iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 Issue: IX Month of publication: September 2020

DOI: https://doi.org/10.22214/ijraset.2020.31589

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue IX Sep 2020- Available at www.ijraset.com

Optimization of Coil Spring using Design of Experiments (DOE)

Dhruv Muni[1], Mitesh Girase[2], Kishan Desai[3], Siddharth Panchal[4], Rutvik Trivedi[5], Bhavik Trivedi[6], Sagarsingh Kushwah[7], Shreyashkumar Parekh[8]
[1, 2, 3, 4, 5, 6, 7, 8]*Mechanical Engineering Department, R. N. G. Patel Institute of Technology*

Abstract: Problems occur in automobiles when driving bumps on road and insufficient road conditions. This work aims at improving the performance of the helical coil spring used in hatchback suspension cars via various spring parameters to make it more powerful than the current hatchbacks. A helical coil spring is used by 4-wheel cars that are part of the Indian automotive hatchback category. It is noted that due to heavy the weight of the springs and loads on it, the vehicle usually makes a drift over one side of the road. To omit such problems, the method of redesigning and optimizing is utilized. An optimizing technique well known as the design of experiments (DOE) is used for current work in ANSYS 18.1 workbench to optimize and omit the current problems in the helical coil spring. Also, Different materials are being compared to check the suitability and the better material for coil spring.

I. INTRODUCTION

The most crucial element of the suspension system is the suspension. Because it is the element that controls the shock and regulates the comfortability. In addition, it dissipates kinetic energy. Besides, the suspension system also improves the ride comfort, influence of rough road, and vehicle control (1). As of the most element, the suspension system commences various elements that are ball joints, arm rods, axles, and springs. Spring is the most flexible part of the suspension system and can be defined as the elastic body. It gets deformed when the load is applied on it, However, it returns to its original shape and size when the load is removed. This phenomenon happens because of the strain energy in the spring (2).

Nowadays, most of the light automotive vehicles have helical coil spring as the front part of its suspension system. While leaf spring is used on the rear part of the suspension system. The manufacturing process of leaf spring is that the specific material (Usually steel) wire is heated and the desired shape is produced (3). During designing any of the elements, defining the failure criteria is the most crucial part. The failure of the spring can be due to the poor property of the material, high cyclic load, fatigue load, etc. The withstand capacity of the spring to the load greatly depends on the number of turns, wire diameter (d), mean diameter (D), and the length of the spring (L).

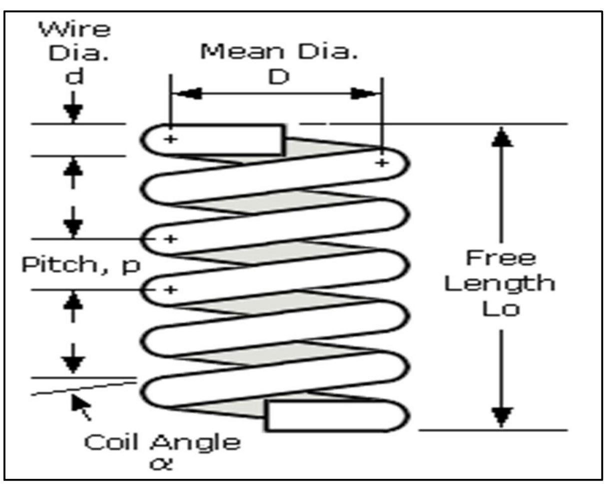

Figure 1: Nomenclature of coil spring

In the current work, the optimum number of turns, wire diameter (d), mean diameter (D), and the length of the spring (L) are obtained using the Design of Experiments (DOE) method. Also, different materials are compared based on the deformation capacity and shear stress criteria. So, which material is more suitable for the coil can be obtained.

II. DESIGN OF EXPERIMENTS (DOE)

Design of Experiments (DOE) also known as Experimental design (ED) is classified as the applied statistics division, which deals with the preparation, execution, analysis, and interpretation of controlled tests to evaluate the parameter value factors or a group of parameters. DOE is a versatile method for data collection and interpretation which can be used in several experimental contexts (4). It makes it possible to control many input factors to decide how the desired output is affected (response). DOE can also detect essential connexions that can be overlooked when engaging with one element at a time by controlling many inputs at the same time. Both potential combinations (full factorial) or just a subset (fractional factorial) of possible combinations may be tested (5).

