Finite Element Analysis of Helical Coil Spring with Cushioning Buffer

T. A. Jadhav, M. P. Angaj, V N Kapatkar
Department of Mechanical Engineering,
Sinhgad College of Engineering, Vadgaon, (Bk), Pune,
411041, Maharashtra, India
(Savitribai Phule Pune University)

***Abstract*— Stiffness of spring depends on various parameters such as spring diameter, spring index, coil diameter and grade of material etc. In this study effect of coil spring with and without polyurethane cushion buffer on spring damping capabilities has been analyzed. Modal analysis, harmonic analysis and explicit analysis has been carried out by Finite Element Analysis, in order to analyze the optimum position of cushioning buffer i.e. at top of spring, middle of spring or at the bottom of spring. Finite element analysis has been carried on helical coil spring with and without polyurethane cushion buffer at two excitation frequencies i.e. 1Hz and 2Hz. From finite element analysis results, it was observed that the acceleration of spring using cushioning buffer reduced by 23% as compare to spring without cushioning buffer.**

Keywords—Cushioning buffer, Suspension, Energy absorption, Damping, Polyurethane Buffer.

I. INTRODUCTION

A spring used in various applications gradually decreases the damping capability over the period of time. In order to enhance the damping capability, the cushioning buffer is inserted at appropriate location on the spring. Cushioning buffer acts as a damper in spring mass system. In any physical systems, damping means to dissipate the energy stored in the spring by means of oscillations. Cushioning buffer is made up of polyurethane material which is having good damping capability. Generally cushioning buffer is placed at middle of spring to get maximum damping. There are several circular holes provided on cushioning buffer for dissipation of heat. Particularly for automotive application cushioning buffer improve driving comfort and stability at curve roads also provides good breaking capability.

Ahmad Partovi Meran [1] has analyzed the damping performance of an elastomer buffer embedded in the suspension of an automobile by FEM and analytical approaches. Damping performance has been increased significantly due to application of cushioning buffer. Xun Chen et.al [2] have studied the effect of cushioning buffer on high pressure cylinder. The finite element model of excavator was validated with experimental analysis. The oblique planes on the outer surface of cushioning bush play the most important role in the cushioning of cylinder piston. A. K. Malik et.al [3] have investigated experimentally restoring and damping characteristic of elastomer buffer. The nonlinearity is more important in the damping characteristics as compared to that in the stiffness characteristics. Yuqi Wang et.al [4] have discussed fatigue life of suspension component of automotive suspension. Model was simulated with help of MATLAB software. Stress calculated based on Von Misses stress criterion for a quarter car model. After application of cushion, damping reduces at the maximum deformation and maximum acceleration condition. C.R. Mehta et.al [5] have carried out experimental analysis of cushioning. It was observed that the equivalent viscous damping coefficient of cushion materials decreased with the increase in frequency and maximum amplitude of vibration. It decreases very sharply in the lower frequency range up to 3 Hz.

Kazem Reza Kashyzadeh et.al [6] have studied fatigue analysis of suspension for different road conditions at vehicle velocity of 100Km/hr. MATLAB software was used to simulate road conditions and fatigue analysis. The fatigue crack was observed after 46388.9 Km of vehicle running. H. B. Pawar et.al [7] optimized spring parameters in order to reduce weight of the suspension. Analysis shows that the stiffness of modified spring has been increased by 10% compare to existing spring.

The aim of this work is to find damping capability of helical coil spring with and without Cushing buffer by Finite Element Analysis approach and to decide optimum location of the cushioning buffer.

II. ANALYSIS OF SPRING AND CUSHIONING BUFFER

A) Modeling of spring

The parameters of WagonR front suspension helical coil spring is used for analysis. Both ends of spring are flat and grounded in order to weld it on flat plates. The model of spring is prepared using CATIA V5.

The helical spring used for analysis have wire diameter 10 mm, spring index 10.5, free length of 385mm and 37mm pitch. The material used for spring is spring steel having modulus of elasticity 200GPa. Fig 1 shows the CAD model of helical coil spring without cushioning buffer.

