Static and Dynamic Characteristics of Slotted Cylinder Spring

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Abstract

Slotted cylinder spring (SCS) is a unique and unusual spring with special properties and configuration. There is a little or even no literature on its behavior under static and dynamic modes of stresses. In this research an attempt was made to study the characteristics of such a spring under both static and dynamic loading using a finite element method with the aid of ANSYS11 program. Two cases were studied, one with three slots and the other with four slots. Five modes shapes of each case were employed. The transient analysis due to impact and static loadings were presented.
The results showed that the SCS are more complicated in compression with the conventional helical compression springs regarding the deflection resulted from applying static or dynamic loads. The SCS is capable of absorbing loads to such a range which is impossible in the case of conventional spring. It is very clear that the stiffness of a four slots springs was higher than that of three slots, even through the distribution of the deflection along the spring was the same. The natural frequency of the four slots spring is much higher than that of three slots spring. In the case of the impact loading, the results showed that the response at the bottom of the spring is zero and gradually increased towardthe top of the spring. This was more obvious in the case of three slots spring.

Keywords: Spring, slotted cylinder spring, ANSYS, Finite elementmethod, vibration, dynamic analysis, natural frequency, impact load

1. Introduction

The slotted cylinder spring can be considered as parallel series assembly from cylindrical pipes having grooves like windows and represented the flat rings, connected by vertical path. It's equivalent to the compressive spring when collected on each other and vice versa, and it's used in equipments with different sizes. Like any other spring, the design of the slotted cylinder spring depends on geometric parameters, material parameters and load- deflection characterization. The slotted cylinder springs are specified within the rigid stiffness springs, i.e. with hard axial load, the body of spring displaced gradually. The slotted cylinder springs used in many fields of industry, like transducer for the generation of seismic waves, which combined the small and large stiffness of elastic elements in electromechanical equipments and in the bridges and buildings to damp the earthquakes. Other application is growing continuously like slotted cylinder spring used in the large press to damp the impact of the punch on the die.

The most prominent task for which the springs aredesigned in the machine partsfor energy storage, and rewind for the purpose of achievinga particular act at a particular time, as an important parameter entry in the design which is the space occupied by the spring, it is an important factor in the design, and this might affects the design of the dies. The slotted cylinder spring meets the work requirements for small spaces and with great local capacity which can not be provided by springs from other types.In the design of dies there are complications in the size of the die as a result of the availability of small powerful springs according to the space available for designer is forced to fight many complexities in the design of the die. The use ofslotted cylinder springs in the dies and specially in the cutting dies simplified the design process and makes it more economical and practical at the same time.

2. Previous Research

The report of***Wilhem A. Schneider, 1963*** [1] It's the only one who worked on the slotted cylinder spring, in this report the unique characteristics of high load capacity and low deflection in extremely small size was discussed. Theexperimental and theoretical investigation is reported by ***Wilhem A. Schneider, 1963*** [1]. ***V. Yıldırım (2009) [2]*** studied the free vibration of cylindrical isotropic helical springs loaded axially. ***Ikechukwu Celestine Ugwuoke (2008) [3]*** studied the dynamic model for the constant-force compression spring based on the pseudo-rigid-body model.***B.Vijaya Lakshmi and I. Satyanarayana (2012) [4]*** studied static and dynamic analysis on composite leaf spring in heavy vehicle, ***Gaikwad and Kachare (2013) [5],*** studied the static analysis of helical compression spring used in two-wheeler horn.***Christine Vehar Jutte and Sridhar Kota (2008) [6]*** design of nonlinear springs for prescribed load-displacement functions, they presented a generalized nonlinear spring synthesis methodology that (i) synthesizes a spring for any prescribed nonlinear load-displacement function and (ii) generates designs having distributed compliance.***K.A. Saianuraag &BitraguntaVenkataSivaram (2012)[7]*** , studied the comparison of static, dynamic & shock analysis for two & five layered composite leaf spring, the leaf springs are modeled with unigraphics software NX7.5 and the analysis is carried out using ANSYS 11.***G. Harinath Gowd and E. Venugopal Goud (2012)[8]*** studied the static analysis of leaf spring, in this work the analyzing the safe load of the leaf spring, which will indicate the speed at which a comfortable speed and safe drive is possible. A typical leaf spring configuration of TATA-407 light commercial vehicle is chosen for study. Finite element analysis has been carried out to determine the safe stresses and pay loads.***Krzystof Michalczyk(2006) [9]***presented the modern construction of slotted springs, it was proven that maximal stresses in such springs under load have higher values than the stresses calculated with previous method. ***Viatcheslav Gnateski (2012) [10]*** presented a vibration damping device adapted to receive an electronic component and reduce vibration.

