International Engineering Research Journal Page No 1542-1548

Analysis of Static and Dynamic Behavior of Variable Pitch Cylindrical Compression Springs in Comparison with Constant Pitch Cylindrical Compression Springs

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***Abstract*--- Behavior of constant pitch cylindrical helical springs subjected to axial load has already been illustrated in the past theories. Unlike cylindrical spring, the stiffness behavior of variable pitch helical compression spring has nonlinear phase. From literature survey it is found that, more research is required in an experimental investigation and analysis of dynamic response of constant pitch cylindrical spring. Different parameters can be used to study dynamic and static response of constant pitch cylindrical helical springs and variable pitch helical compression spring and the effect of that on the behavior of dynamic response.**

In this study, the dynamic response of cylindrical compression springs and variable pitch helical compression spring could be finding out by simulation. By doing experimentation one can evaluate and validate dynamic response of both springs. By comparing the dynamic response and the results of variable pitch helical compression spring with existing systems, one can conclude that which spring will be better for suspension system. This comparison will lead us to the development of better suspension system, if it shows better results. This would help to decide the suitability of variable pitch helical compression spring against cylindrical springs under the given operating conditions.

***Index Terms*— Constant pitch cylindrical compression spring, Comparison between both springs, Variable pitch cylindrical compression spring,**

I. INTRODUCTION

In automobiles, generally the suspension systems are used which have a limited range of response to the impact and jerks due to the different road conditions. Shock absorbers and springs work together to keep tire in contact with the road. Shock absorbers are the heart of our vehicle's suspension system. They absorb the effects of uneven surfaces, reduce vibration and keep the tires in constant contact with the road under all driving conditions; therefore stability and safety depend on them. The purpose of the springs is to support the loads of the vehicle and to absorb the stresses imparted by the road surface, keeping the vehicle body in the correct attitude with respect to the road.

Now days, in automobiles mostly constant pitch helical compression cylindrical springs are used in shock absorber for suspension purpose. It has limited range of response. As design for comfort, becoming more important factor so that we need such a suspension system which will respond to every type of jerks and impacts due to different road conditions. The constant pitch helical compression cylindrical springs has linear stiffness whereas the variable pitch helical compression springs have non-linear stiffness. In variable pitch helical compression springs, there is a necessary increase in the applied force to compress the spring due to the flexibility of the larger-diameter coils causing progressive contact with one another. This characteristic can be advantageous for spring-supported vibrating objects by reducing the resonant (bouncing) amplitudes commonly found in constant-diameter, spring-supported systems. The cylindrical compression springs will have a tendency to buckle when subjected to loading. Hence, spring can no longer provide the intended force. The best alternative is replacing cylindrical spring by variable pitch helical compression springs.When the space in the axial direction is limited.

By comparing the dynamic response and the results of variable pitch helical compression springs with existing systems, one can conclude that which spring will be better for suspension system. It is possible to develop a good suspension system which will have a wide range of response, if it shows better results.

II. LITERATURE REVIEW

Study dynamic characteristic of springs for which test can be carried out at different speeds and loads for the sprung and unsprung mass with Variable wire diameter and Uniform wire diameter springs on test rig of quarter model of car. S. B.Raijade et. al. [1] a comparison between cylindrical and conical springs has been made at the point of buckling of cylindrical spring in respect of their load and deformation.

Rajkumar V. Patil, et al. [2] by the static test and FEA analysis author proven that the stress and deformations of the helical spring is going to be reduced by using the new material. C.Madan Mohan Reddy et. al. [3] represents a general study on the analysis of spring. Compression springs are commonly used in the I.C. Engine valves, 2 wheeler horn & many more and are subjected to number of stress cycles leading to fatigue failure. Supriya Burgul et al. [4]

P.S.Valsange et al. [5] analyses the effect of influence of the coatings on the maximum values of dynamic stresses and the values of natural vibration frequencies of springs. Krzysztof Michalczyk et al. [6] evaluate the effects of the presence of non-metallic inclusions in the early failure of a helical spring subjected to regular design loads during its operation. A FEM analysis was applied in order to evaluate stresses in a helical spring that presented early failure during regular operating loads due to the presence of non-metallic inclusions in the matrix of the material. R. Puff et al. [7]

