A Comparative Study of Wave and Coil Spring Using FEM Approach

Mr. Siddhant R. Patil[1], Prof.PoonamS.Talmale[2],KCT's Late G.N. Sapkal C.O.E.Nashik

***Abstract*—The suspension system for two wheelers used helical coil spring to provide cushioning effect and prevents road shocked being transmitted to the passenger as wave spring occupies less space than coil spring, hence in this paper we are comparing wave spring and coil spring theoretically and numerically on ANSYS 15.0 by structural and modal analysis.Structural steel, Brass, Beryllium copper are taken as spring materials further it is optimized by changing number of turns and free length of spring using taguchi method in MINITAB 16.0**

***Index Terms*—ANSYS, Coil spring, Modal analysis,MINITAB structural analysis, taguchi.**

I. INTRODUCTION

Spring is defined as an elastic body whose function is to distort when loaded and to recover its original shape when load is removed there are many types of springs such as helical spring, conical springs, torsion spring, leaf spring.Springs are used to exert force and to store energy.Wave spring, also known as a coiled wave spring .It is manufactured on edge cooling by pre-hardening flat wire. Wave spring has width and thickness instead of circular coil diameter as in case of coil spring. It occupies less space than coil spring for same loading condition.

M.Venkatesan et al. [1] has presented design and analysis of composite leaf spring in light vehicle. He took composites of glass reinforced polymer as spring material with objective to compare stiffness, load carrying capacity, weight saving of composite leaf spring. The composite leaf spring showed lesser stress, more stiffness and natural frequency is higher than of conventional steel leaf spring.

J P Karthik et al [2] has presented Analysis of Fatigue life of a parabolic spring using finite element method. He performed finite element method and observed stress distribution and damage in spring by varying material as SAE1045-450-QT, SAE1045-595-QT and SAE160-825-QT.Results showed that SAE1045-595-QT gives higher life than other two materials. The fatigue life of parabolic spring by Goodman approach is 2.9201×10^5sec.

C.Madan Mohan Reddy et al.[3] has presented the testing and analysis of two wheeler suspension helical compression spring. He chooses chrome vanadium steel as new spring material and reduced deflection and stress in a spring. From

This literature it can be seen that chrome vanadium steel is more suitable for shock absorber application than hard drawn steel wire.

N. Lavanya etal. [4] studied design and analysis of a suspension coil spring for automotive vehicle. He analyze safe load with different materials for suspension spring. He took low carbon structural steel and chrome vanadium as spring material. Analysis results showed that low carbon structural steel has better performance as spring material than chrome vanadium material.

P.L. Pavani et al. [5] have presented design, modeling and analysis of wave spring. He attempts to replace coil spring with wave spring for that he studied performance of wave spring by FEA. The FEA results show that wave spring possess less deflection and more stress when compared with coil spring.

Kautaro Watanabe et al. [6] have formulated different formulae for calculating the stress correction factor of helical spring. He presented analytical formula and a chart of the maximum shear stress and maximum principal stress which take initial pitch angles into consideration. These formulae were formulated by FEM and design of experiments.

.

II.RESEARCH GAP

The following graph shows the percentage variation of research work on types of spring use for structural analysis of spring.

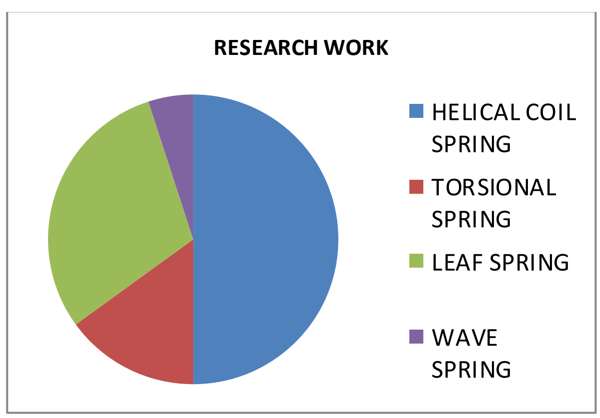

Fig.1 Graph of Percentage variation of types of springs use for structural

analysis

From above graph it is seen that most of the work is done using Helical Coil Spring which is 47.61% according to literature. For Leaf Spring only 28.57% and for torsion spring 14.28% work has been done .in case of wave spring only fem work has been presented.Wave spring means aspring with thickness and width. Only one analysis is done on this type of spring by FEM approach. Hence it is required to study the wave spring analysis for different applications. In this paper we are using wave spring for shock absorber application.