No studies have been devoted to the case of static and dynamic slotted cylinder spring. This paper presents an investigation theoretically and numerically via ANSYS software to predict the design characterization of the slotted cylinder springand have a novel discussionof the dynamic behavior (natural frequencies, mode shapes and transient response) of the slotted cylinder spring.

3.Theoretical Part

The total deflection of a slotted cylinder spring is reported by ***Wilhem A. Schneider, 1963*** [1] as follows:

$$\delta_{tot} = \frac{n_{ss}.L_s^3.P}{n_s.16.b.h^3.E} \qquad (1)$$

Where :

P.. total compression load

E.. Yong's modulus of elasticity

L_s.. length of slot

n_{ss}.. number of slot section

n_s.. number of slots per section

b.. wall thickness

h.. height of horizontal path

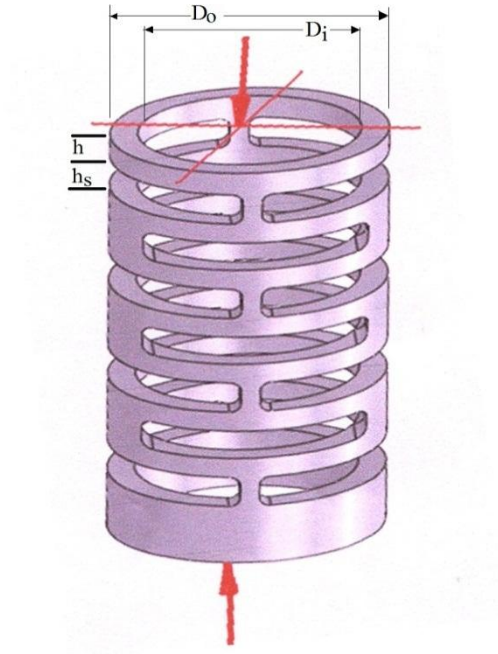
δ_{tot} .. total deflection

4.Numerical Investigation

Numerical simulations allow the analysis of a complex phenomena without resorting to expensive prototypes and different experimental measurements. ANSYS is a finite element analysis software package. This program analyzes and solves a wide range of different problems, such as the modal , harmonic and transient analysis. The typical analysis in ANSYS involves three distinct processors [11], (1) the processor (PREP7), (2) (SOLUTION) and (3) following the general post processor (POST1) and time history postprocessor (POST26).

The processor (PRESP7) contains the commands needs to build a model.

Defining element types (SOLID45), real constant, material properties (Steel with Young modulus (E)=210 Gpa, possion's ratio= 0.33 , and density $(\rho) = 7850\ Kg/m^3$, $yield\ stress\ (\sigma_y) = 1030\ Mpa$), creating model geometry as in Fig.1.



where :
Outer diameter (D_o) =50.8 mm
Inner diameter (D_i) = 44.45 mm
Height of Horizontal path (h) =2.38 mm
Height of slot (h_s) = 0.78 mm
No. of slots = 60