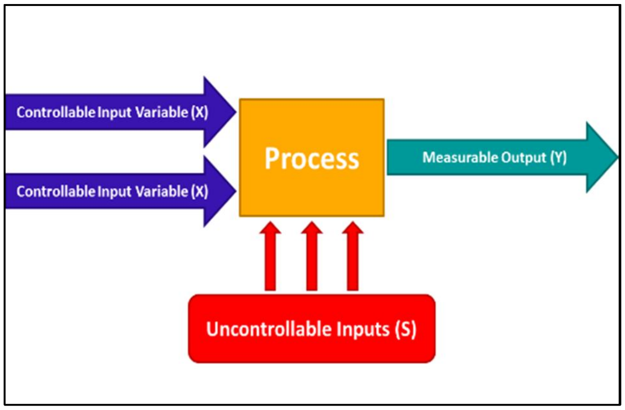

Figure 2: Design of Experiments

Taking an example of the Design of Experiments (DOE), consider a system having X and Y as the two controllable inputs, whereas S as the uncontrollable input. After performing the DOE, the results obtained will be optimum that is measurable output Y as shown in figure 1. So, it can be said that DOE is also a great optimizing tool that helps to obtain measurable inputs after receiving the controllable and uncontrollable inputs simultaneously.

III. METHODOLOGY

A. Selection of Material

Based on the mechanical properties such as Brinell Hardness, Modulus of Elasticity, Fatigue Strength, Poisson's Ratio, Shear Modulus, Ultimate Tensile Strength, Yield Tensile Strength, and Density the four material were selected for this work. The materials are ASTM A-227 Carbon-Spring Steel, ASTM A-228 Music Wire Spring Steel, ASTM A-231 Chrome-Vanadium Spring Steel, ASTM A-401 Chrome-Silicon Spring Steel (6).

B. Calculations

Deformation, strain energy, and shear stress were taken into consideration to optimize the dimensions as well as the better material for the helical coil spring. To evaluate the deformation, strain energy, and shear stress, the following equations were used (7-8):

$$G = \frac{E}{2(1+\mu)} \quad (1)$$

$$K = \frac{Gd^4}{64R^3n} \quad (2)$$

$$\delta = \text{free length} - \text{solid length} \quad (3)$$

$$F = k \times \delta \quad (4)$$

$$\Delta d = \frac{Fs}{K} \quad (5)$$

$$\tau_{torsional} = \frac{16FsR}{\pi d^3} \quad (6)$$

$$\tau_{direct\ shear\ stress} = \frac{4Fs}{\pi d^2} \quad (7)$$

$$\tau_{max} = \tau_{tortional} + \tau_{direct\ shear\ stress} \quad (8)$$

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IV. DESIGN OF EXPERIMENTS (DOE)

The following steps were performed in ANSYS 18.1 workbench for the design of experiments.

A. Selection of Parameters

This is the first step to perform the DOE. The parameter governing the DOE for coil springs are Wire diameter, Mean diameter, Pitch, Length of spring, Number of turns, and Force.

B. Assigning Intervals to Different Parameters

The intervals were taken according to manufacturable value:

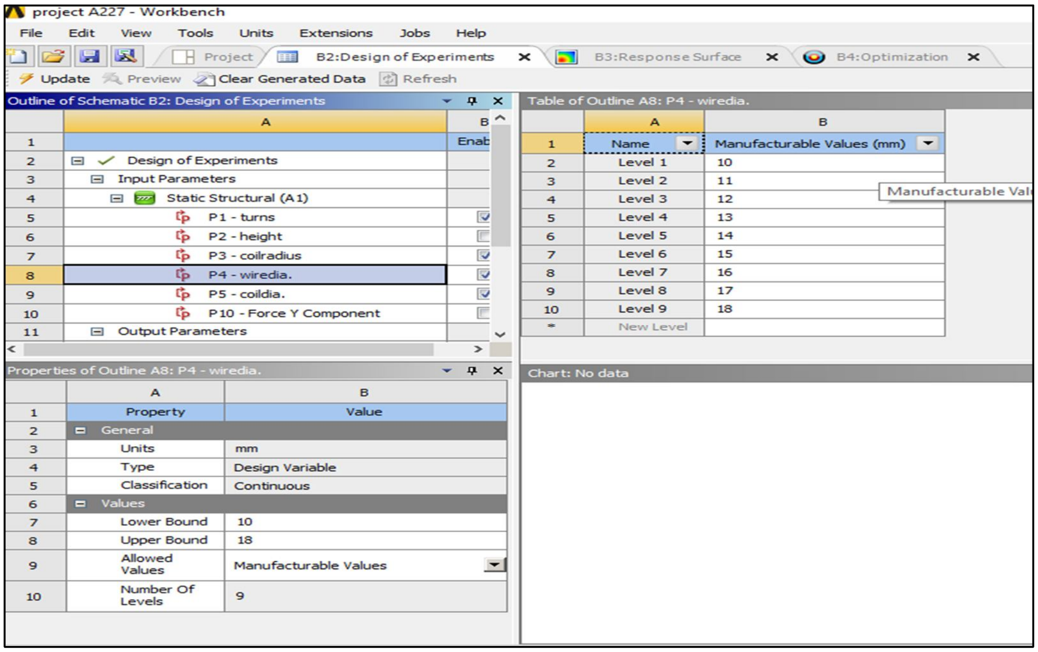

Figure 3: Wire Diameter

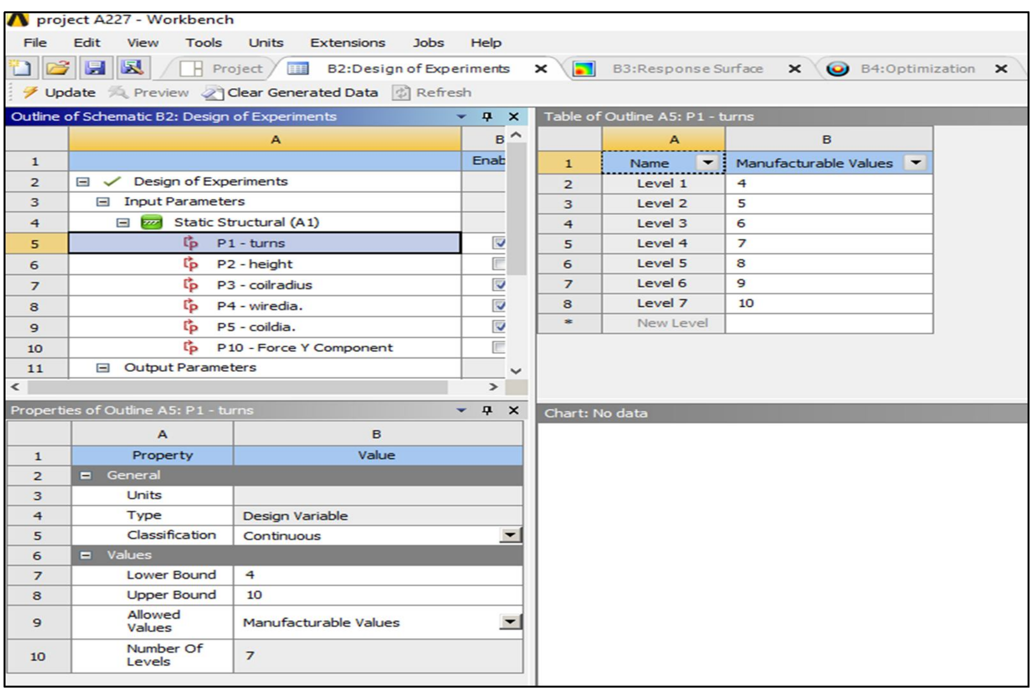

Figure 4: Number of turns

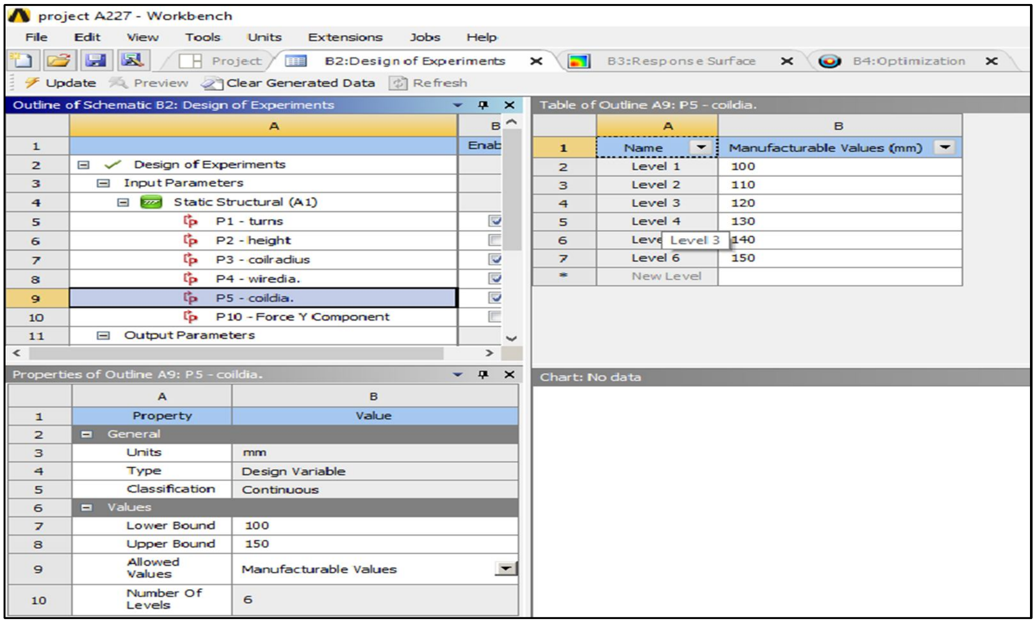

Figure 5: Coil diameter

V. RESULTS AND DISCUSSION

Tables 1, 2, and 3 show the deformation comparison, strain energy comparison, and shear stress comparison for different materials.

Table 1: Deformation Comparison

Sr. No.	Material	Deformation (mm)
1	ASTM-A227 Carbon Spring Steel	94.382
2	ASTM-A228 Music Wire	96.33
3	ASTM-A231 Chrome-Vanadium	89.663
4	ASTM-A401 Chrome-Silicon	89.663

Table 2: Strain energy Comparison

Sr. No.	Material	Strain Energy (mj)
1	ASTM-A227 Carbon Spring Steel	55.892
2	ASTM-A228 Music Wire	57.046
3	ASTM-A231 Chrome-Vanadium	53.098
4	ASTM-A401 Chrome-Silicon	53.098

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Table 3: Shear stress comparison

Sr. No.	Material	Shear Stress (MPa)
1	ASTM-A227 Carbon Spring Steel	435
2	ASTM-A228 Music Wire	435
3	ASTM-A231 Chrome-Vanadium	435
4	ASTM-A401 Chrome-Silicon	435

Figure 6. 7, and 8 shows Variation of Safety Factor with respect to Wire Diameter, Variation of Mean Diameter with respect to Shear Stress, and Variation of Wire Diameter with respect to Shear Stress.

