration and protect structure from damage. They are also used as a mechanical energy storing machine element in safety devices. Spring rate, energy absorbing capacity, lateral stability and smooth response to a range of load, space efficiency and high natural frequency are important aspects that a designer looks for while designing a helical compression spring. Cylindrical helical compression spring is the most prevalent form of compression spring. On the other hand, conical form is less in use. This paper aims at comparative evaluation of spring rate 'K' of cylindrical and conical helical compression spring. Since, spring rate 'K' is an important characteristic of a spring and it directly affects mechanical properties of a spring like deflection response to an external load, buckling and surging, this paper opens an option in the field of spring design.

II. LITERATURE SURVEY

Lavanya et al. (2014) The authors have done design and analysis of a suspension coil spring for automotive vehicle. Generally for light vehicles, coil springs are used as suspension system. The present work attempts to analyze the safe load of the light vehicle suspension spring with different materials. This investigation includes comparison of modeling and analyses of primary suspension spring made of low carbon-structural steel and chrome vanadium steel and suggested the suitability for optimum design. The results show the reduction in overall stress and deflection of spring for chosen materials[1]. **Patil et al. (2014)** In this paper, an analytical buckling equation for conical spring with its experimental verification has been proposed by authors. They used it along with the existing theories to locate the phase of compression of conical spring at which buckling occurs. Subsequently, a comparison between cylindrical and conical springs has been made at the point of buckling of cylindrical spring in respect of their load and deflection. This would help to decide the suitability of conical springs against buckling failure of cylindrical springs under the given operating conditions[2]. **Patil et al. (2013)** The authors have done buckling analysis of straight helical compression springs made of ASTM A229 GR-II, ASTM A 313 materials (Type 304 & 316). Though the buckling mainly depends upon their geometrical properties rather than their material properties, an attempt has been made to confirm experimentally the results obtained previously by different researchers and to carry out analyses with springs made of different materials for their suitability in various applications[3]. **Christopher et al. (2013)** The authors proposed an analysis of spring by varying coil diameter in PRO/E and ANSYS .In the research wire diameter of spring has been changed from present 6.7 mm to 7.5 mm. The loading constraints are one end of spring is fixed and end set free and the load so applied are in three different categories simply the weight of bike, bike with one person and bike with two person and the results so obtained are value of stress and deformation both get lowered with the increase of wire diameter[4]. **Prawoto et al. (2008)** The author had given an automotive suspension coil springs, their fundamental stress distribution, materials characteristic, manufacturing and common failures. A coil's failure to perform its function properly can be more catastrophic than if the coil springs were used in lower stress. As the stress level was increased, material and manufacturing quality became more critical. This paper discussed several case studies of suspension spring failures. The finite element analyses of representative cases were finite element modeling in metallurgical failure analysis synergizes the power of failure analysis into convincing quantitative analysis[5]. **Llano-Vizcaya et al.(2007)** In this paper, the authors have done an experimental investigation to assess the stress relief influence on helical spring fatigue properties. First S–N curves were determined for springs treated under different conditions (times and temperatures) on a testing machine. Next the stress relief effect on spring relaxation induced by cyclic loading was evaluated. This methodology used in the experimental work and procedures used in the relaxation tests, fatigue tests and residual stress measurements. Finally, residual stresses were measured on the inner and outer coil surfaces to analyze the effect of heat treatment[6]. **Chiu et al. (2007)** In this paper the authors presented four different types of helical composite springs were made of structures including unidirectional laminates

(AU), rubber core unidirectional laminates (UR), unidirectional laminates with a braided outer layer (BU), and rubber core unidirectional laminates with a braided outer layer (BUR), respectively. It aims to investigate the effects of rubber core and braided outer layer on the mechanical properties of the aforementioned four helical springs. According to the experimental results, the helical composite spring with a rubber core can increase its failure load in compression. Therefore, author wanted to say that the shock absorbers with high performance might be expected to come soon [7].

Berger et al. (2006) In this paper the author presented the first results of very high cycle fatigue tests on helical compression springs. The springs tested were manufactured of Si–Cr-alloyed valve spring wire with a wire diameter between 2mm and 5 mm, shotpeened and the fatigue tests were continued up to 108cycles or even more. The aim should be to elaborate results about and insights concerning the level of the fatigue range in the stress cycle regime up to 109cycles, about the mechanisms causing failures and about possible remedies or measures of improvement[8].

Fakhreddine et al. (2005) In this paper the authors presented an efficient two nodes finite element with six degrees of freedom per node, capable to model the total behavior of a helical spring. The working on this spring was subjected to different cases of static and dynamic loads and different type of method (finite element method, dynamic stiffness matrix method) were governing equations by the motion of helical spring. This element permitted to get the distribution of different stresses along the spring and through the wire surface without meshing the structure or its surface[9].