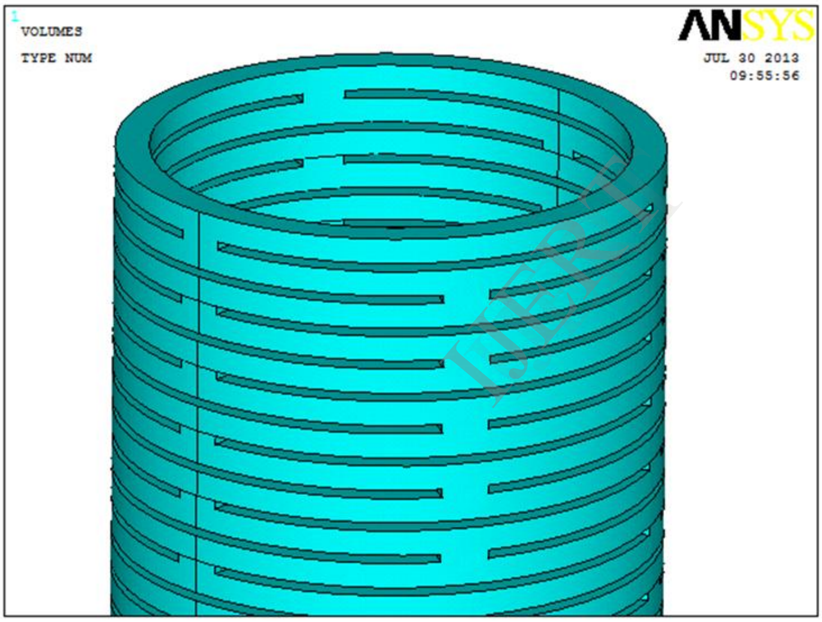


Fig.1 Slotted cylinder spring

Then meshing the created model [12], mesh must be regular, one section is built and meshed then copy for 60 sections, this is important in minimizing the solution time and increasing the accuracy when boundary condition is applied. In this work the finite element model is built up manually (through the APDL) according to the steps which will be followed, automatic building of the mesh is possible through a macroprogram [13], in the present work the design and analysis are concerned for the slotted cylinder spring. Different geometries are used (three slots and four slots with different geometry parameters). Fig.2 shows the meshing of the slotted cylinder spring.

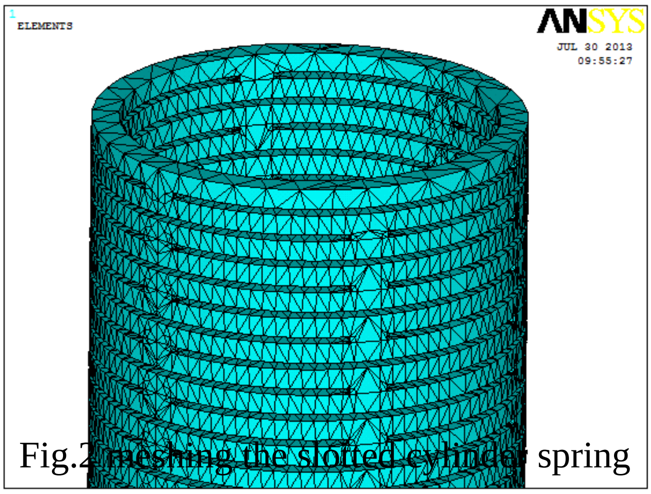


Fig.2 meshing the slotted cylinder spring

The solution processor (SOLUTION) has the commands that allow to apply the boundary conditions and loads. Once all the information are made available to the solution processor, it solves the nodal solution. The solutions to be obtained depend on the type of analysis that should be performed, in the present work, three types of analysis are used, STATIC, MODAL, and TRANSIENT. In the STATIC solution, it can be get the deflection for the slotted cylinder spring according to equation(2) [14].

$$[K]\{u\} = \{P\} \quad \ldots\ldots (2)$$

Whereas in Modal and Transient analysis , it can be used the following equation

$$[M]\{\ddot{\delta}\} + [K]\{\delta\} = \{F_{(t)}\} \quad \ldots\ldots (3)$$

Where:

[K] = overall stiffness matrix = $\sum_{i=1}^{M}[K_e]$

[M] = overall stiffness matrix = $\sum_{i=1}^{M}[M_e]$

$[F_{(t)}]$ = assemblage of resultant vector of nodal forcing Parameters

While in the MODAL solution , Hani [15], show the details of the theory used in this dynamic characteristics, so only basic points are described in brief as below. In the first step, eigen modes of the slotted cylinder spring are obtained from the following equation

$$([K_s] - \omega^2[M_s])\{u\} = 0 \quad \ldots\ldots (4)$$

the eigen mode of the slotted spring of the n modes from Eq.(4) as follows :

$$u = \sum_{i=1}^{n} \phi_i C_i = \Phi C \qquad \text{……………………………………………..…….. (5)}$$

In the second step, this reduced eigenvalue equation is solved.