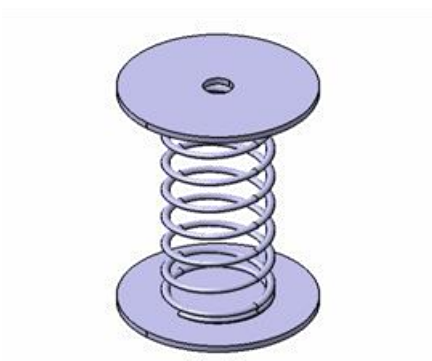

Fig. 1 Spring without cushioning buffer

Fig. 2 shows the spring with cushioning buffer. The cushion is provided at middle of spring in order to analyze the performance. The other configurations of sprig models were prepared with cushioning buffer at top and bottom of spring. Eight circular holes are provided on circumference of cushion. The outer diameter of cushioning buffer is 24 mm, inner diameter is 10 mm and length of 325 mm.

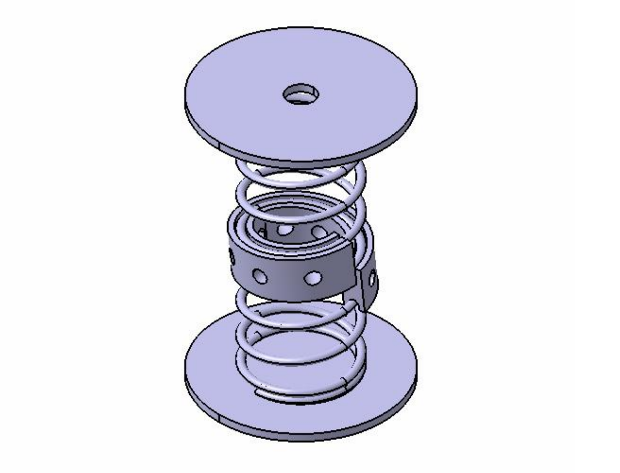

Fig.2 Spring with cushioning buffer

B) *Modal analysis*

The CAD model is imported in ANSYS for analysis, the spring steel material is assigned for spring while structural steel is for upper and lower plate and for cushioning buffer Polyurethane.

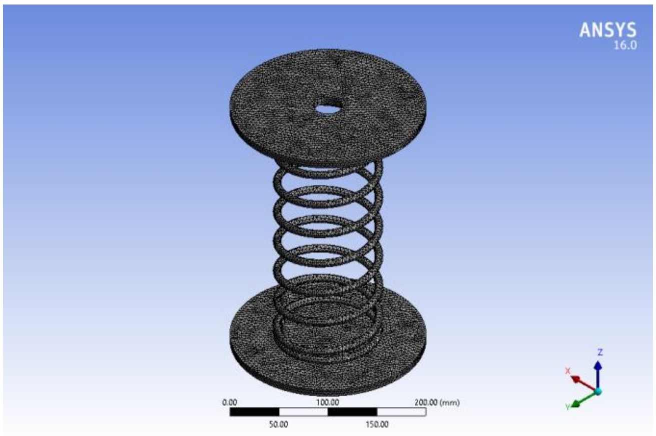

Fig. 3 Meshing of spring without cushioning buffer

Meshing of spring is done with tetra meshing with mesh size of 4 mm and number of nodes equal to 118851 and numbers of elements are equal to 68880.

Modal analysis is carried out to find out natural frequency of the system. The boundary conditions are used as; the lower plate is fixed and distributed mass of 10Kg is applied on upper plate and frictionless support is provided on circumference of upper plate. The boundary conditions are decided based on quarter-car model approach, however due to experimental limitations we use said mass.

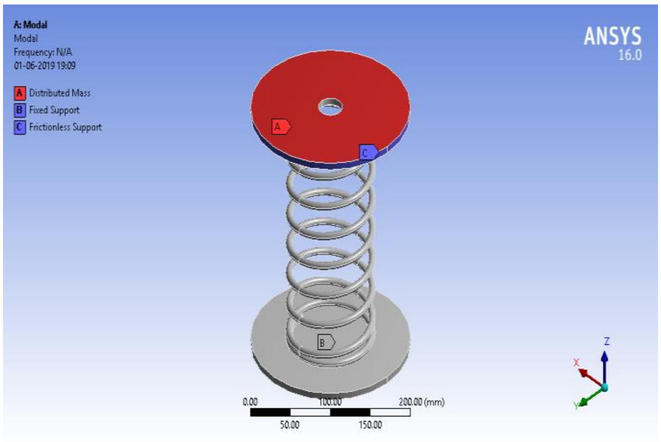

Fig.4 Boundary condition

Different mode shapes and frequencies are obtained by performing modal analysis and values corresponding to there are presented in Table I. Fig 5 shows the mode shape and natural frequency at first mode.

