Modification in the Design of Two Wheeler's Suspension Spring using Finite Element Analysis and Observing variation of Stress and Deflection with varying Pitch of the Spring

Ruchika Saini[1], Tanmay Khare[2], Suyash Agrawal[3], Kushagra Chawda[4]

[1]*Asst. Professor, Jabalpur Engineering College, M.P., India-482011*
[2]*Student (2016-2020) Jabalpur Engineering College, M.P., India-482011*
[3]*Student (2016-2020) Jabalpur Engineering College, M.P., India-482011*
[4]*Student (2016-2020) Jabalpur Engineering College, M.P., India-482011*

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Abstract - *This is a computational study of the suspension spring of two wheeler's followed by modification suggestions. The current methods of calculations of the spring parameters fail to account for the role of the spring pitch in developing stresses. Stresses and deflections are critical factors for designing a sustainable spring and play critical roles in the performance. This paper suggests reducing the stresses developed by varying the pitch while proving the correlation between pitch variation and stress production. This is accomplished by geometric modeling of different models of spring and simulating it with applied boundary conditions. The study is further extending to propose ways to reduce stresses in the spring. Finally, the suggested changes can reduce the maximum stresses in the suspension spring components by as much as 50%, from 1963MPa in the original spring to 958MPa in a double coil spring.*

Key Words: Suspension Spring, Shock Absorber, CATIA, ANSYS, 3-D Modeling, Finite Element Analysis (FEA), Von Mises Stress

1.INTRODUCTION

A **shock absorber** or **damper** is a mechanical or hydraulic device designed to absorb and damp shock impulses. It converts the kinetic energy of the shock into heat energy which is then dissipated. Most shock absorbers are a form of dashpot (a damper that resists motion via viscous friction).[2]

Coil springs or leaf springs are commonly used in Spring-based shock absorbers, and torsion bars are used in torsional shocks. As springs only store and do not dissipate or absorb energy, Ideal springs alone do not work as shock absorbers. Vehicles typically employ a combination of hydraulic shock absorbers and springs or torsion bars, in which "shock absorber" refers specifically to the hydraulic piston that absorbs and dissipates vibration.

Hydraulic shock absorbers commonly consist of a cylinder with a sliding piston arrangement. The cylinder is filled with fluid (such as a hydraulic fluid) or air. This fluid-filled piston/cylinder combination is known as a dashpot[3]. The helical spring generates two types of stresses: torsional shear stress and direct shear stress responsible for the spring's failure. The primary stresses in the wire of a helical spring are due to torsion.

The Figure shows a helical spring made of round wire under an axial load, P. If the spring radius (r) is much greater than the wire diameter (D), the wire may be treated as a straight round beam under a torsional load, P_r, as indicated in Figure. Superposing the stress due to torsion of the wire on the uniform shear stress due to direct shear $\frac{4P}{\pi D^2}$, the following Equation for the maximum shear stress in the spring may be obtained:

$$f_{smax} = \frac{16Pr}{\pi D^3}\left(1 + \frac{D}{4r}\right)$$

In the cases of heavy coil springs composed of wire with a relatively large diameter, D, in comparison to r, the initial curvature of the spring must be accounted for. This is done in the following Equation:

$$f_{smax} = \frac{16Pr}{\pi D^3}\left(\frac{4m-1}{4m-4} + \frac{0.615}{m}\right)$$

where,

$$m = \frac{2r}{D}$$

This Equation reduces to Equation (1) as r/D becomes large. The total deflection (δ) of around spring of n free coils is:

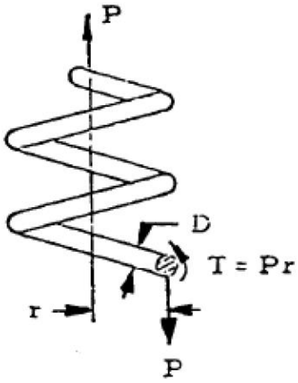
$$\delta = \frac{64Pr^3n}{GD^4}$$

This Equation neglects the deflection due to direct shear, which is given by:

$$\delta_s = \frac{8PRn}{Gd^2}$$

This However, this portion of the deformation is generally negligible compared to the value of δ given by Equation (4) and is thus generally ignored.