In TRANSIENT solution.The impact load is applied as shown in Fig.3

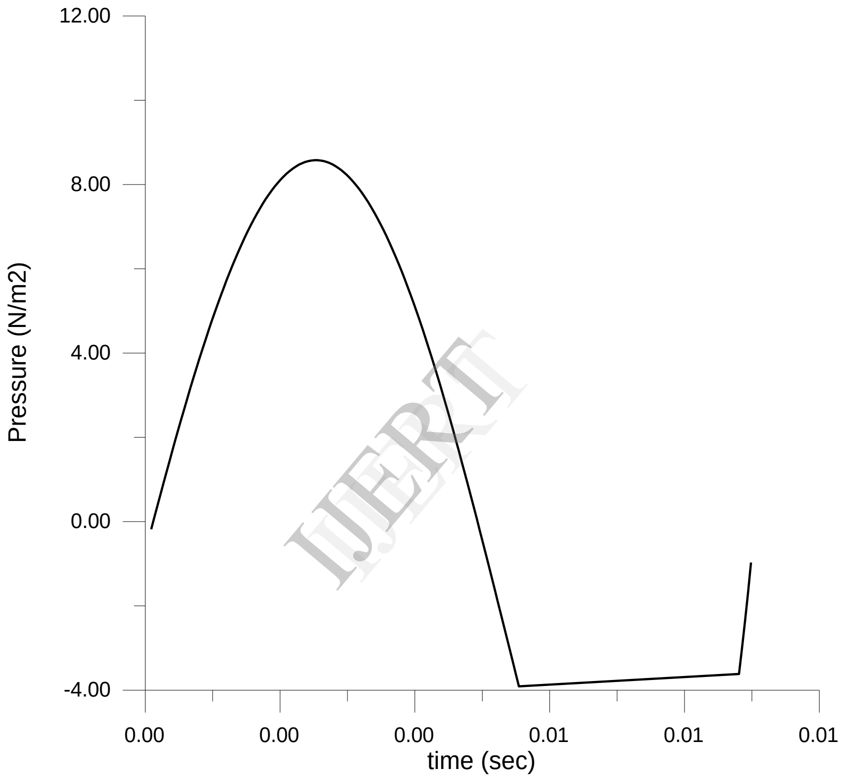


Fig.3 Impact load applied on the slotted cylinder spring

Slotted cylinder springs are very often subjected to transient excitation. A transient excitation is a highly dynamic, time- dependent force exerted on the solid or structure, such as earthquake, impact and shocks [16] .

The discrete governing equation system for such a structure is still equation(3), but it often requires a different solver from that used in eigenvalue analysis. The widely used method is the so-called direct integration method. The direct integration method basically uses the finite difference method for time step-ping to solve equation(3). There are two main types of direct integration method: implicit and explicit. Implicit methods are generally more efficient for a relatively slow phenomena, and explicit methods are more efficient for a very fast phenomenon, such as impact and explosion. The most widely used algorithm is Newmark's method thatused in ANSYS for transient analysis.

5.Results and Discussion

Slotted cylinder spring model analysis is investigated in which the static analysis is investigated for each case as shown in Fig.4 , it can be deduced that the stiffness of the slotted cylinder spring in case of four slots is more than three slots , but the distribution of the deflection along the spring is the same as shown in Figs. 5 and 6. Eigenvalue and eigenvector for each case is studied. Free vibration analysis consists of studying the vibration characteristics of the slotted spring, such as natural frequency and mode shapes.The natural frequency and mode shapes of a slotted cylinder spring are very important parameters in the design of a machine parts and dies and punches for dynamic loading conditions and minimization of machine and dies failures, Fig.7 shows the natural frequencies for each case (3 slots and 4 slots)against to five mode shapes, from this figure it can be deduced that the natural frequency for four slotted cylinder spring is more higher than that of three slots since the SCS with four slots have higher stiffness than three slots. Figs. 8 and 9 show the five mode shapes for each case (3 slots and 4 slots) , it can be seen it is the same mode shapes. Also a forced vibration is studied by imposing the slotted cylinder spring to the impact loading (as shown in Fig.3) to show its response for both cases. Figs.10 and 11 show the response of the slotted cylinder spring with three slots and four slots respectively, it can be seen that the response at the bottom is zero and increased toward the top of the spring for each case but the response of the spring with three slots is more than that four for slots.