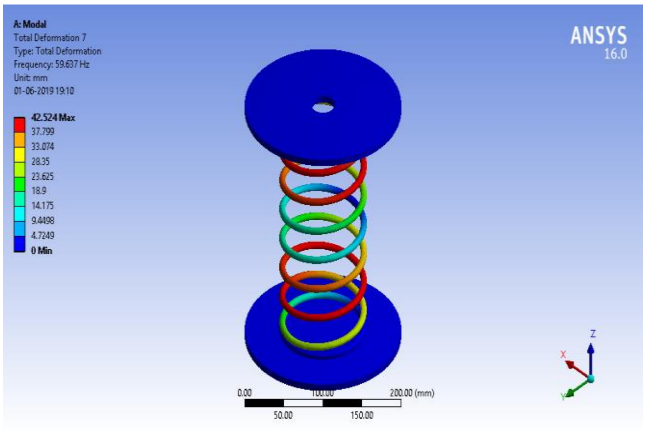

Fig. 5 Modal analysis without cushioning 1

From ANSYS different natural frequencies were obtained for spring without cushioning buffer.

Table. I Frequencies of spring without cushioning buffer obtained from FEA

Mode No.	Natural frequency (Hz)
1	59.637
2	128.36
3	191.07
4	250.82
5	310.1
6	377.1

Further analysis of spring with cushiniong buffer is carried with same identical procedure. Meshing of spring with cushioning buffer is done with tetra meshing with number of nodes equal to 154838 and numbers of elements are equal to 92193.

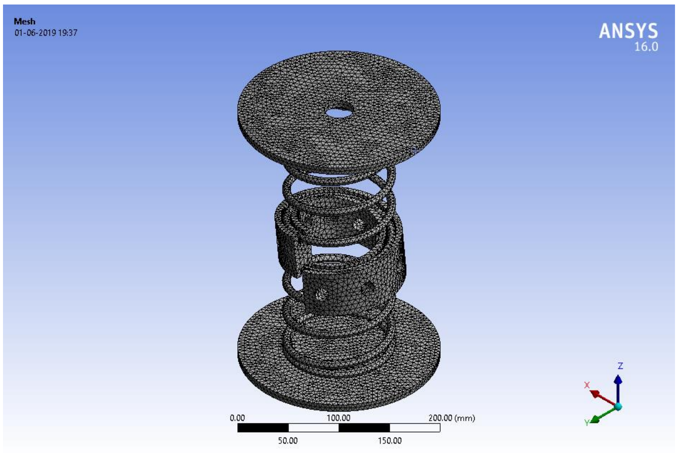

Fig. 6 Meshing of spring with cushioning buffer

The modal analysis is carried out in similar fashion as shown in Fig.7.

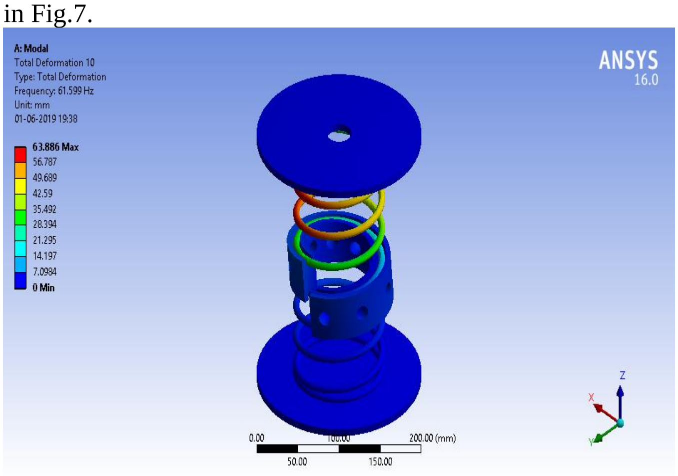

Fig.7 Modal analysis with cushioning buffer

The modal analysis results are shown in Table II.

Table. II Natural frequencies with cushioning buffer

Mode No	Natural frequency
1	61.599
2	130.26
3	194.09
4	254.33
5	324.92
6	397.1

C) Harmonic analysis-

Harmonic analysis has been carried out in order to find out relation between output acceleration with input acceleration. CAD model which was prepared using CATIA v5 is imported in ABAQUS 6.14-3. In ABAQUS spring steel material was assigned to spring and Polyurethane was assigned to cushioning buffer. The frictional contact was assigned to the spring and cushioning buffer.