All of the equations in this section apply to both compression and tension springs, and in both cases, the maximum shear stress occurs at the inside of the wire.



For 3D modeling of the Helical Spring, we have utilized CATIA v5. CATIA is one of the world's leading high-end CAD/CAM/CAE software packages. CATIA (computer-aided three-dimensional interactive application) is a multi-platform PLM/CAD/CAM/CAE commercial software suite developed by Dassault systems and marketed worldwide by IBM[1]. CATIA is written in the C++ programming language. CATIA provides open development and architecture through interfaces, which can be used to customize or develop applications. The applications in programming interfaces supported visual basic and C++ programming languages. Commonly referred to as the 3D product Lifecycle management (PLM) software suite, CATIA supports multiple stages of product development. The stages range from conceptualization, through design (CAD) and manufacturing (CAM), until analysis (CAE). Each workbench of catiaV5 refers and each stage of product development for different products. CATIA V5 features a parametric solid/surface-based package that uses NURBS as the core surface representation and has several workbenches but provides KBE (knowledge-based engineering) support.
The Part Design Workbench is used to create Solid geometry using a Feature-based approach. In general, the features are produced from sketches created in the Sketcher workbench. The specification tree contains all the features created along with the sketch used to define them. All the Solid features are contained within a node called a Part Body. They also contain wireframe sketches that are used to create the features. As you create features, they are added to the tree in order of creation. There may be multiple Part bodies within a CAT Part that can be learned together to form complex solid models. Part bodies can be added to the Specification Tree by selecting the body from the Insert drop-down menu in the Part Design Workbench. The Part body can then be renamed by editing its properties.

Our study has taken actual dimensions of "Bajaj Discover 150cc" and "Bajaj Pulsar 150cc" suspension spring. Helical spring is the essential component behind the shock absorbers, which bears the torsional and direct shear stresses. We do have formulas to calculate the stresses and deflection of the spring, as illustrated above. However, it does not explain the stress variation on the spring by varying pitch. Since the values of stress generated to give a brief idea about the life of any mechanical component where more is the stress, less is the life of the product keeping the material the same.

The idea is to reduce the overall stress values by variating the spring pitch, plotting the pitch versus stress diagram, and selecting the optimized design parameters for minimum stress values generated in the spring material. Further, using two of the optimized springs in a double-coiled helical spring reduces stress values.

The Part Modelling of Helical Spring is done on CATIA, and ANSYS Static Structural is used to carry forward the analysis to calculate Von-mises stress and Total Deflection of the models.

2.MATERIALS AND METHODS

2.1 Load Calculations

Before Consider a 150cc motorbike that uses a helical spring-based suspension system.

Weight of the bike (alone)	= 140 Kg
Weight of 1 person	= 75 Kg
Weight of 2 persons	= 150 Kg

Therefore,

Total Weight of the bike with one person	= 215 Kg
Total Weight of the bike with one person	= 290 Kg

Assuming $\frac{2}{3}^{rd}$ of the weight acts on the rear wheel,

Therefore, avg. the force acting on the rear wheel [Bike + 1 person]

$$= \left(\frac{2}{3} \times 215 \times 9.81\right) \text{N}$$

= 1406.1 N

And, avg. force acting on the rear wheel [Bike + 2 persons]

$$= \frac{2}{3} \times 290 \times 9.81 \ \text{N}$$

= 1896.6 N

This is a dynamic load (suddenly applied load). Hence the total load acting on the rear wheel

= 2 × (avg. force acting on the rear wheel)

Hence, as there are two suspensions (one on either side) on the wheel, the load acting on one suspension

= avg. the force acting on the rear wheel

= 1406.1 N for {Bike + 1 person}

&

1896.6 N for {Bike + 2 persons}

2.2 3-D Modelling on CATIA v5:

We have used CATIA V5 for the geometric modeling of the suspension springs, which are to be used in ANSYS analysis. The dimensions of the springs are as follows:

	D (in mm)	d (in mm)	H (in mm)
Spring - 1	49.2	7.5	235
Spring - 2	35.0	6	235

For the above dimensions, we have varied the pitch of the springs to study the variation of stress and deflection with pitch variation.