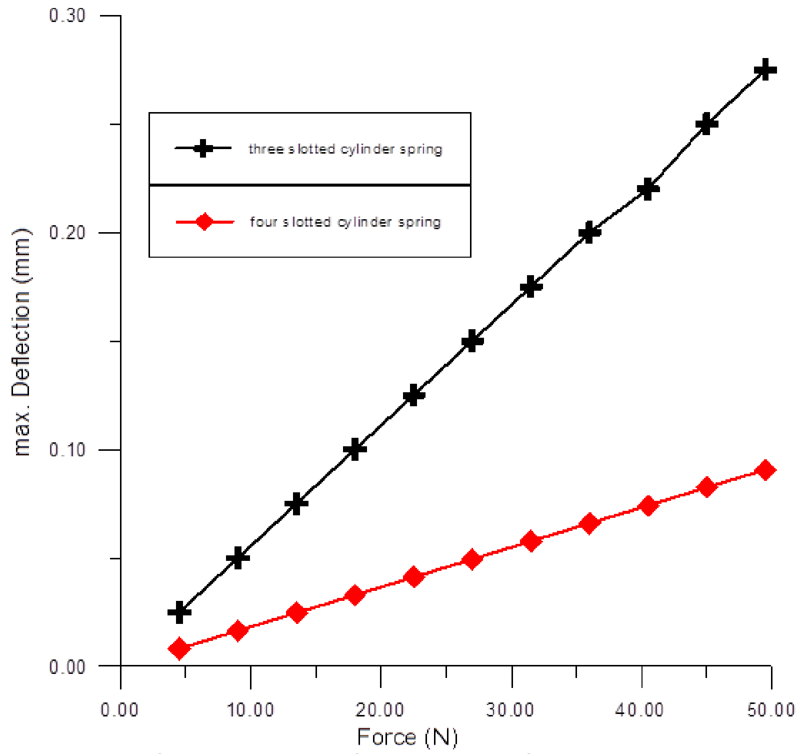


Fig.4 Force- Deflection curves for three and four slotted cylinder spring

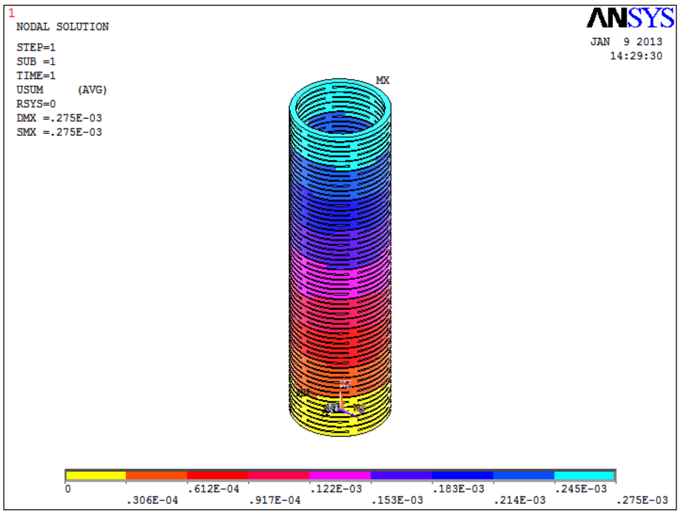


Fig.5The distribution of the deflection along the slotted cylinder spring with three slots

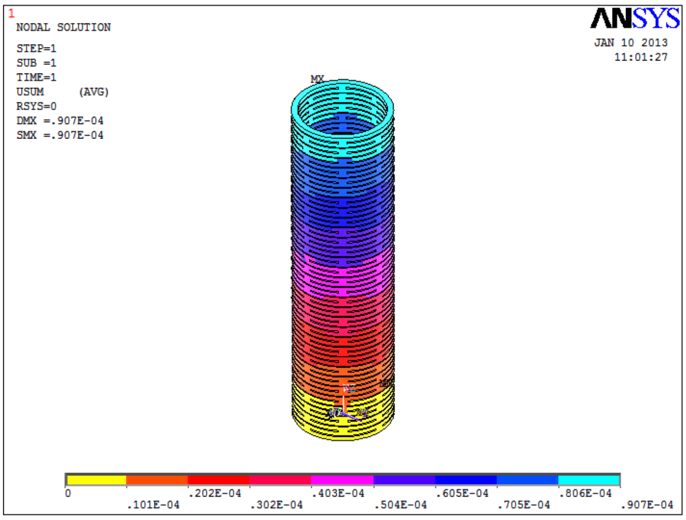


Fig. 6 The distribution of the deflection along the slotted cylinder spring with four slots