III. THEORETICAL ANALYSIS

In theoretical analysis stress, deflection and stiffness of spring is calculated by using analytical formulae for SS, brass and beryllium copper. Spring specification and material properties are given in Table-I andTable II respectively.

A. Formulae for wave spring

1. Operating stress, $S=\frac{3\Pi PDm}{4b\, t^2 N^2}$……………………….(1)

Where,
D_m = mean diameter in mm,
P= load in N,
b = width of material in mm,
N=number of waves per turn,
t= thickness of material in mm,
S= stress in MPa

2. Deflection$\delta=\frac{(PKDmZ)\ ID}{(E\, b\, t^3 N^4 OD)}$…………………………….(2)

Where,
K=multiple wave factor,
Z=number of turns,
N= number of waves per turn,
ID and OD are inside and outside diameters,

3. Spring stiffness (k) $=\frac{W}{\delta}$……………..……………..(3)

Where,
W= Load on the spring
δ = Deflection of spring

B. Formulae for coil spring

1. $\tau=\frac{KB*8*W*D}{\pi*d^3}$……………………………………….(4)

Where
τ= maximum shear stress
K_B= Wahl's stress factor
W= Load on the spring
D= Mean Diameter of the spring coil
d= Diameter of the spring wire

2. Deflection $(\delta)=\frac{8\,WD^3\,n}{Gd^4}$…………………………….(5)

W= Load on the spring
D= Mean Diameter of the spring coil
n = No. of turns
G = Modulus of rigidity
D = Diameter of the spring wire

3. Spring stiffness (k) $=\frac{W}{\delta}$……………………………. (6)

Where,
W= Load on the spring
δ = Deflection of spring

C. Load calculation for shock absorber application

Weight of bike = 131kg
Let weight of 1person = 75Kg
Weight of 2 persons = 75×2=150Kg
Weight of bike + persons = 281Kg
Rear Suspension = 65% of 281 = 182.65Kg
Considering dynamic loads it will be double W = 365.3Kg
=2 (365.3 ×9.81)
= 3583.593N
For single shock absorber weight = $\frac{W}{2}$= 1791.79N

Putting all the specifications of shock absorber spring from Table-I and Table-IIin equations (1), (2), (3), (4), (5) and (6) the results obtained are shown in TABLE-III.

TABLE-I
Spring Specification

Parameter	Coil spring	Wave spring
Mean Diameter (Dm)	60mm	60mm
Coil Diameter (d):	12 mm	-
Number of turns (n)	12	10
Pitch (p)	24mm	-
Free length (Lf)	300mm	300mm
Thickness (t)	-	0.54mm
Number of waves per turn (N)	-	2
Width of wave (b)	-	0.5mm
Internal Dia. (ID)		47mm
Outer dia. (OD)		54mm

TABLE –II
Material Parameters

Parameters	Value		
Material	SS	Beryllium copper	Brass
Yeild strength	300MPa	685MPa	414MPa
Shear modulus	0.769×10^5	49.5×10^3	41.5×10^3
Poissons ratio	0.3	0.29	0.33
Young's Modulus	2×10^5MPa	1.27×10^5	1.103×10^5MPa
Mass Density	7850 kg/m^3	8300 kg/m^3	8600 kg/m^3

TABLE-III
Theoretical Results

Material	Deflection of Coil Spring in mm	Deflection of Wave Spring in mm	Stiffness of Coil Spring in N/mm	Stiffness of Wave Spring in N/mm
Structural Steel	23.30	14.41	76.90	124.34
Brass	43.17	28.45	41.50	62.98
Beryllium copper	36.65	24.89	48.88	71.98

IV.NUMERICAL ANALYSIS OF SPRING

Design of spring is modeled in PRO-E software by using the properties given in Table-I as shown in Fig.3 (coil spring) and Fig.4 (Wave spring). And imported in ANSYS software.