Jiaxi Zhou et al. [8] a prototype of QZS vibration isolates or with cam–roller–spring mechanisms has been developed. The static and dynamic characteristics have been studied based on a piece wise nonlinear model. When setting the compression smaller than but close to1it can achieve a large displacement range with small stiffness, which is very useful to low-frequency vibration isolation. Hassen Trabelsi et al. [9] Procedure and preliminary research results of long-term fatigue tests up to a number of 109 cycles on shot peened helical compression springs with two basic dimensions, made of three different spring materials. This research project dealed with the VHCF properties of six variants of shot peened helical compression springs (three spring steel wire materials with two different wire diameters each). The VHCF-tests were performed with test equipment at a frequency of about 40 Hz. B. Kaiser et al. [10] The effect of shot peening (SP) on the very high cycle fatigue behavior of 3Cr13 high strength spring steel was investigated. The samples that underwent electro-polishing (EP) and SP treatments were analyzed at 20 kHz by ultrasonic fatigue tests. Baohua Nie et al. [11] the vibration of a coil, excited axially, in helical compression springs such as tamping rammers are discussed. This paper investigated the resonance and beat phenomena of strains due to forced sinusoidal excitation in helical springs. To study vibrations in helical springs subjected to a sinusoidal excitation, we propose a coupled model. Anis Hamza et al. [12]

III. Objectives

The project deals with the study and analysis of static and dynamic behaviour of variable pitch cylindrical compression spring. And the comparison with dynamic behaviour of constant pitches compression spring.

The main objectives of this project are

1) Find out static and dynamic behaviour of variable pitch cylindrical compression spring.
2) Comparison between variable and constant pitch compression spring.
3) Analysis of variable pitch cylindrical compression spring.

IV. Variable Pitch Spring

To achieve a variable rate in dynamic applications where the cyclic rate of load application is near the natural spring frequency the Variable pitch springs are used. During deformation lesser pitch become inactive and the natural frequency of a spring changes. Variable pitch springs has not a single resonant frequency throughout the cycle and the spring has a spectrum of frequency response so that surging and spring resonance are minimized.

In Certain engineering applications involve springs that have progressive or variable rates. Unlike ordinary compression springs which are design to have a linear spring rate but Variable pitch springs can have multiple rates or a progressively increasing/decreasing spring rate as the spring compresses. One way this can be done by varying the pitch, or the center to center distance between the coils. By doing this, some of the coils close up faster than the rest of the coils and become ‘inactive’, meaning they no longer absorb the compressive energy resulting from applied forces. By lessening the amount of active energy absorbing coils, the spring in turn becomes stiffer and the rate increases. With this technology, increasingly greater ranges between rates can be obtained. Springs can even be designed to have a decreased rate as the spring compresses, which is not possible by varying the pitch alone. The transitions between spring rates can easily be controlled by how the spring is manufactured. Barber Spring currently has the resources and know-how to design and manufacture both variable pitch and variable bar springs. Engineers on staff can calculate and design springs to fit any progressive rate requirement you may have.

If the natural spring frequency is near or corresponds with that of the cyclic rate of the load application then Variable-pitch springs are utilized. Natural frequency of the springs changes as coils of lesser pitch become inactive during the spring’s function. This will result in minimizing of surging and spring resonance. Variable pitch springs are used to minimize resonant surging and vibration.

Fig. 1. Variable Pitch Spring

The springs may or may not be preloaded, but preloading is advisable. In practice only one spring is used with a varying pitch in coils. For variable pitch spring all the other formulae given in this standard shall apply.

V. Methodology

Nomenclature-
D_i= inner diameter
D_o= outer diameter
W= width
L_f= free length
p=pitch
SP=starting pitch
EP=end pitch
H=height
Φ= diameter
L= length
t= thickness
ρ= density
ν= poisons ratio
G= young's modulus
E= shear modulus

A. Test Rig and Experimentation

To analyze the behaviour of Variable Pitch Cylindrical Compression Springs (VPCCS) in Comparison with Constant Pitch Cylindrical Compression Springs (CPCCS), the test-rig shown in fig. 2 and 3 has been developed.

This test rig consists of, Bottom rigid plate with the supports and bolted to four supporting bars from bottom side, the upper plate is used for only supporting the four bars at the proper positions and also bolted to this four bars from upper side, the middle plate is sliding plate and it's can freely slide in up and down position using supporting bars and one niddle is welded at bottom side of the for measuring accurate reading of the deformation of the spring on scale which is attach at the one side of rigid bottom plate.