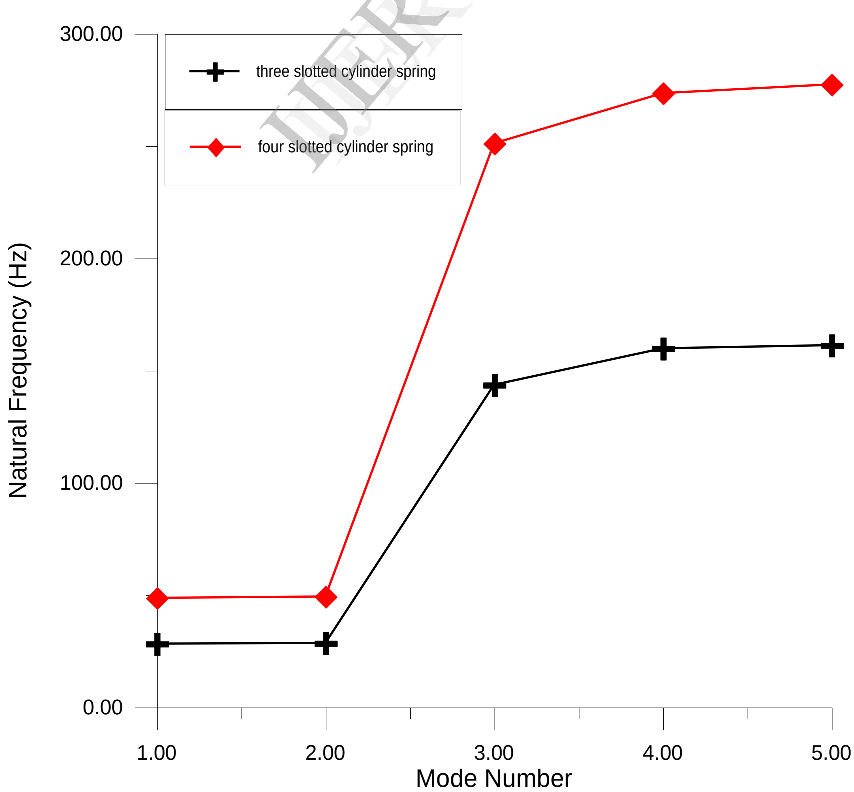


Fig. 7The natural frequencies for three and four slotted cylinder spring

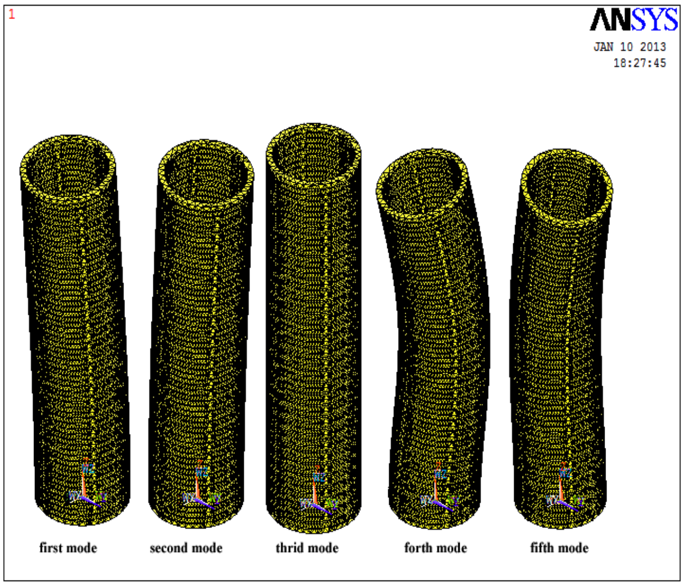


Fig.8The modes shape of the slotted cylinder spring with three slots