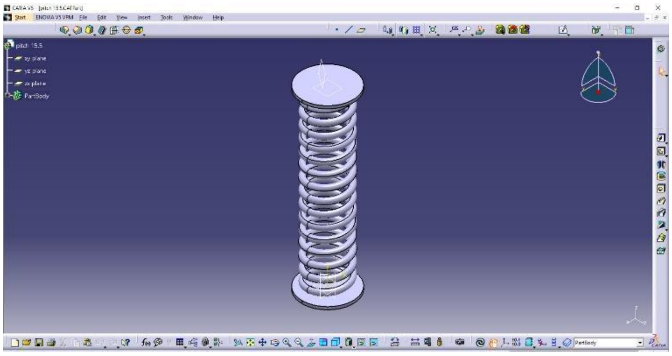


FIGURE 1 – Spring-1 3-D Model

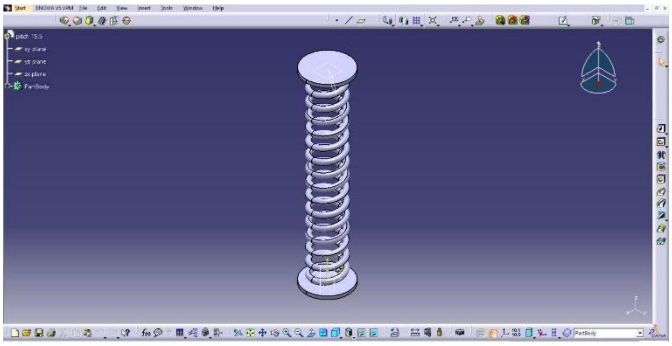


FIGURE 2 – Spring-2 3-D Model

2.3 Analysis of Spring-1 on ANSYS 18.0:

The ANSYS Finite Element Analysis software is a platform for analyzing and automating customized simulations which can be extended to parametrizing these simulations[5]. The ANSYS structural software is compatible with several physical world machines, making it all the more useful. The performance and behaviors of complex structures can be accurately understood and predicted using ANSYS.

Three-dimensional stresses and strains build up in many directions. A common way to express these multi-directional stresses is to summarize them into an "Equivalent" stress, also known as the "Von Mises" stress[6]. By definition, von mises stresses are referred to as "An averaged stress value calculated by adding the squares of the 3 component stresses (X, Y, and Z directions) and taking the square root of their sums". This value allows for a quick method to locate potential problem areas with one plot. Knowledge of stresses and deflections allows for the safe design of structures capable of supporting their intended loads.[7]

We have varied the pitch (from 11mm to 20mm) for Spring-1, keeping the other dimensions constant, and performed static structural analysis on ANSYS for Maximum Loading Condition (i.e., 1896.6 N)

Boundary Conditions –

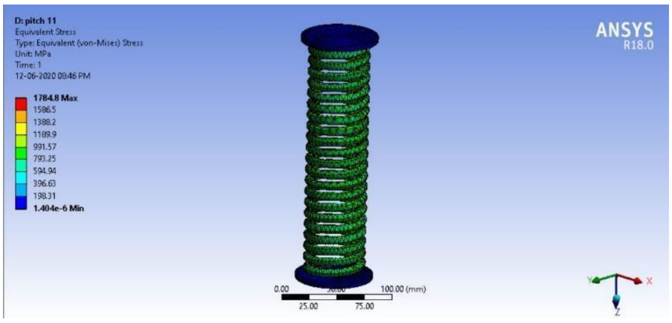
i) Fixed Support at one end
ii) Load of 1896.6 N at the other end

We have added Von Mises Stress and Total Deflection probes in our analysis setup. In this stage, we have used Stainless Spring Steel as the material of spring. The properties of Stainless Spring Steel are shown in Table – 1.