The sliding and rigid plate also consists of aluminium rods for guiding the loads and guiding the position of springs on the plates at centre respectively. This test rig is capable of taking load of 80 kg. The detail about test rig part is given in table I.

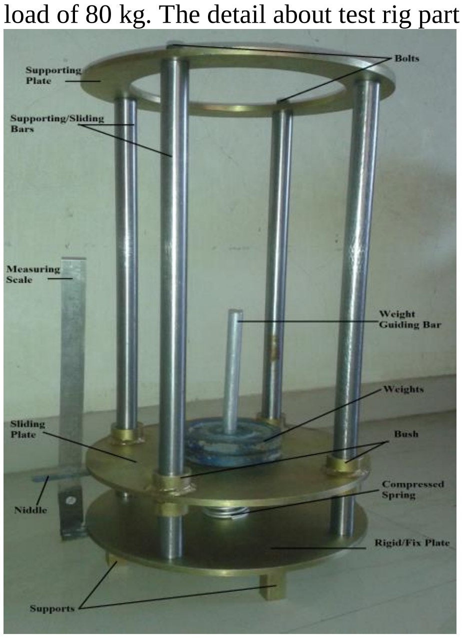


Fig. 2.Actual Test Rig

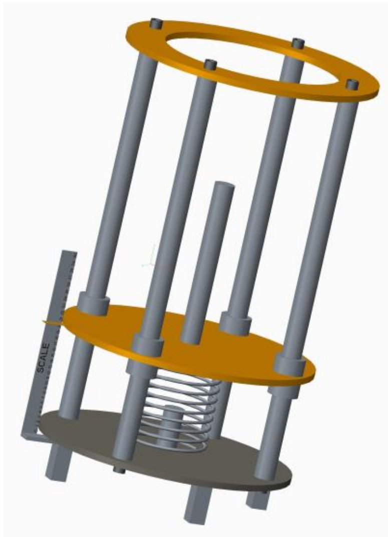


Fig. 3.Modelled Test Rig

TABLE I
Test Rig Specifications

Sr. No.	Test Rig Parts	Parts Name	Dimensions (mm)	Material & Material Properties
1		Supporting Rod	H=550 Φ=25	Mild Steel Bright $\rho=7.8 Mg/m^3$ ν=0.29
2		Bush	L=48 D_o=38 D_i=25	G=76 GPa E=210 GPa
3		Upper Plate	D_o=320 D_i=220 t=8 4holes=10	
4		Sliding Plate	D_o=320 t=8 4holes=25	
5		Bottom Plate	D_o=320 t=8 4holes=10	
6		Support	H=50 W/L=20 L=20	
7		Bolt	M10 L=570	-

8		Wt. Guiding Bar	H=30 D_o=15	Aluminium ρ=2.7Mg/m^3 ν=0.34 G=28 GPa E=70GPa
9		Spring Guiding Bars	H=30 D_o=15	
10		Scale	1 ft.	-

B. *Experimental Method*

The experiment consists of four springs, along with two is variable pitch cylindrical compression springs and others are constant pitch cylindrical compression springs. The springs are made from same material but having different dimensions. The material properties and dimensions of each spring are given in table II.

TABLE II
MATERIAL PROPERTIES AND DIMENSIONS OF SPRINGS

Sr. No.	Springs	Dimensions (mm)	Material Properties
1	 Spring 1	D_i=45 D_o=53 w=4 L_f=126 p=12	Stainless steel 304 ρ=7.8 Mg/m^3 ν=0.28 G=76 GPa E=210 GPa
2	 Spring 2	D_i=45 D_o=53 w=4 L_f=126 p=12 SP=8, EP=15	
3	 Spring 3	D_i=45 D_o=53 w=4 L_f=132 p=11	
4	 Spring 4	D_i=45 D_o=53 w=4 L_f=132 p=11 SP=7, EP=18	

These experiment consist of static test and the test procedure as per the below-

1) Firstly select the group of VPCCS and CPCCS such as they have compare to each other i.e. from above table II spring no. 1 and 2 compare with each other as well as spring no. 3 and 4 compare with each other.