III. RESEARCH GAP

From literature survey following research gap is available.

a) The work has been done to understand the change in mechanical properties of spring by changing material. Chrome-vanadium steel has been tried in place of hard drawn carbon steel.
b) The work has also been done to understand the change in mechanical properties of spring by increasing the diameter of the spring wire. However, a few works have been done to understand the change in mechanical properties of coil spring with change of shape in longitudinal direction. The shape like conical, barrel and hourglass has not been tried in place of cylindrical shape.

These research gaps have been used in defining and formulating problem statement.

IV. PROBLEM STATEMENT

To analyses how tapering of a straight helical compression (cylindrical Vis-a-Vis conical spring) improves spring rate 'K'. Since, spring rate 'K' is an important characteristic of a spring and it directly affects mechanical properties of a spring like deflection response to an external load, buckling and surging, this paper explores an option in the field of spring design.

V. OBJECTIVE

To do a comparative evaluation of spring rate 'K' of cylindrical and conical helical compression spring.

VI. MATERIAL SELECTION

While certain materials have come to be regarded as spring materials, they are not specially designed alloys. Spring alloys are high strength alloys which often exhibit the greatest strength in the alloy system [11].for example in steels, medium and high carbon steels are regarded spring materials. Hard drawn carbon steel ASTM A227 is one of the widely used among the spring steels for static application. It is commercially available in standard form and wire size. The chemical composition of hard drawn carbon steel ASTMA227 is [12]:-

Carbon(C): 0.60-0.8%,
Manganese (Mn): 0.8%(max),
Phosphorous (P): 0.04%
Sulphur (S): 0.04%

In the present work, the springs (cylindrical and conical Shape) have been coiled out of 3.5mm as well as 4mm diameter hard drawn carbon steel ASTM A227 wire. The specifications of cylindrical and conical springs that have been used for evaluation are as given below.

Table I:Cylinderical and conical springs parameters

Parameters	Cylindrical Spring	Conical Spring
Free Length, L_f	265mm	265mm
Outer Diameter, D_o	25mm	25mm (base end),15mm (apex end)
Pitch, p	6.8mm	6.8mm
Wire Diameter, d	4mm,3.5mm	4mm,3.5mm
Total no. of Coils, N_t	40	40
No. of Active Coil, N_a	38	38
Type of End	Squared and Ground	Squared and Ground

The material properties of hard drawn carbon steel ASTM A227 are as tabulated below [11].

Table II: Mechanical Properties of ASTM A227

Young Modulus of Elasticity, E	196.5 GPa
Shear Modulus of Elasticity, G	78.6 GPa
Density, ρ	7.86g/cm2
Poisson's Ratio, μ	0.25

VII. MATERIALS AND METHODS

The change in load per unit deflection is called spring rate 'K'. For cylindrical helical compression spring with small helix angle spring rate is expressed as[11]

$$K= Gd^4/8D^3N_a$$

G-Shear deflection, d-wire diameter, D-Mean Diameter of spring, N_a-no. of active coil

For conical helical compression spring with small helix angle spring rate is expressed as [11]

$$K= Gd^4/16(R_1+R_2)(R_1^2+R_2^2)N_a$$

G-Shear deflection, d-wire diameter, R_1-initial coil radius, R_2-final coil radius, N_a-no. of active coil

For spring made of ASTM A227 material of wire diameter 3.5mm putting the values in the above equations for 'k, one gets

Table III: Spring Rate Calculation for Cylindrical and conical spring of wire size(d=3.5mm)

Sample-1 (cylindrical spring) d=3.5mm D_o=25mm,D= D_o-d = 25-3.5=21.5mm, N_a =38,G= 78.6 GPa	Sample-2 (Conical spring) d=3.5mm,R_1=15mm, R_2=25mm N_a =38,G= 78.6 GPa
K=3.9	K=4.56

For spring made of ASTM A227 material of wire diameter 4mm putting the values in the equation for 'k',one gets

Table IV: Spring Rate Calculation for Cylindrical and conical spring of wire size(d= 4mm)

Sample-3 (cylindrical spring) d=4mm D_o=25mm,D= D_o-d = 25-3.5=21.5mm, N_a =38,G= 78.6 GPa	Sample-4 (Conical spring) d=4mm, R_1=15mm, R_2=25mm N_a =38,G= 78.6 GPa
K=6.66	K=7.79

Owing to high slenderness ratio, the spring comes under frictional loading from the inner wall of the tube/cavity or from the surface of the rod that is used to restrict lateral deflection of the spring as it deflects axially under compression [10,11]. The expression used in the literature on spring design to calculate spring rate does not take it into account and therefore the result that we get is at flaw. It seems that one needs to introduce a frictional loading factor 'f' to the standard expression for calculating spring rate 'k'.