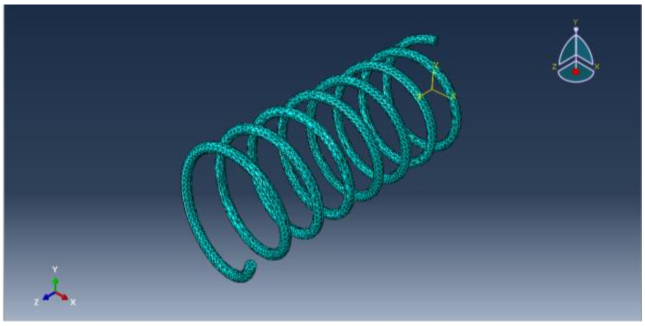

Fig.8 Meshing of Spring without cushion

Meshing of spring is done with 3D tetra meshing with mesh average size of element being 5mm because accuracy of result depends upon it. Minimum element size was 4mm selected such that it will reduce computational time. Number of nodes equal to 48885 and numbers of elements are equal to 13452.

Boundary conditions applied to the spring without cushioning buffer are as follows, the yellow arrow in fig. 9 shows body force, blue arrow show velocity and displacement constraint, bottom of spring was fixed which shown by orange arrow and load of 98.1N was applied on top of spring.

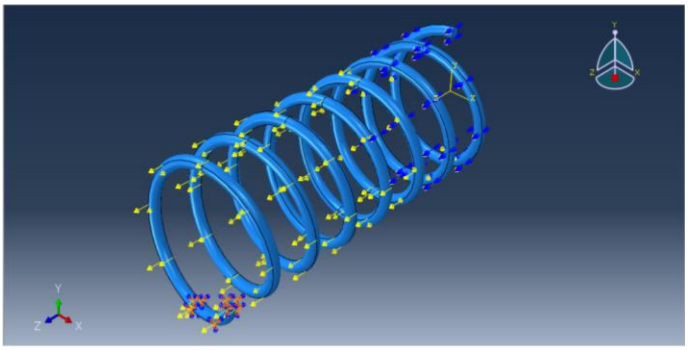

Fig.9 Boundary Condition

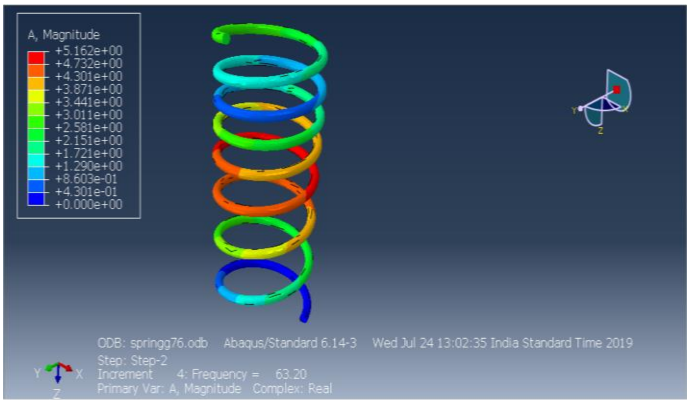

Fig.10 Harmonic analysis at 1Hz excitation

Fig. 10 shows harmonic analysis of spring without cushioning buffer at 1Hz excitation frequency. The maximum acceleration observed was 5.16 m/s^2.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 09, September-2019

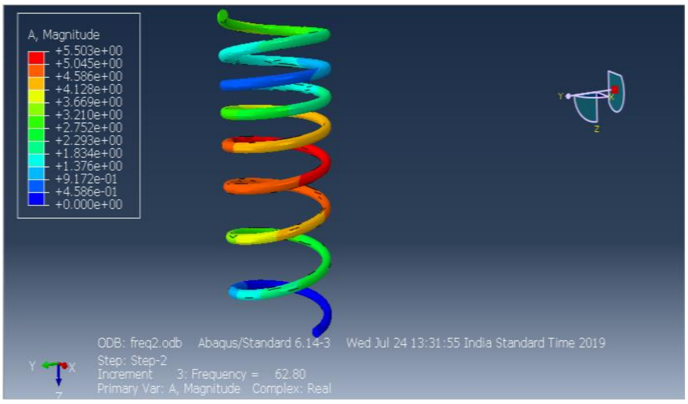

Fig.11 Harmonic analysis at 1Hz excitation

Fig. 11 shows harmonic analysis of spring without cushioning buffer at 2Hz excitation frequency. The maximum acceleration observed was 5.503 m/s^2.