Table – 1 – Properties of Stainless Spring Steel

Material	Density (in kg/mm3)	Young's Modulus (in MPa)	Shear Modulus (in MPa)
Stainless Spring Steel	0.00000775	193000	73664

The screenshots of stress analysis for various pitches for Spring-1 are as follows:



D: pitch 11
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
12-06-2020 08:46 PM

FIGURE 3 - Pitch=11 mm

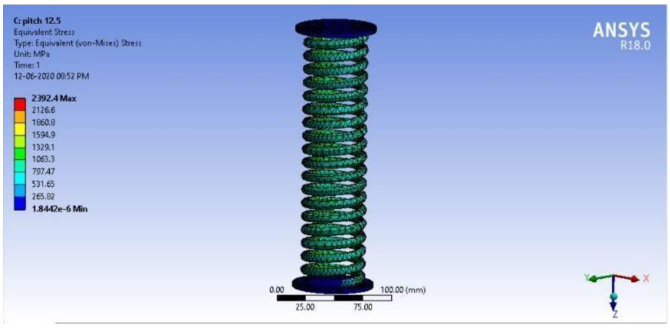


FIGURE 4 - Pitch=12.5 mm

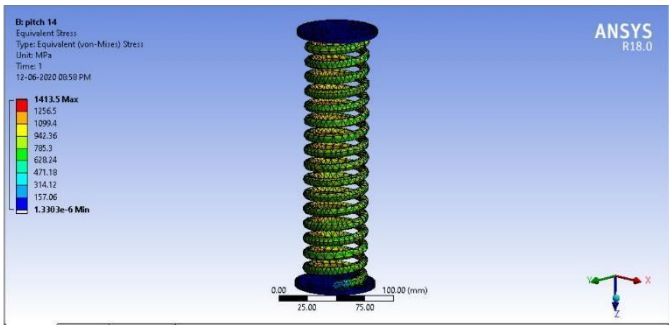


FIGURE 5 - Pitch=14 mm

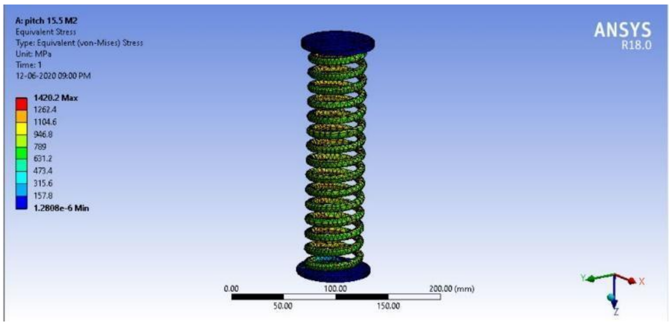


FIGURE 6 - Pitch=15.5 mm

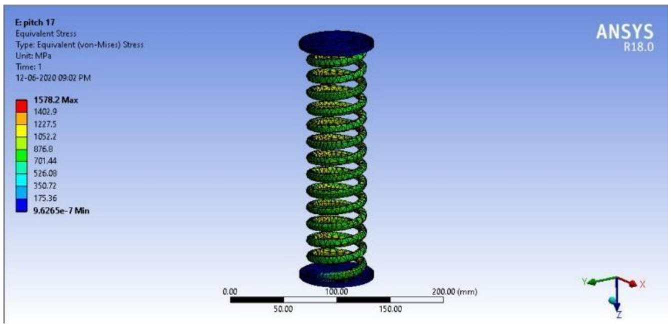


FIGURE 7 - Pitch=17 mm

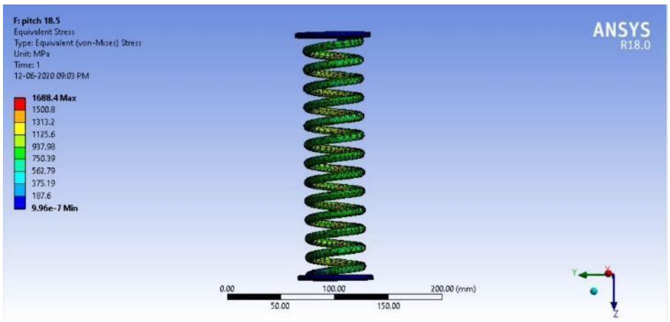


FIGURE 8 - Pitch=18.5 mm

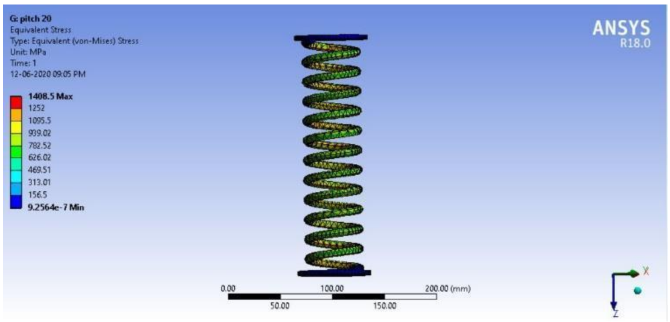


FIGURE 9 - Pitch=20 mm

Table – 2 - DATA FOR SINGLE COIL HELICAL SPRING-1 (for a full load, i.e., 1896.6 N)

Sr. No.	**Pitch (in mm)**	**Maximum Deflection (in mm)**	**Maximum Stress (in MPa)**
1.	11	141.890	1784.80
2.	12.5	126.000	2392.40
3.	14	113.280	1413.50
4.	15.5	101.910	1420.02
5.	17	94.599	1578.20
6.	18.5	87.111	1688.40
7.	20	81.410	1408.50

2.4 Analysis of Spring-2 on ANSYS 18.0:

We have varied the pitch (from 10.5 mm to 19.5 mm) for Spring-2, keeping the other dimensions constant, and performed static structural analysis on ANSYS for Maximum Loading Condition (i.e., 1896.6 N)

Boundary Conditions –

i) Fixed Support at one end
ii) Load of 1896.6 N at the other end

We have added Von Mises Stress and Total Deflection probes in our analysis setup. In this stage, we have used Stainless Spring Steel as the material of spring. The properties of Stainless Spring Steel are shown in Table – 1.

The screenshots of stress analysis for various pitches for Spring-2 are as follows:

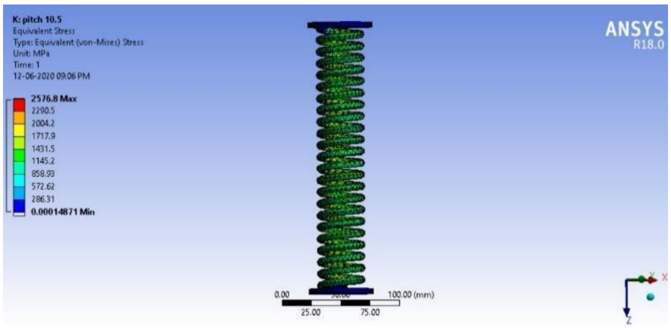


FIGURE 10 - Pitch=10.5 mm

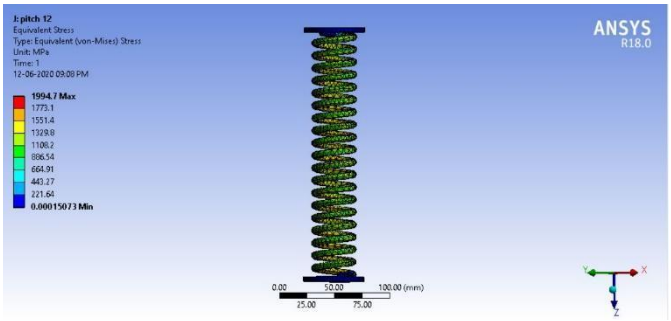


FIGURE 11 - Pitch=12 mm

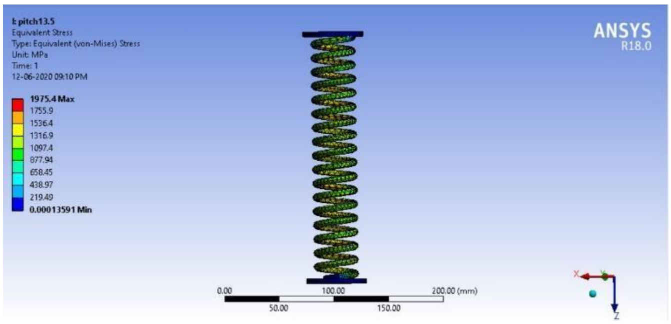


FIGURE 12 - Pitch=13.5 mm

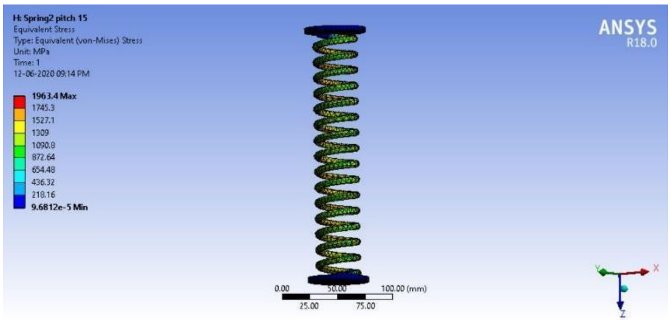


FIGURE 13 - Pitch=15 mm

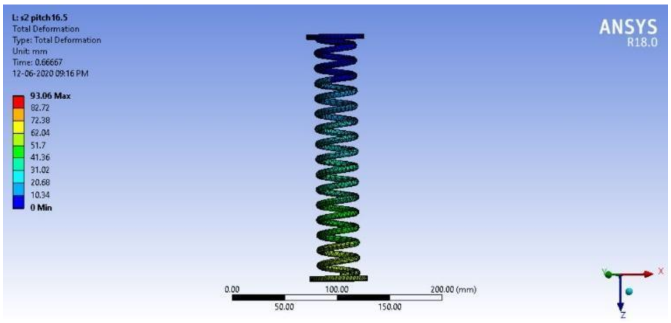


FIGURE 14 - Pitch=16.5 mm

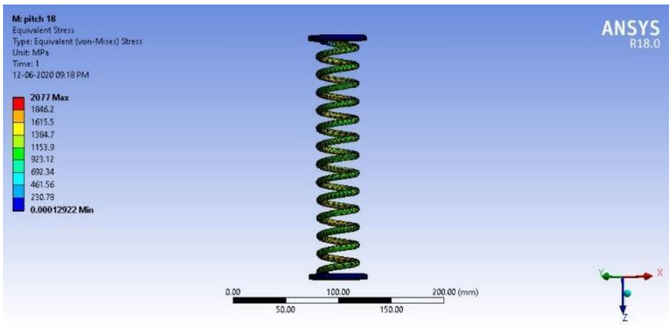


FIGURE 15 - Pitch=18 mm

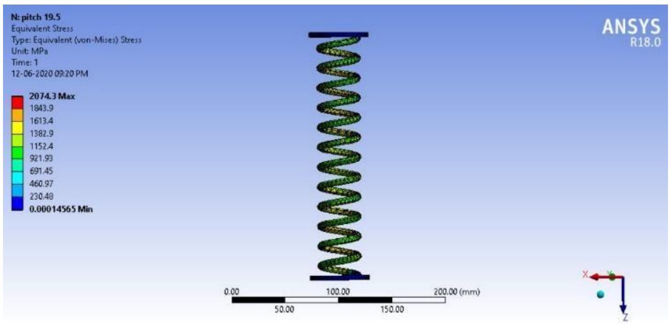


FIGURE 16 - Pitch=19.5 mm

Table – 3 - DATA FOR SINGLE COIL HELICAL SPRING-2 (for a full load, i.e., 1896.6 N)