2) Then sliding plate of test rig is given at some height from bottom plate such as we can put spring easily between the sliding and bottom plate.

3) After putting the spring properly on bottom plate then release the sliding plate on spring and find out the deformation of spring for sliding plate load.

4) Then we can put another load on sliding plate and find out deformation in spring for increasing load.

5) This procedure can be carried out for gradually increasing load and find out deformation in spring at each load.

6) The same procedure is also carried out for remaining springs and find out deformation in each springs at each increasing load. The Values of deformation of springs find out from static test is shown in below table III.

Table III
EXPERIMENTAL DEFORMATION OF SPRINGS AT INCREASING LOADS

Sr. No.	Load (N)	Deformation in Spring (mm)			
		Spring 1	Spring 2	Spring 3	Spring 4
1	0	0	0	0	0
2	56.73	39	35	45	39
3	64.82	46	43	50	44
4	72.90	51	48	58	50
5	92.57	65	61	72	62
6	112.24	78	74	88	74

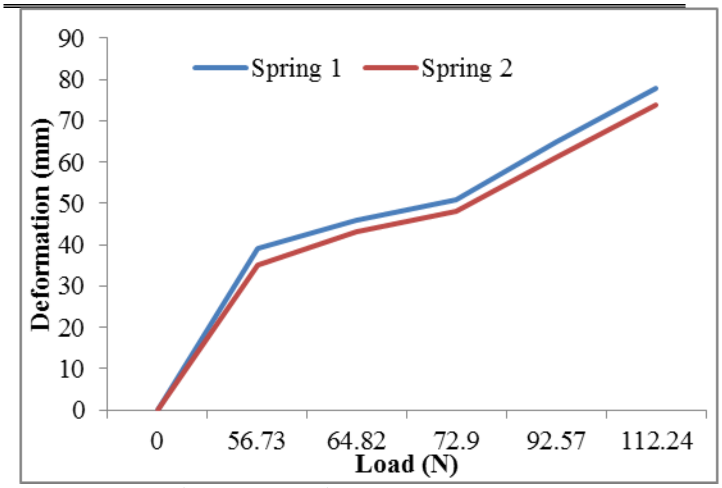


Fig. 4.Load vs. Deformation graph for spring 1 and spring 2

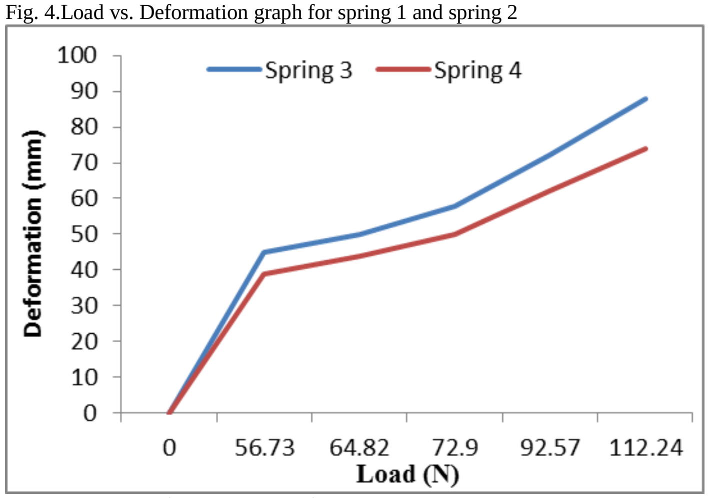


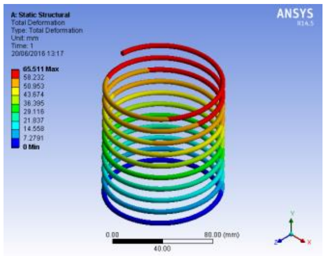
Fig. 5.Load vs. Deformation graph for spring 3 and spring 4

This procedure is also carried out in ANSYS software and find out total deformation in each spring at increasing loads.

The data taken from experimentation is plotted in graphical format which is shown in Fig. 4. and Fig. 5.

The numerical results formed in ANSYS software for each springs and each loads are shown in fig. 6 to fig. 9.