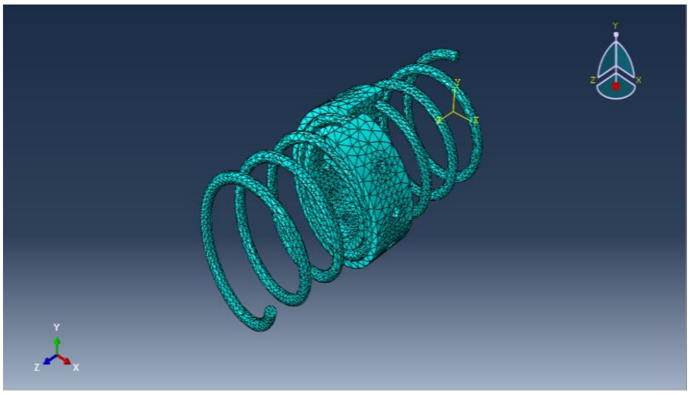

Fig.12 Meshing of Spring with cushion

Fig. 12 shows the spring with cushioning buffer. Meshing of spring with cushioning buffer kept similar as meshing of spring without cushioning buffer. To carry out mesh tetra mesh was used with average element mesh size of 5mm. The number of nodes equal to 65421 and numbers of elements are equal to 19523.

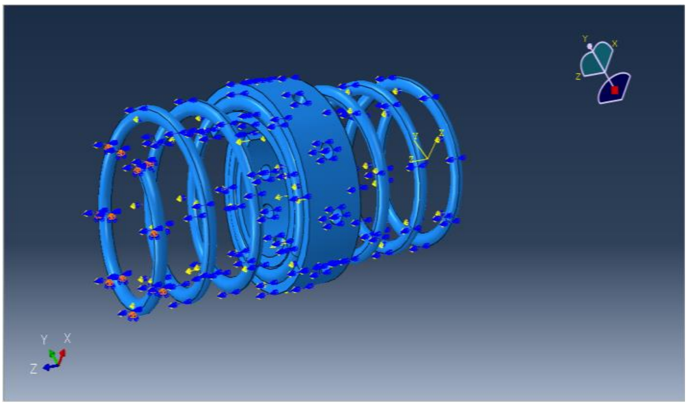

Fig.13 Boundary Condition

The boundary conditions applied for spring with cushioning buffer are as follows. The yellow arrow in fig. 13 shows body force, blue arrow shows velocity and displacement constraint, bottom of spring was fixed which shown by orange arrow. The load of 98.1N was applied on top of spring.

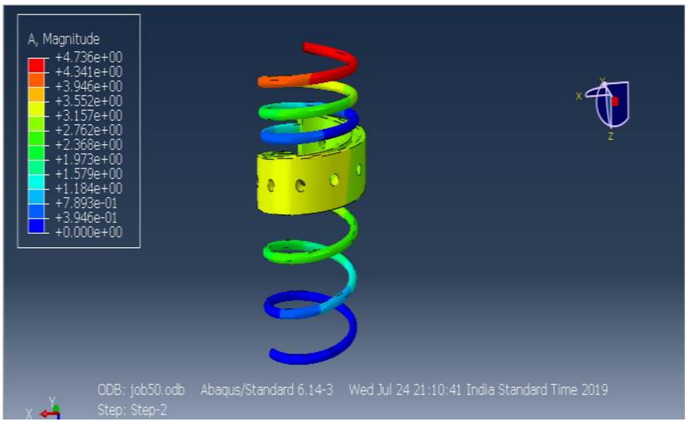

Fig.14 Harmonic analysis at 1Hz excitation

Fig. 14 shows harmonic analysis of spring with cushioning buffer at 1Hz excitation frequency. The maximum acceleration observed was 4.736 m/s^2.