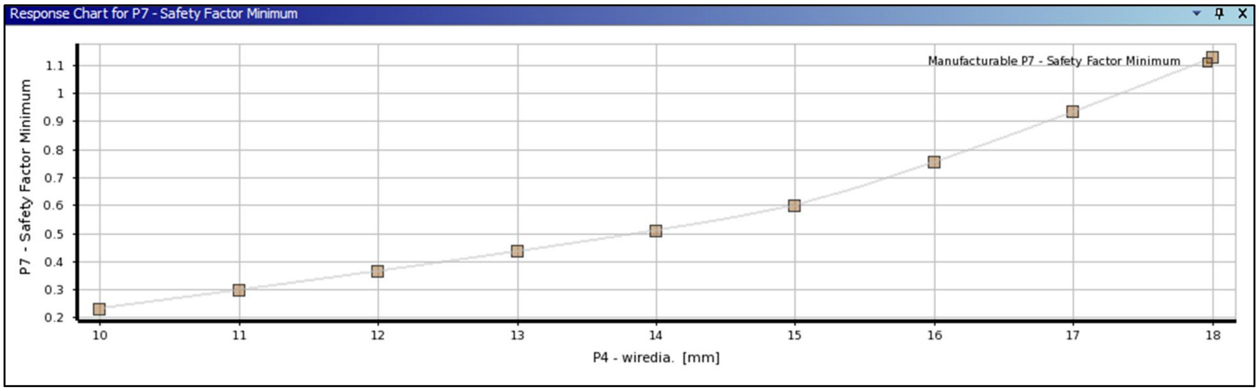

Figure 6: W.D. VS SAFETY FACTOR

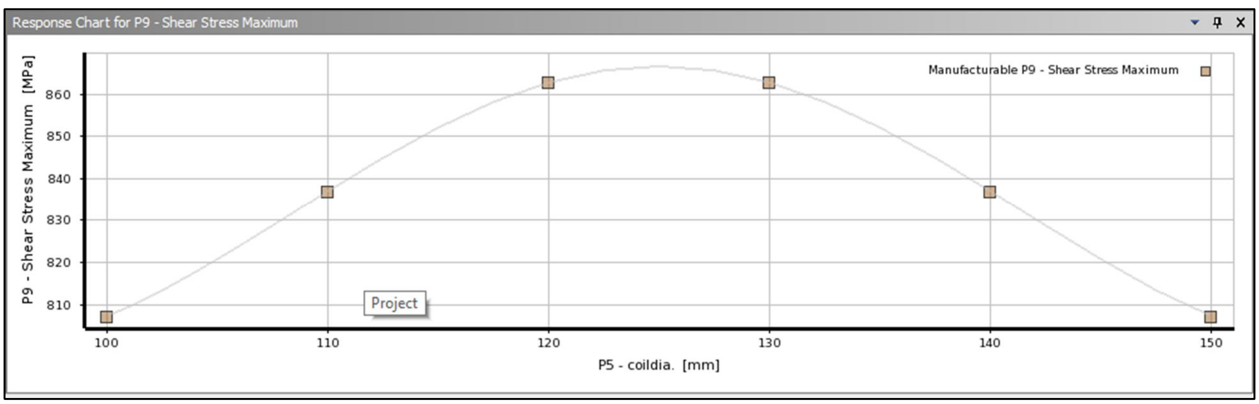

Figure 7: M.D. VS SHEAR STRESS

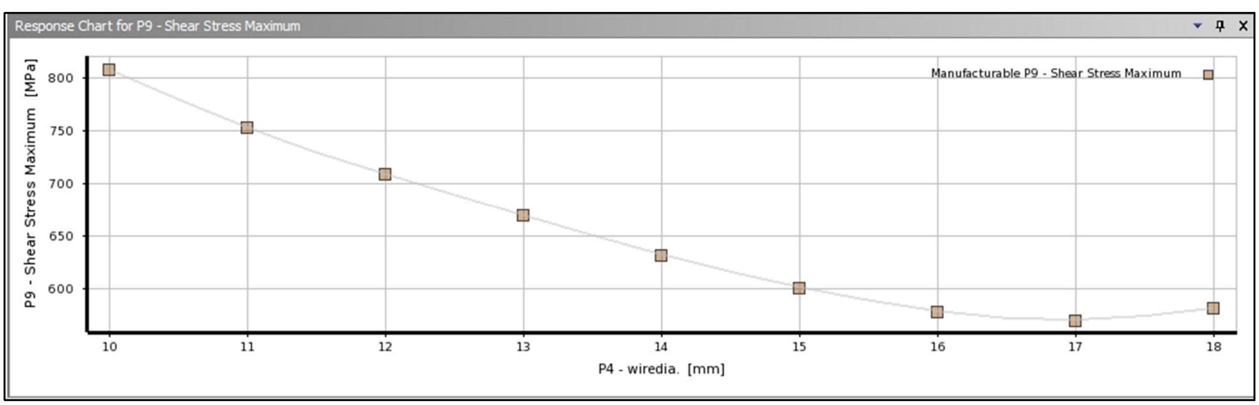

Figure 8: W.D. VS SHEAR STRESS GRAPH

VI. CONCLUSION

After performing DOE of the helical coil suspension spring, the following were the findings:

1) *Deformation:* The minimum deformation is observed with magnitude of 89.663 mm in the ASTM-A231 & ASTM-A401 materials.
2) *Strain Energy:* The maximum amount of strain energy generated using ASTM-A228 material is 57.046 mJ which shows good energy absorption characteristics therefore A-228 absorbs more strain energy compared to other materials.
3) *Shear Stress:* The values of shear stress are almost the same for all four materials with the magnitude of 435.81 MPa

Therefore, it was concluded that ASTM A-228, A-231 & A-401 have better results over the existing material which is A-227 used currently in hatch-backs.

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