Along with the results of spring 1 and spring 2 are compare to each other's and spring 3 and spring 4 compare to each other's.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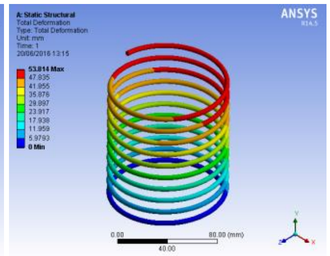
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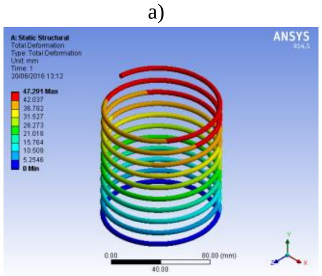
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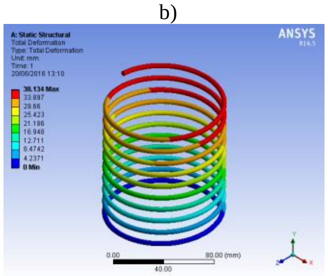
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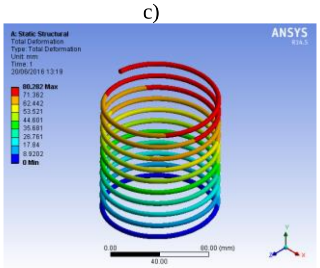
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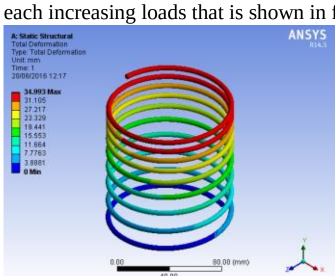
Fig. 6. The numerical results for spring 1 at the load a) 56.73N b) 64.82N c) 72.90N d) 95.57N and e) 112.24N

Results of spring 1 and spring 2 clear that the deformations in spring 2 is comparatively lower than the spring 1 at the each increasing loads that is shown in fig. 6 and fig. 7. And also Results of spring 3 and spring 4 clear that the deformations in spring 4 is comparatively lower than the spring 3 at the each increasing loads that is shown in fig. 8 and fig. 9.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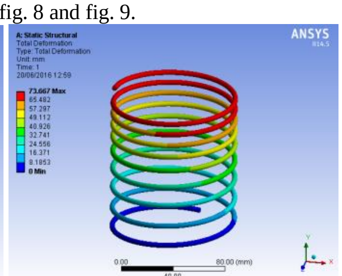
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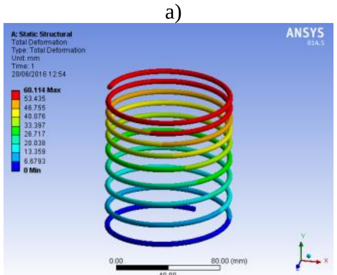
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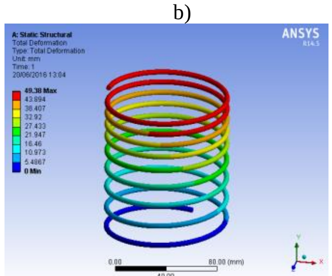
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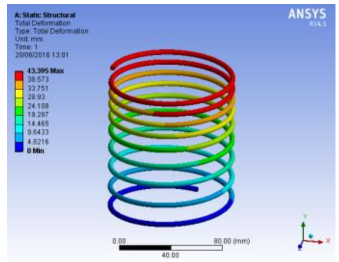
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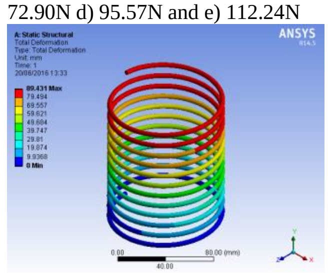
Fig. 7. The numerical results for spring 2 at the load a) 56.73N b) 64.82N c) 72.90N d) 95.57N and e) 112.24N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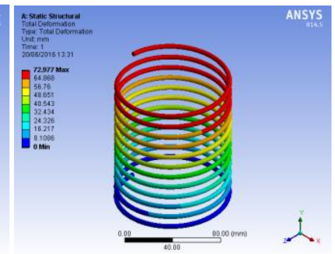
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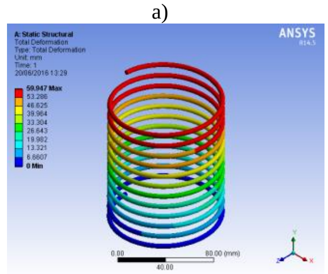
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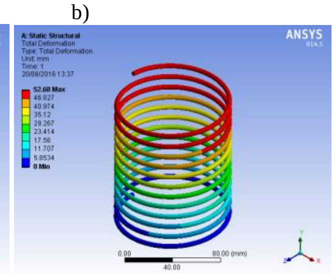
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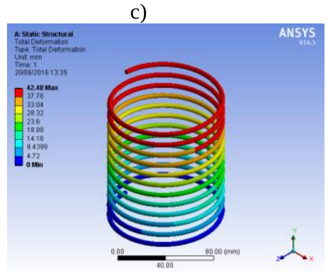
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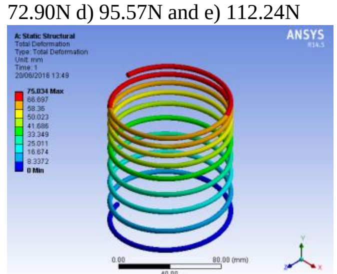
Fig. 8. The numerical results for spring 3 at the load a) 56.73N b) 64.82N c) 72.90N d) 95.57N and e) 112.24N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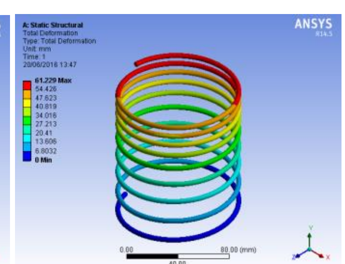
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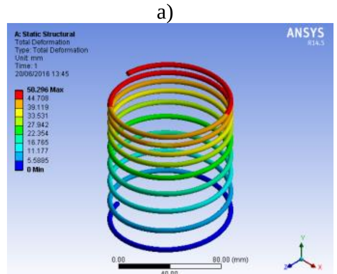
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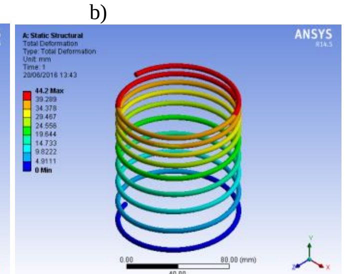
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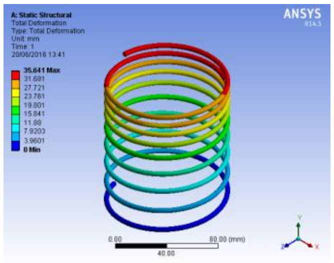