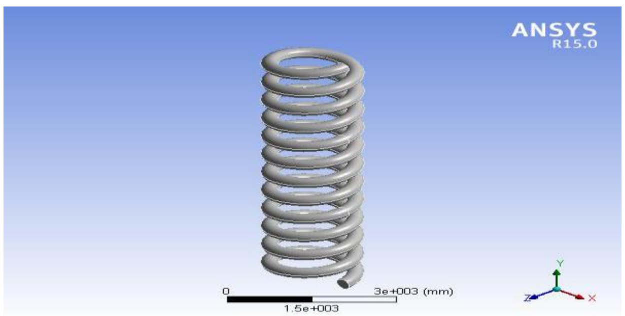

Fig.3 Coil Spring Model

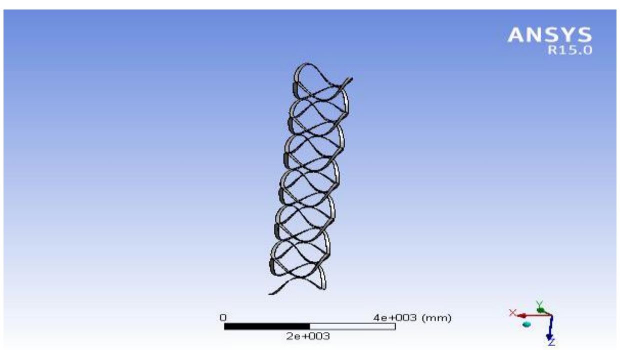

Fig.4 Wave spring model

1) *Deflection Analysis for Coil Spring*

For S.S. spring of free length 300mm and 12 turns the deflection is 23.18mm, for brass it is 43.995 mm and 35.37mm for beryllium copper material as shown in Fig.5(SS), Fig.6(Brass) and Fig.7(Beryllium copper).