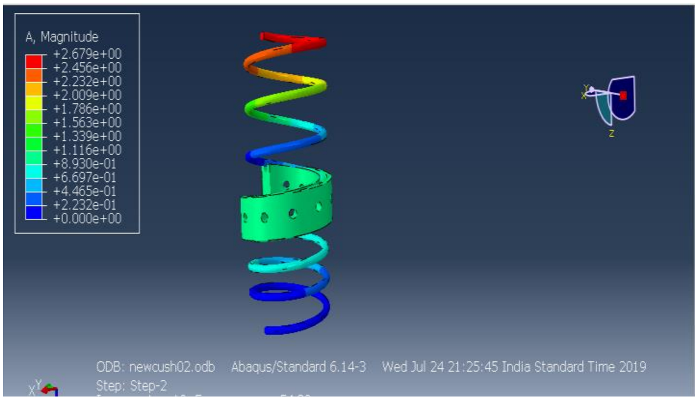

Fig.15 Harmonic analysis at 2Hz excitation

Fig. 15 shows harmonic analysis of spring with cushioning buffer at 2Hz excitation frequency. The maximum acceleration observed was 2.68 m/s^2.

C) Explicit analysis

To understand the effect of position of cushioning buffer, the cushioning buffer placed near to top of spring. Same boundary conditions were applied as of spring with cushion at middle. Here values for acceleration and time were taken from experimental data in frequency domain. From these data we got acceleration at each mode. The acceleration is converted into velocity by using equation 1. Table III shows that the acceleration and corresponding velocities. These boundary conditions were applied to the spring with cushioning buffer at middle.

$$a = \frac{\Delta v}{\Delta t} \quad (1)$$

Where, a = Acceleration (g)
v = Change in velocity (m/s)
t= Change in time (sec)

Table. III Acceleration and velocity with cushioning

Sr.No.	Acceleration(g)	Velocity(m/s)
1	0.576	5.65
2	0.326	3.20
3	0.260	2.55
4	0.181	1.77
5	0.171	1.67

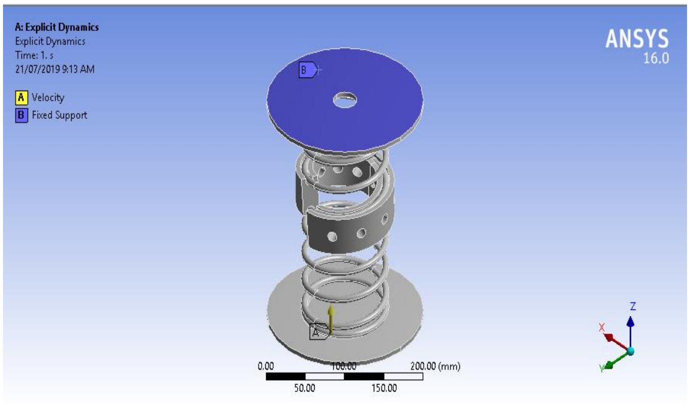

Fig.16 Boundary conditions for spring with cushioning at middle

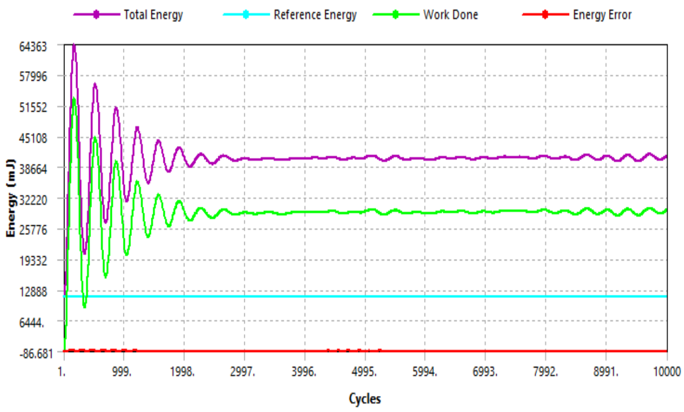

Fig.17 Total energy at velocity 5.65 (m/s)

Fig. 17 shows that variation of total energy over number of cycles. The 5.65 m/s velocity was applied to the spring with cushioning buffer at middle of spring. The maximum total energy observed was 64363 mJ and it goes on reducing over time due to damping capabilities of spring and cushion.

Table. IV Total energies with cushion

Sr.No.	Velocity(m/s)	Maximum energy with cushion(mJ)
1	5.65	64363
2	3.20	20646
3	2.55	13111
4	1.77	6316.7
5	1.67	5623.2

Table. IV shows that the velocities corresponding to each mode and maximum total energy of it. Maximum total energy 64363 mJ was observed at first mode at 5.65 m/s velocity. Maximum total energy goes on decreasing from first mode to last mode.