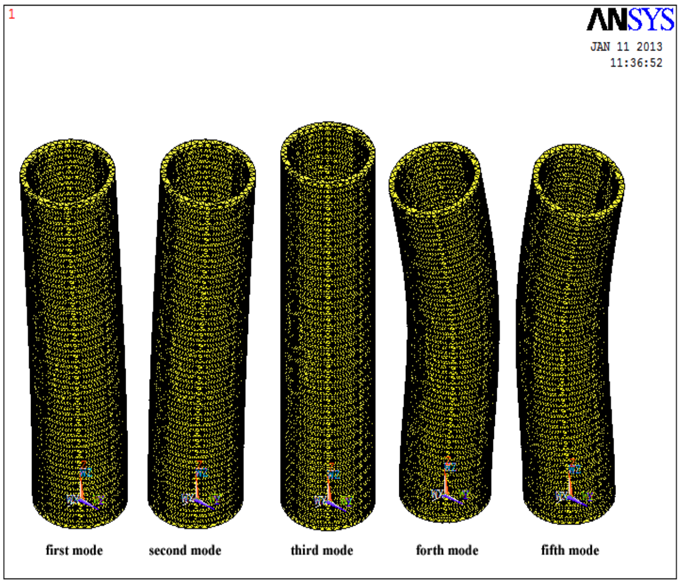


Fig.9The modes shape of the slotted cylinder spring with four slots

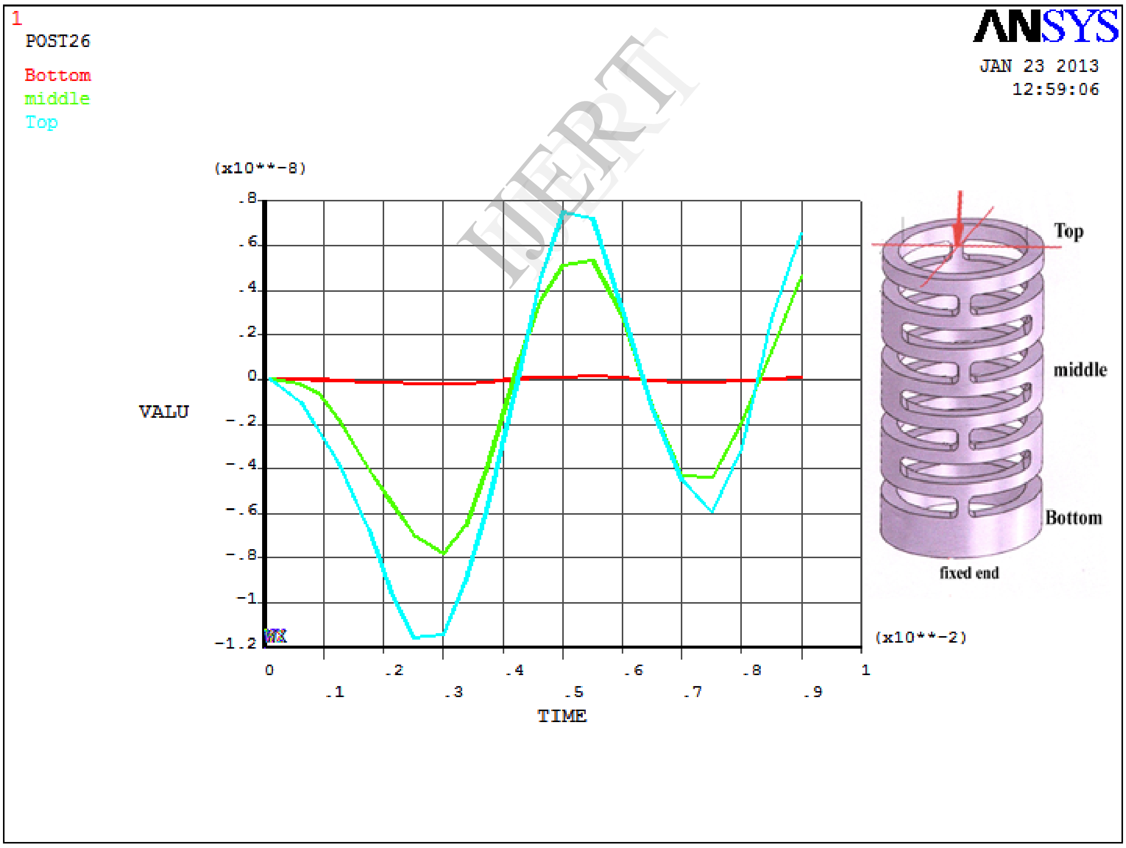


Fig. 11 Response to the impact load at three points on the four slotted cylinder spring