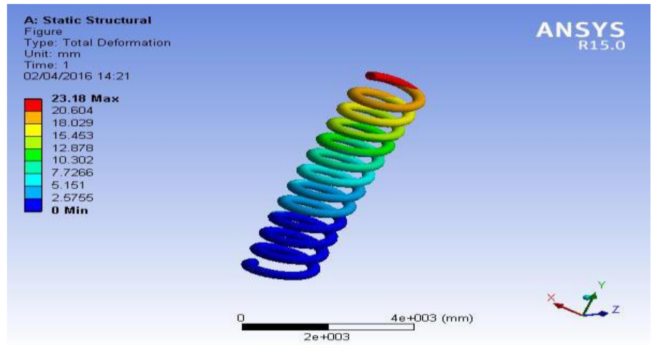

Fig. 5 Deformation of SS spring

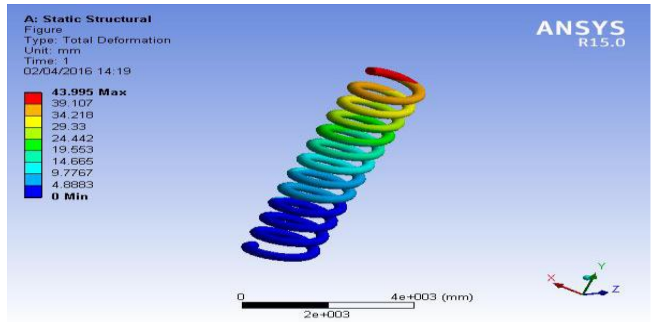

Fig. 6 Deformation of brass coil spring

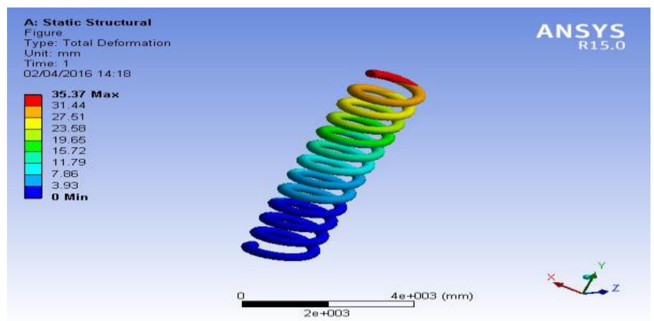

Fig.7 Deformation for beryllium copper coil spring

2) *Deflection Analysis for Wave Spring*

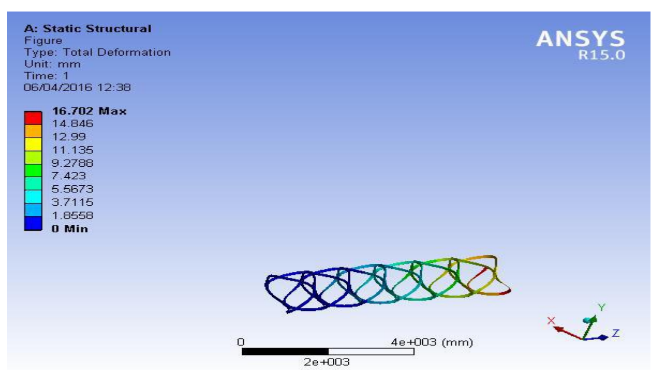

Fig.8 Deformation of SS spring

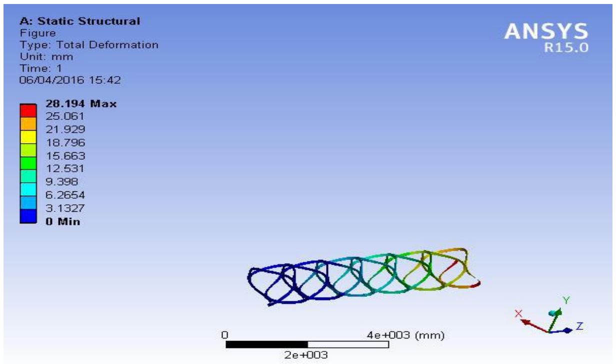

Fig. 9 Deformation of brass coil spring

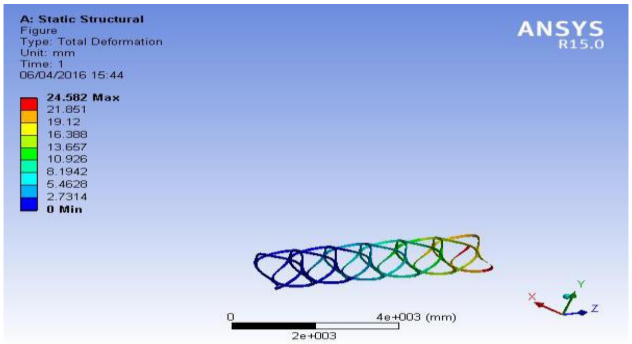

Fig.7Deformation for beryllium copper coil spring

3) Modal analysis for coil spring

The lowest natural frequency for Structure steel coil spring is 10.668 Hz, 8.05Hz for Brass and 8.99Hz for Beryllium copper for 12 numbers of turn and 300 mm free length is as shown in Fig.8, 9 and10.