Therefore, the equation for calculating spring rate 'k' for high slenderness ratio and supported in a tube/cavity or over a rod can be

$$K= f\,(Gd^4/8D^3N_a)$$

[for cylindrical helical compression spring]

$$K=f(Gd^4/16(R_1+R_2)(R_1^2+R_2^2)N_a$$

[for conical helical compression spring]

The calculation for friction loading factor 'f' is based on the following assumptions.

a) The eccentricity of load during Compression Test is negligible.
b) The friction is between wall of cavity and coils of the spring under Test.
c) The female cavity inner wall does not rub against the male cavity outer wall.
d) There is no lubricating agent available between coils of spring and cavities of the fixtures.

Helical compression spring that has ratio of free length to mean diameter (L_f /D) also called Slenderness ratio greater than four can buckle. In order to restrict the lateral deflection of a long spring due to buckling, it is guided either in a cavity or over a rod. In some cases, a rod inside a cavity is also in use. However, friction between the spring and cavity or rod will affect the loads, especially when the slenderness ratio is high[10,11]. Minimum diametric clearance between the spring and cavity or rod is: 0.05D - when D_c is greater than 13 mm and 0.10D - when D_c is less than 13 mm; where Dc is the diameter of the rod or cavity. In this work, a fixture has been used to accommodate the springs for testing purpose on UTM. The fixture consists of two parts namely male cavity and female cavity. These cavities are basically hollow cylinders with rectangular bases for a stable support on the UTM. The female cavity has a rod welded centrally in it. The spring is put in the female cavity of the fixture while the male cavity is put on top of the spring. The arrangement is kept on the UTM for compression test. The load Vs deflection response displays on the computer screen that has been connected to the UTM. The photograph below shows the compression test being performed.

Fig.1: Compression Test of spring on UTM and display of P Vs δ response of spring on computer screen

There has been gradual application of load at a constant rate during Compression Test. Care has been taken to see that the male cavity of the fixtures goes squarely inside the female cavity without rubbing against each other and creating unnecessary friction. The test was stopped the moment spring touches the solid height. It is clearly visible as a sudden rise in the loading condition i.e. the peaks at the extreme corner of Load Vs Displacement graphs. Load Vs Displacement graphs for cylindrical as well as conical spring of wire dia. 3.5mm and 4mm as the outcome of the Compression Test are given below. One can appreciate the smooth load Vs deflection response of a conical spring vis-à-vis cylindrical spring. The nature of the graph approaches linearity in conical helical compression spring while it is not show in the case of cylindrical helical compression spring.

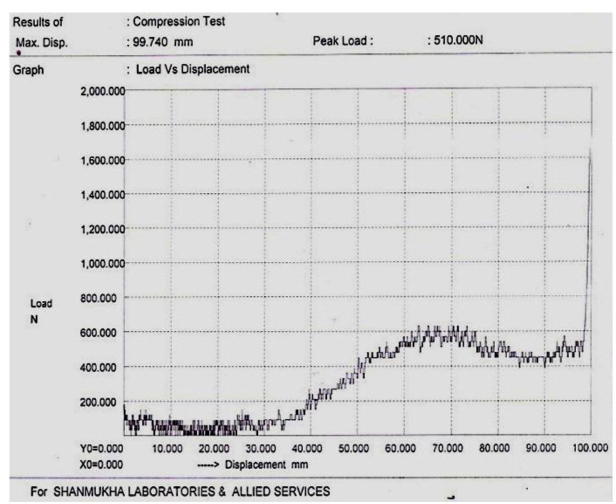

Fig.2: Result of compression test on UTM for Cylindrical spring (wire dia. 3.5mm)

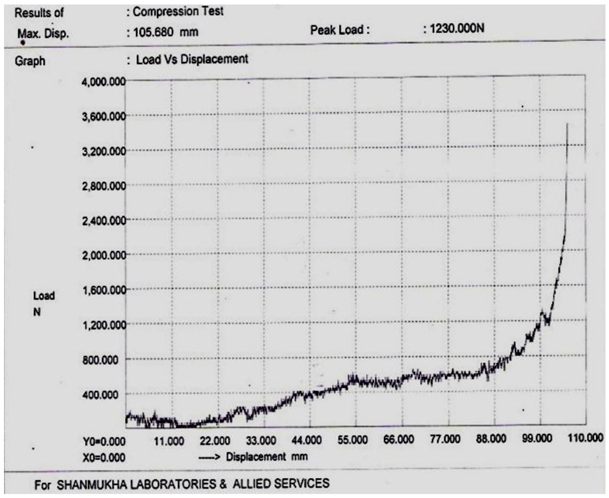

Fig.:3 Result of compression test on UTM for conical spring (wire dia. 3.5mm)