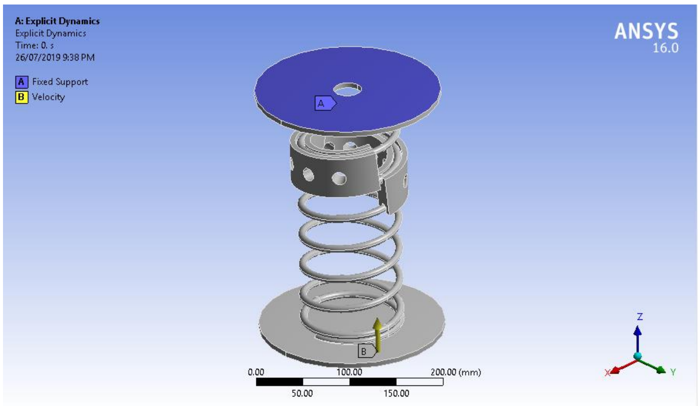

Fig.18 Boundary conditions for spring with cushioning near to top end

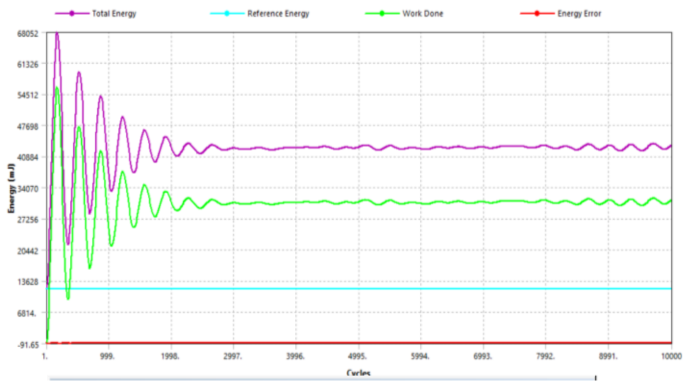

Fig.19 Total energy at velocity 5.65 (m/s)

Fig. 19 shows that variation of total energy over number of cycles. The 5.65 m/s velocity was applied to the spring with cushioning buffer at top of spring. The maximum total energy observed was 68052 mJ and it goes on reducing over time due to damping capabilities of spring and cushion.

Table. V Total energies with cushion

Sr.No.	Velocity(m/s)	Maximum energy with cushion(mJ)
1	5.65	68052
2	3.20	21830
3	2.55	14112
4	1.77	6678.9
5	1.67	5945.2

Table. V shows that the velocities corresponding to each mode and maximum total energy of it. Maximum total energy 68052 mJ was observed at first mode at 5.65 m/s velocity. Maximum total energy goes on decreasing from first mode to last mode.

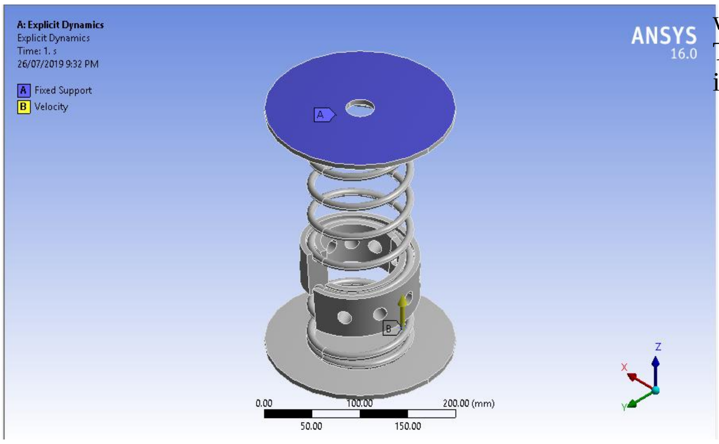

Fig. 20 Boundary condition for spring with cushioning near to bottom end

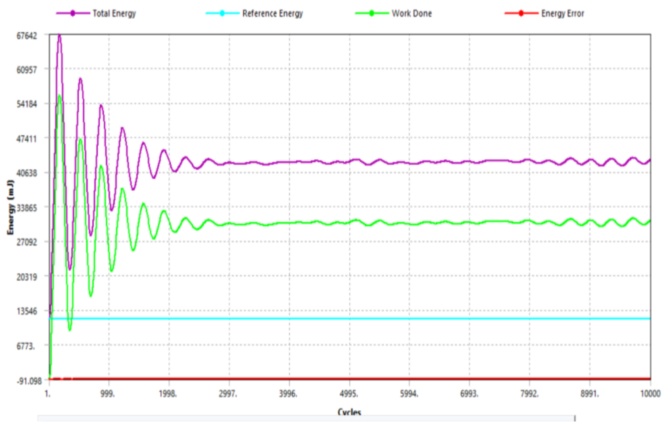

Fig.21 Total energy at velocity 5.65 (m/s)

Fig. 21 shows that variation of total energy over number of cycles. The 5.65 m/s velocity was applied to the spring with cushioning buffer at bottom of spring. The maximum total energy observed was 67642 mJ.