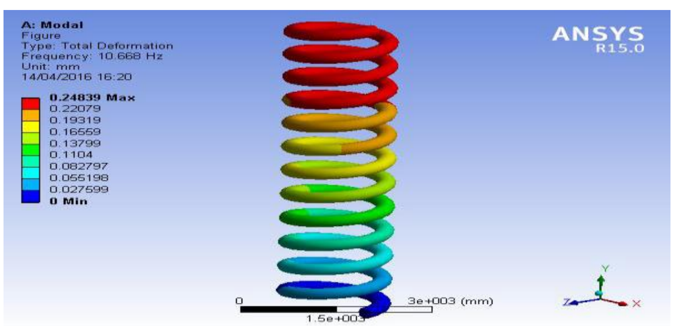

Fig.8 Frequency for SS coil spring

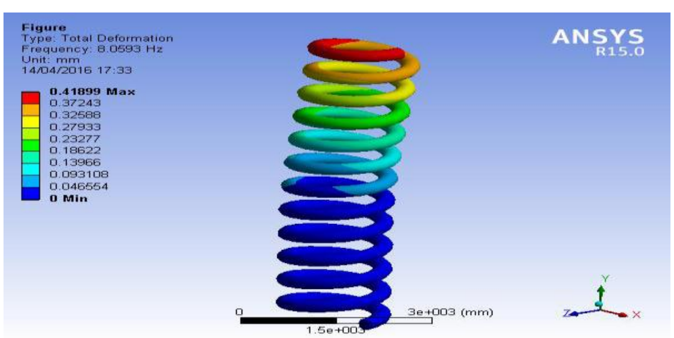

Fig.9Frequency for brass coil spring

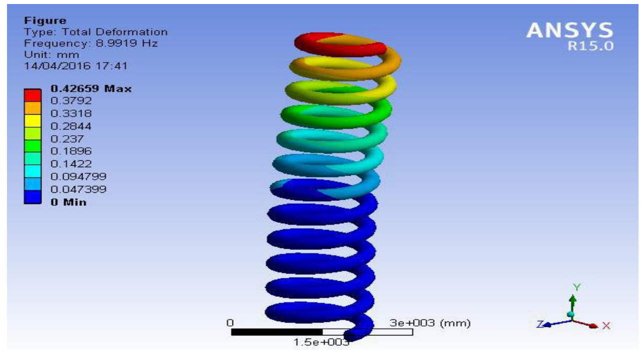

Fig.10Frequency for beryllium copper coil spring

4) Modal analysis of wave spring

The lowest natural frequency for Structure steel wave spring is 16.70Hz, 28.19Hz for Brass and 24.58 Hz for Beryllium copper for 12 numbers of turn and 300mm free length is as shown in Fig.11, 12 and 13.

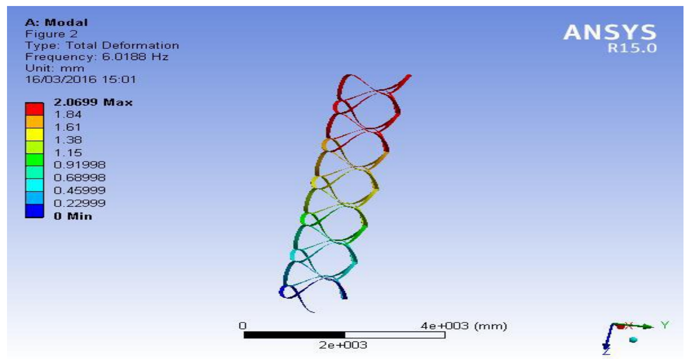

Fig.11 Frequency for SS wave spring

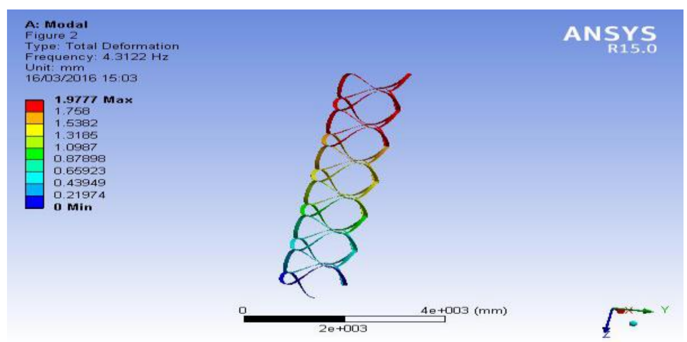

Fig.12Frequency for brass wave spring

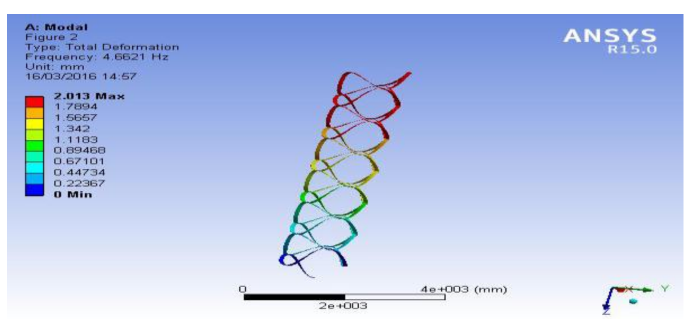

Fig.13Frequency for beryllium copper wave spring

V. TAGUCHI DESIGN METHOD

A. Selection of suitable statistical method

Various statistical designs are employed for selection of parameters, such as application of various design of experiment (DoE) includes Factorial design, Factorial design, Response surface methodology, Artificial neural networks (ANNs), and Taguchi method.

Taguchi Technique shall be used to conduct the experiments: - The Taguchi method has become a influential tool for improving output during research and development, so that better quality products can be produced quickly and at minimum cost.