Sr. No.	Pitch (in mm)	Max. Deflection (in mm)	Max Stress (in MPa)
1.	10.5	128.520	2576.80
2.	12	113.670	1994.70
3.	13.5	100.650	1975.40
4.	15	93.060	1963.40
5.	16.5	93.060	1963.40
6.	18	78.046	2077.00
7.	19.5	72.417	2074.30

2.5 Selection of optimum spring dimensions:

From the above-tabulated data obtained from the analysis of Spring-1 and Spring-2, we will pick the pitch for which the lowest stress is obtained. Hence the dimensions of the chosen pitch values for Spring-1 and Spring-2 are as follows:

SPRING-1: D=56.7mm; d=7.5mm; Pitch=20mm**;** H=235mm

SPRING-2: D=41.0mm; d=6mm; Pitch=15mm; H=235mm

2.6 Proposed Optimized Design:

After selecting the above two configurations of springs 1 & 2, we propose an enhanced design for suspension springs. The two springs, viz. Spring-1 and Spring-2 have different diameters and pitches but the same length. Hence, they can be configured co-axially to make a **Double Coil Helical Spring.** It was supposed to have a lesser value for maximum stress under similar loading conditions. To verify this, we have modeled a double Coil Helical Spring geometry on CATIA V5 and analyzed it on ANSYS 18.0. The configuration for the proposed design is shown below:

	D (in mm)	d (in mm)	Pitch (in mm)	H (in mm)
Outer Spring	49.2	7.5	20	235
Inner Spring	35.0	6	15	235

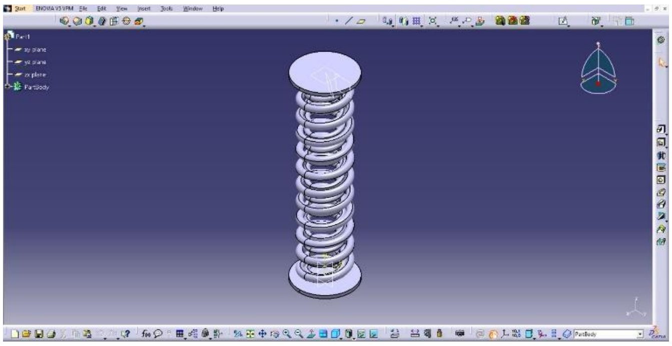


FIGURE 17 – 3-D Model of Double Coil Helical Spring

3. RESULTS AND DISCUSSION

i. We applied similar boundary conditions on the proposed design, which were applied on Spring-1 and Spring-2, and the results are as follows.

ii. To verify the results to an even better extent, we analyzed three different materials industrially used in suspension springs.

Boundary Conditions –

1) Fixed Support at one end

2.1) Load of 1406.1 N at the other end

2.2) Load of 1896.6 N at the other end

The properties of the materials used in the above analysis are tabulated below:

Table – 4 – Properties of Materials

Material	**Density (in kg/mm3)**	**Young's Modulus (in MPa)**	**Shear Modulus (in MPA)**
Non-alloy Spring Steel	0.00000783	206800	83000
Oil-tempered Low Carbon Spring Steel	0.00000786	206842	79289.709
Stainless Spring Steel	0.00000775	19300	73664

Table – 5 – DATA FOR DOUBLE COIL HELICAL SPRING

Material	**Load (in N)**	**Max. Deflection (in mm)**	**Max Stress (in MPa)**
Non-alloy Spring Steel	1406.1	32.199	710.43
	1896.6	43.431	958.25
Oil-tempered Low Carbon Spring Steel	1406.1	33.612	709.57
	1896.6	45.337	957.10
Stainless Spring Steel	1406.1	36.168	709.47
	1896.6	48.785	956.96

iii. Hence, we can observe from the above data that the stresses in the Proposed design, i.e., Double Coil Helical Spring, have considerably reduced compared to the stresses induced in Spring-1 and Spring-2.