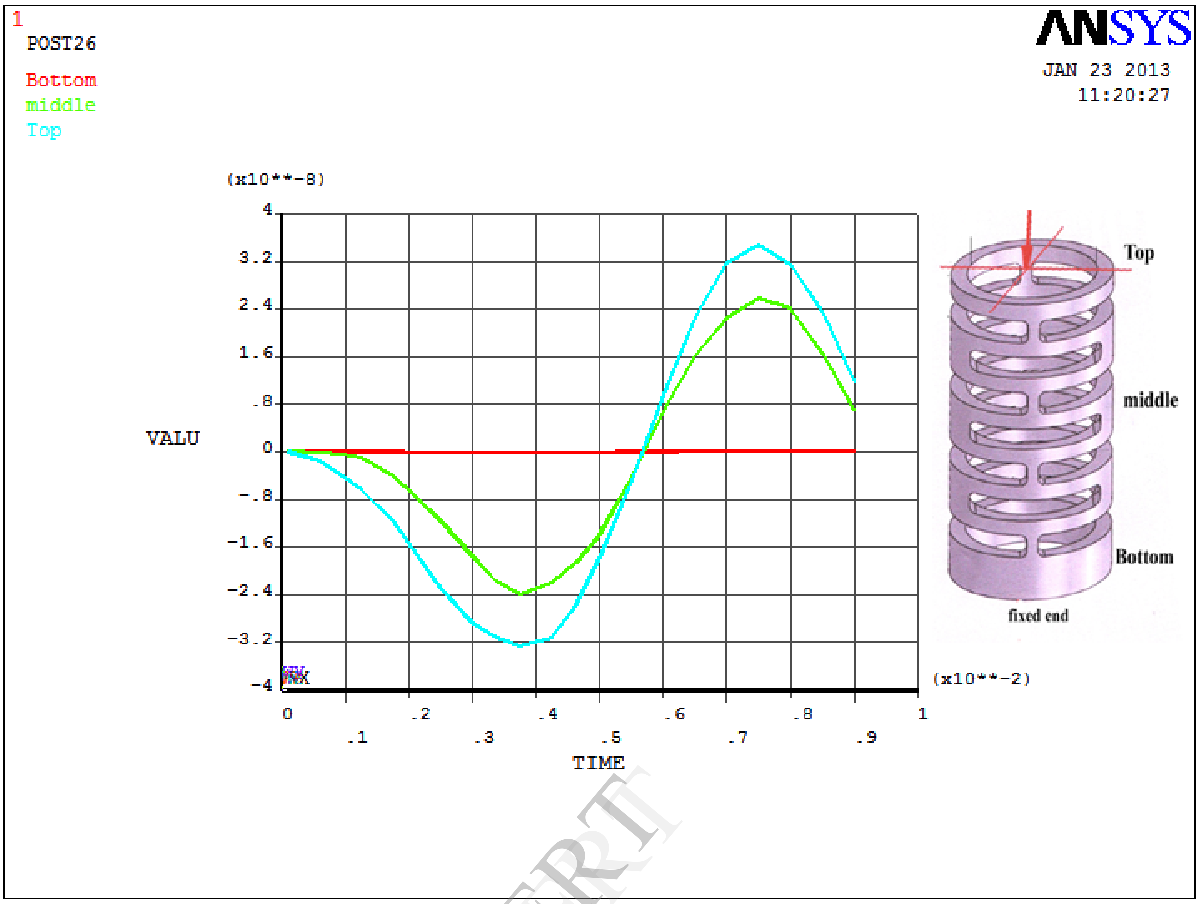


Fig. 10 Response to the impact load at three points on the three slotted cylinder spring

6.Conclusions

1- The slotted cylinder springs are more complicated in the manufacturing process compared to the conventional one, but the former will do jobs which can never being accomplished with conventional one.
2- It can be deduced from the static analysis that the stiffness of the slotted cylinder spring in case of four slots is more than three slots, but the distribution of the deflection along the spring is the same
3- For Modal analysis, it can be deduced that the natural frequency for four slotted cylinder spring is more higher than that of three slots.
4- At impact load, it can be seen that the response at the bottom of the spring is zero and increased toward the top of the spring for each case but the response of the spring with three slots is more than that for four slots.

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