B. Taguchi design

Taguchi design of experiment is one of these techniques which are used widely. The Taguchi method involves reducing the variation in a process through robust design experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting and the levels at which they should be varies. “Orthogonal Arrays” (OA) provide a set of well balanced (minimum) and Dr. Taguchi’s Signal Noise ratios (S/N),which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. There are 3 Signal-to-Noise ratios of common interest for optimization.

$$(S/N)HB = -10\log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n}\left(1/\sqrt{Yi}\right)$$

$$(S/N)LB = -10\log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n}\left(\sqrt{Yi}\right)$$

$$(S/N)NB = -10\log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n}\sqrt{(Yi - M)}^{4}$$

Above 3 equations are main criteria for designing model as first describes “Higher is better (HB),second one is“Lower is better (LB)” and last one is “Nominal is better (NB)”.

The factors and their levels are shown in Table XII.

Table XII Selected Factors and their Levels.

TABLE XII

Selected Factors and their Levels

Factors	Levels		
	1	2	3
No. of Turns	8	10	12
Free length	250	280	300

C. Selection orthogonal array

Since controllable factors are 2 and 3 levels are considered so L9 (3*4) orthogonal array has been selected for analysis of given output signal response. Following is the design matrix for L9-3 Taguchi method.

Table –XIII

OA with Control Factors

Experiment No	Control Factor	
	No. of Turns	Free Length
1	8	250
2	8	280
3	8	300
4	10	250
5	10	280
6	10	300
7	12	250
8	12	280
9	12	300

D. Analysis of Signal to Noise Ratio

In Taguchi design noise represents undesirable parameter while signal represents undesirable parameter. In this experimental work “Lower is better” criteria is selected.

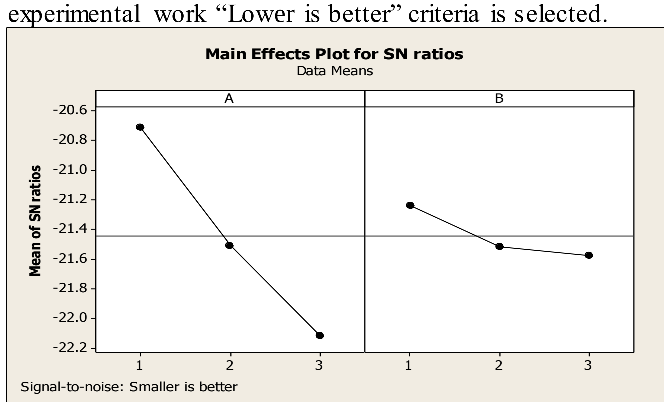

Fig.14 Main effect plot for SN ratios

VI.RESULT & DISCUSSION

TABLE IV

Comparison of deformation for wave and coil spring for different material

Materials	Deflection in mm	
	Coil Spring	Wave spring
SS	23.18	16.702
Brass	43.99	28.194
Beryllium copper	35.37	24.582

TABLE V

Comparison of frequency of wave and coil spring for different materials

Materials	Frequency in Hz	
	Coil Spring	Wave spring
SS	10.668	6.0188
Brass	8.0593	4.3122
Beryllium copper	8.991	4.6621

TABLE VI

Comparison of deformation for wave and coil spring by varying no. of turns

No of turns	Coil Spring deformation in mm			Wave Spring deformation in mm		
	SS	Brass	Beryllium copper	SS	Brass	Beryllium copper
8	15.16	26.20	22.82	11.322	20.236	14.257
10	19.62	34.04	28.92	15.449	28.123	24.579
12	23.18	28.92	35.37	16.702	28.194	24.582

TABLE VII
Comparison of frequency for wave and coil spring by varying no. of turns

No of turns	Frequency of Coil Spring in Hz			Frequency of Wave Spring in Hz		
	SS	Brass	Beryllium copper	SS	Brass	Beryllium copper
8	14.57	10.59	10.96	10.28	7.36	7.97
10	12.72	9.57	9.73	7.75	5.55	6.00
12	10.66	8.05	8.99	6.01	4.31	4.66

TABLE VIII
Comparison of deformation in mm for wave and coil spring by varying free length

Free length	Coil Spring			Wave Spring		
	SS	Brass	Beryllium copper	SS	Brass	Beryllium copper
250	22.76	28.14	35.04	16.79	24.16	28.02
280	23.02	28.32	35.16	17.08	24.43	28.54
300	23.18	28.92	35.37	17.33	24.85	28.72