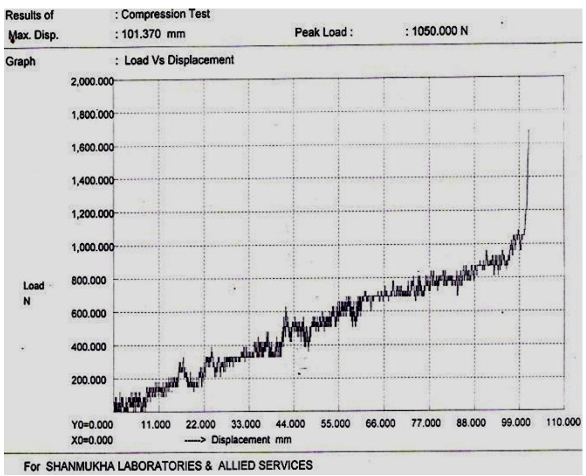

Fig.4: Result of compression test on UTM for Cylindrical spring (wire dia. 4.0mm)

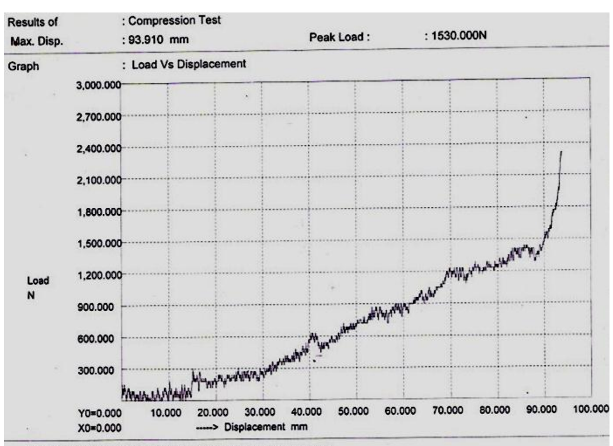

Fig.5: Result of compression test on UTM for conical spring respectively (wire dia. 4.0mm)

The analytical value of peak loads based on maximum deflection outcome reflected in load Vs deflection graph are tabulated below. The corresponding values for friction 'f' have also been tabulated. It is on higher side for conical spring vis-a-vis cylindrical spring. The linear relationship for load Vs deflection is used for calculation of peak load. The friction loading factor 'f' is calculated for these springs as below

f= Peak load (Experimental) / Peak load (Analytical)

For spring made of ASTM A227 material of wire diameter 3.5mm.

Table V: Friction loading factor for cylindrical and conical spring of wire dia. 3.5mm

Parameters	Cylindrical spring	Conical spring
Spring rate 'K'	3.9	4.56
Maximum deflection, δ_{max}	70.0mm	99.74mm
Peak load, P_{max}	273.0 N	454.8 N
Friction loading factor, 'f	1.87	2.7

For spring made of ASTM A227 material of wire diameter 4.0mm.

Table VI: Friction loading factor for cylindrical and conical spring of wire dia. 4mm

Parameters	Cylindrical spring	Conical spring
Spring rate 'K'	6.66	7.79
Maximum deflection, δ_{max}	93.91mm	101.37mm
Peak load, P_{max}	635.44N	789.67 N
Friction loading factor, 'f'	1.68	1.94

VIII. RESULTS AND DISCUSSIONS

The analytical value of peak loads based on maximum deflection at peak load reflected in load Vs deflection graph have been tabulated along with experimental value for the same. The corresponding values for friction loading factor 'f' have also been tabulated. It is on a higher side for conical spring vis-a-vis cylindrical spring for the same material (hard drawn carbon steel material ASTM A227) used for manufacturing of both spring forms. One also observes that conical springs made of the same material (hard drawn carbon steel material ASTM A227) have higher spring rate and smooth load Vs deflection response in comparison to cylindrical spring for the same diameter as well as change in diameter (i.e. 3.5mm dia. to 4mm dia.) The deflection range is also higher for conical spring than that for cylindrical spring.

IX. CONCLUSION

It is evident from analytical calculation and experimental validation that spring rate 'K' is higher for conical helical compression spring than that for cylindrical helical compression spring. Load Vs Deflection response is also smooth for conical Vis a Vis cylindrical spring. Since, spring rate 'K' directly affects mechanical properties of a spring like deflection response to an external load, buckling and surging, conical helical compression spring provides a good option in the field of spring design. It is noteworthy that for the same material, tapering of a helical compression spring of cylindrical form increases spring rate 'K' and thereby improves critical natural frequency and critical stability for spring with high slenderness ratio(L/D > 4).

Thus, it can be concluded that conical spring provides an option vis-avis cylindrical spring for static load as well as gradual load application.

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