Table. VI Total energies with cushion

Sr.No.	Velocity(m/s)	Maximum energy with cushion(mJ)
1	5.65	67642
2	3.20	21698
3	2.55	13779
4	1.77	6638.6
5	1.67	5909.7

The table. VI shows that the velocities corresponding to each mode and maximum total energy of it. Maximum total energy 67642 mJ was observed at first mode at 5.65 m/s velocity. Maximum total energy goes on decreasing from first mode to last mode.

III. RESULTS AND DISCUSSION

Finite Element Analysis of spring with and without cushioning buffer has been carried out to obtain vibratory characteristics of the spring, such as mode shapes, corresponding frequencies and energy variations by changing the positions of cushioning buffer. The natural frequencies for both the cases are shown in Table I and Table II.

The harmonic analysis has been carried out at two different excitation frequencies 1Hz and 2Hz for spring with and without cushioning buffer. These results are summarized in Table. VII The significant reduction in acceleration amplitude is observed by using cushioning buffer.

Table. VII Acceleration from harmonic analysis

Sr.No.	Parameter	At 1 Hz excitation frequency	At 2 Hz excitation frequency
1	Acceleration of spring	5.16 (m/s^2)	5.50 (m/s^2)
2	Acceleration of spring with cushion	4.73 (m/s^2)	2.68 (m/s^2)

Further explicit analysis was carried out at three locations of cushioning buffer. It is observed that maximum energy absorption achieved at cushioning buffer at middle location.

IV. CONCLUSION

1. The output acceleration was reduced by 9% and 12 % for spring without cushioning buffer, where as 23% and 48% reduction was observed of spring with cushioning buffer at 1Hz and 2 Hz excitation frequency respectively.
2. The frequencies obtained from finite element analysis for spring with cushioning buffer are slightly more than spring without cushioning buffer
3. Maximum energy was absorbed when cushioning buffer located at middle of the spring.

REFERENCES

[1] Ahmad Partovi Meran. (2018) Numerical analysis of elastomer buffer embedded in thesuspension of automobile for vibration damping improvement, International Journal of Automotive Engineering and Technologies
[2] Xun Chen, Fuqian Chen, Jun Zhou, Lihong Li, Yanliang Zhang, (2015) Cushioning structure optimization of excavator arm cylinder, Automation in Construction, 53, PP 120–130.
[3] A.K.Malik, Leiting Dong, Wujun Chen, Jianhui Hu, ZhenyuQiu, Jinyu Zhou. (2017) Mechanical properties and structural performance of ETFE (ethylene tetra fluoro ethylene) cushion structures at low temperatures, Engineering Structures, 136, PP 420–429
[4] Yuqi Wang, K.H. Low, (2005) Damped response analysis of nonlinear cushion systems by a linearization method, Computers and Structures, 83, PP 1584–1594.
[5] R. Mehta, V.K. Tewari. (2010) Damping characteristics of seat cushion materials for tractor ride comfort, Journal of Terramechanics, 47, PP 401–406.
[6] Kazem Reza Kashyzadeh, Mohammad Jafar Ostad-Ahmad-Ghorabi, Alireza Arghavan, (2015) Fatigue life prediction of package of suspension automotive under rndom vibration based on road roughness, Mediterranean Journal of Modeling and Simulation, 04, PP 037-050.
[7] H. B. Pawar, D. D. Desale. (2018) Optimization of Three Wheeler Front Suspension Coil Spring, Procedia Manufacturing, 20, PP 428–433
[8] S.S.Rao,"Natural frequency and mode shapes", in Mechanical Vibration, 5th Edition,SI Edition Private limited, pp no 177-203.
[9] V.B.Bandari,"Spring",in Design of Machine Elements, 3rd Edition, McGraw-Hill Private limited, pp no 393-435.