TABLE IX
Comparison of frequency in Hz for wave and coil spring by varying free length

Free length	Coil Spring			Wave Spring		
	SS	Brass	Beryllium copper	SS	Brass	Beryllium copper
250	9.89	7.96	8.24	5.642	4.15	4.43
280	10.21	8.02	8.63	5.869	4.26	4.58
300	10.66	8.05	8.99	6.01	4.31	4.66

TABLE X
Comparison of shear stress for wave and coil spring by varying no. of turns

No of turns	Stress of Coil Spring in MPa			Stress of Wave Spring in MPa		
	SS	Brass	Beryllium copper	SS	Brass	Beryllium copper
8	22.80	22.84	22.76	12.39	12.56	11.85
10	24.32	24.34	24.28	11.86	12.01	11.39
12	26.91	26.79	26.71	13.07	13.24	12.56

TABLE XI
Comparison of Equivalent stress for wave and coil spring by varying no. of turns

No of turns	Stress of Coil Spring in MPa			Stress of Wave Spring in MPa		
	SS	Brass	Beryllium copper	SS	Brass	Beryllium copper
8	60.02	60.12	59.91	42.07	42.13	41.82
10	63.64	63.67	63.52	44.65	44.74	44.35
12	65.67	65.70	65.57	46.61	46.81	45.99

The deformation of coil spring is more than wave spring for all materials. Deflection for coil SS spring is 23.17 mm which is less than 43.99 mm of brass and 35.37 mm of beryllium copper as shown Table-IV from Table V the natural frequency of for wave spring is more than that of coil spring. The frequency value for SS wave spring is 6.018 Hz which is more than brass and beryllium copper .As the No. of turns increases from 8 to 10 the deformation increases for all three considered materials as shown in Table-VI. And frequency decrease as the no of turns increases as shown in Table-VII.From Table-VIII, Table-IV, Table-X and Table-XI. It is seen that,As the free length increases from 250mm to 300 mm the deformation increases and frequency decreases for all the materials and for both types of springs.

VII.CONCLUSIONS

The deformation in SS spring is less than brass and beryllium copper for both types of springs.Wave spring has less deformation than coil spring but vibrations occurred in wave spring is more than coil spring.As the numbers of turns increases the deformation increases and vibration decreases in both springs for all materials. If free length increases the deflection and frequency increases.
Greater S/N ratio has indication of higher quality parameters. So optimum level of process parameters have higher S/N ratio.

REFERENCES

1) M.Venkatesan, design and analysis of composite leaf spring in light vehicle.International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol.2, Issue.1, Jan-Feb 2012 pp-213-218 ISSN: 2249-6645

2)J. P. Karthik, K. L. Chaitanya, "Fatigue Life Prediction Of A Parabolic Spring Under Non-Constant Amplitude Proportional Loading Using Finite Element Method" International Journal Of Advanced Science And Technology Vol. 46, September, 2012

3) C.Madan Mohan Reddy, "Analysis And Testing Of Two Wheeler Suspension Helical Compression Spring", Iosr Journal Of engineering (Iosrjen) Issn (E): 2250-3021, Issn (P): 2278-8719 Vol. 04,||V1|| Pp 55-60,06 (June. 2014).

4) N.Lavanya," Design And Analysis Of A Suspension Coil Spring For Automotive Vehicle", Int. Journal Of Engineering Research And Applications ISSN : 2248-9622, Vol. 4, Issue 9(Version 5), Pp.151-157, September 2014

5) P.N.L.Pavani,Design, Modeling and Structural Analysis of Wave Springs P.N.L. Pavani et al. / Procardia Materials Science 6 (2014) 988 – 995

6)Kotare Watanabehttp://www.faqs.org/patents/inventor/kotarowatanabe-2

7) SrinivasAthreya,"Application Of Taguchi Method For Optimization Of Process Parameters In Improving The Surface Roughness Of Lathe Facing Operation",International Refereed Journal of Engineering and Science (IRJES) ISSN (Online) 2319-183X, (Print) 2319-1821 Volume 1, Issue 3 (November 2012), PP.13-19.

8) R. S. Khurmi, "Springs," in *Machine Design*, 14th ed., vol. 1, J. Peters, Ed. New Delhi:S-Chand, 2014, pp. 820–884.