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Fig. 9. The numerical results for spring 4 at the load a) 56.73N b) 64.82N c) 72.90N d) 95.57N and e) 112.24N

VI. Result and discussion

The results come out from experimental and numerical data shows that, the deformation occurred in each springs at the various loads of is nearly equals i.e. the value of deformation in spring 2 at the load of 72.90N is 48mm by experimentation and 39.38mm by the numerical method.

TABLE IV
EXPERIMENTAL AND NUMERICAL DEFORMATION IN SPRINGS

			Load (N)					
			0	56.73	64.82	72.90	92.57	112.24
Deformation (mm)	Spring 1	Experimental	0	39	46	51	65	78
		Numerical	0	38.134	47.291	53.814	65.571	80.282
	Spring 2	Experimental	0	35	43	48	61	74
		Numerical	0	34993	43.395	49.380	60.114	73.667
	Spring 3	Experimental	0	45	50	58	72	88
		Numerical	0	42.480	52.680	59.947	72.977	89.431
	Spring 4	Experimental	0	39	44	50	62	74
		Numerical	0	35.641	44.200	50.296	61.229	75.034

VII. Conclusion

The results find out by experimentally and numerically for the static test, shows that deformation in VPCCS is lower than the CPCCS i.e. stiffness of VPCCS are higher than the CPCCS.

The errors find out in the experimental and numerical results is due to the human error in taking readings, problems occurred in manufacturing of springs, not proper selection in numerical methods etc.

ACKNOWLEDGMENT

I take this opportunity to thank all those who have contributed in successful completion of this work. I would like to express my sincere thanks to my guide Prof. S.Y. Taware and Prof. A.H.Kolekar who has guided me to work on this topic and valuable guidance wherever required. Finally, I am thankful to all those who extended their help directly or indirectly in preparation of this paper.

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