4. CONCLUSION

i. The variation of deflection and stress concerning the variation in pitch for spring-1 can be observed as follows (all the graphs below are plotted on MATLAB):

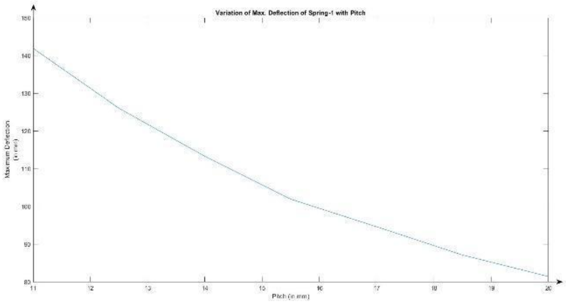


FIGURE 18 – Graph - Deflection v/s Pitch for Spring - 1

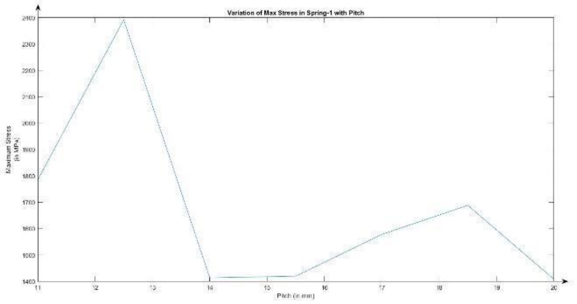


FIGURE 19 – Graph - Stress v/s Pitch for Spring – 1

ii. The variation of deflection and stress concerning the variation in pitch for spring-2 can be observed as follows:

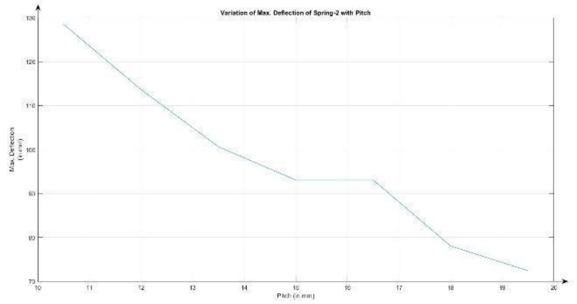


FIGURE 20 – Graph - Deflection v/s Pitch for Spring – 2

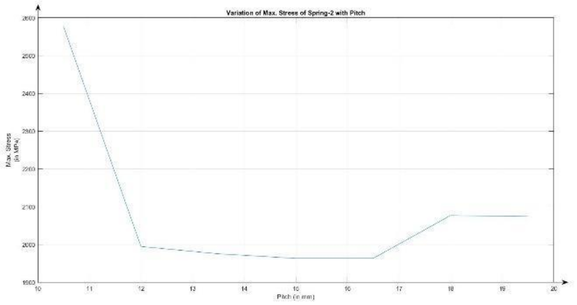


FIGURE 21 – Graph - Stress v/s Pitch for Spring – 2

iii. The Proposed Design, i.e., Double Coil Helical Spring, shows considerably low stresses than the values induced in Spring-1 {pitch=20 mm} and Spring-2 {pitch=15 mm} for similar loading conditions. (from Table 2, 3, and 5)

The maximum stress in Spring-1 = 1408.50MPa
The maximum stress in Spring-2 = 1963.40MPa
The maximum stress in Double Coil Helical Spring
= 958.25 MPa

This shows a fall of 450.25 MPa in stress in an enhanced design concerning Spring-1, which was supposed to be used in the 150cc bike. If the Spring-1 is replaced by the enhanced design, it will increase the overall life of the suspension system under similar loading conditions.

Hence, on proper analysis, we can conclude that the Double Coil Helical Spring is better than Spring-1 and should be employed in two-wheelers for a better life cycle

NOMENCLATURE

b	width of the section
D	Mean Diameter of spring
f_s	Calculated shear stress
G	Modulus of Elasticity
n	Number of active spring coils
P	Axial Load
r	Wire Radius of spring
δ	Spring Deflection
d	Wire Diameter of spring
H	Height of spring

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