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OPTIMIZATION OF DESIGN OF HELICAL COMPRESSION SPRING USING FULL FACTORIAL APPROACH

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Abstract- The present work aims at optimizing the design of helical compression spring. Weight of the spring is considered as the desired objective function and is minimized using full factorial experimental approach. Minitab 17I statistical package is used for finding the optimum level of three factors namely number of turns, spring index and wire diameter that affect the value of response variable i.e. weight of spring. The effect of different levels of above mentioned factors on the response variable as well as regression equation is also modeled in this paper.
Keywords: Helical Compression Spring; Full Factorial design; ANOVA; Weight optimization; Minitab.

1. INTRODUCTION

Helical Compression Springs are the most common metal spring configuration that is primarily used for axial compression load. They are used in a wide variety of applications ranging from actuators, valves, cams and followers, railroad, clocks, internal expanding brakes to spring balances, vibration isolation etc. The design of spring depends upon a number of important parameters such as wire diameter, number of turns, free length, and stiffness of spring, spring index and pitch of spring. The traditional approach for optimization i.e. OFAT (One-factor-at-a-time), where only a single parameter is varied at a time while keeping others fixed suffer some serious drawbacks. Since only one parameter is varied at a time, so any interaction among the different factors become impossible to identify. Also, much time will be consumed in experimentation using OFAT approach and directional errors might creep into the solution.

Factorial design technique offer distinct advantage over OFAT approach that every possible combination of factors is considered with minimum amount of experimentation. Since all probable combination of factors is considered while maintaining randomization, outcome is comparatively much better, more reliable and free from any experimental bias.

This paper focuses on identifying and optimizing the parameters having significant effect on weight of helical compression spring. Full factorial experimental approach is applied and Minitab 17[I] statistical package is used for finding the optimum level of parameters affecting the weight of helical compression spring. Number of turns of spring, spring index and wire diameter are considered as the parameters. The effect of different levels of these factors on the weight of the spring is tested. Pareto chart along with main effect plot and interaction plots, to know the significance of parameters on the objective function have also been presented in this paper.

[I]Information on Minitab 17 can be obtained from Minitab.com. A 30 day trial version of the software is available as a free download.

2. DESCRIPTION OF EXPERIMENTS

The specimens were prepared according to the spring geometry shown in Fig. 1.

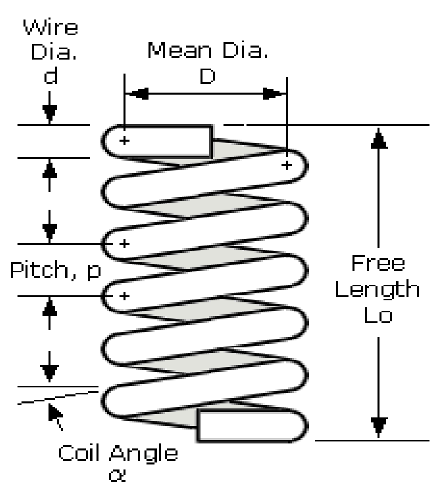

Fig.1. Spring geometry for specimen preparation [1]

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Full Factorial design experimentation approach has been applied to work out all possible factor combinations for the factors that have supposedly significant effects on weight of the compression spring. Spring index (A), Number of turns (B) and Wire diameter (C) have been considered as design parameters and weight of the helical compression spring is taken as response variable.
The important spring properties have been listed in Table 1.

Table 1. Important Spring Properties

Material	Music Wire
Composition	C- 0.70 - 1.00%, Mn 0.2-0.6%
Allowable shear stress	392-500 MPa
Modulus of Elasticity, E	210 kN/mm^2
Modulus of Rigidity, G	80 kN/mm^2

The low and high levels of factors used, coded as +1 and -1 respectively are shown in Table 2.

Table 2. Factors and level of factors

Factors	Level 1	Coding for Level 1	Level 2	Coding for Level 2
Spring index(A)	8	-1	10	+1
Number of turns(B)	8	-1	15	+1
Wire diameter(C)	2.5	-1	10	+1

Since there are 2 levels for each factor, the design requires eight (2^3) test runs. These tests are then performed in a random order and the value of the response variable i.e. weight of the helical compression spring is listed in the right side column of Table 3.

Table 3. Design Matrix and Value of Response Variable

Std Order	Run Order	A	B	C	Response (Weight of spring)
7	1	-1	1	1	120000
5	2	-1	-1	1	64000
2	3	1	-1	-1	1250
4	4	1	1	-1	2343.75
1	5	-1	-1	-1	1000
8	6	1	1	1	150000
3	7	-1	1	-1	1875
6	8	1	-1	1	80000

3. ANALYZING FACTORIAL DESIGN

Various plots like Main Effects plot and Interaction plot are obtained to examine effects of parameters on response variable using Minitab. The analysis is made at 95% level of confidence (or 5% level of significance).
From the Pareto charts as shown in Fig. 2, it can be concluded that C is the most significant factor followed by Factor B. Three- way interactions in this study have not shown any significant effect on the response.

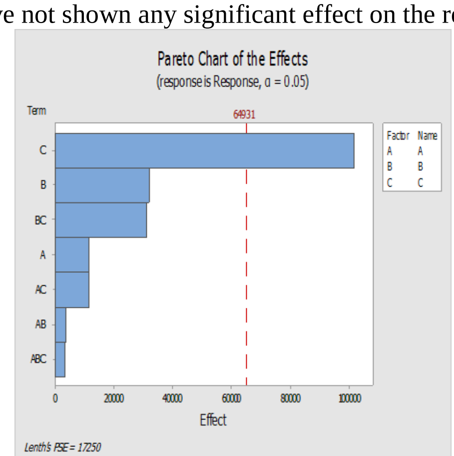

Fig.2. Pareto Chart

Since the interactions AB and ABC have minimum significant effect, so the analysis is done again after omitting the above two interactions.
The Pareto Chart obtained after omitting AB and ABC interactions has been shown in Fig. 3.

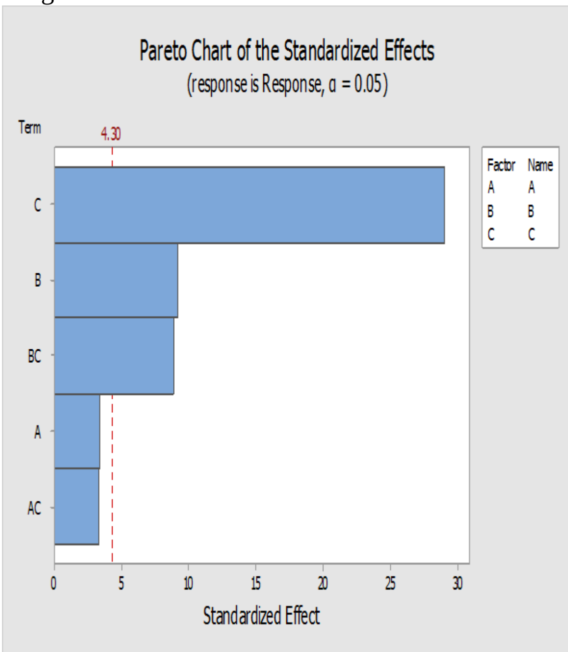

Fig.3. Pareto Chart after omitting interactions AB and ABC.

The chart shown in Fig.3 further dictates that the interaction AC is not much significant. So, the analysis is done again after making necessary changes in the design.
The Pareto Chart (after omitting interaction AC) is shown in Fig. 4.

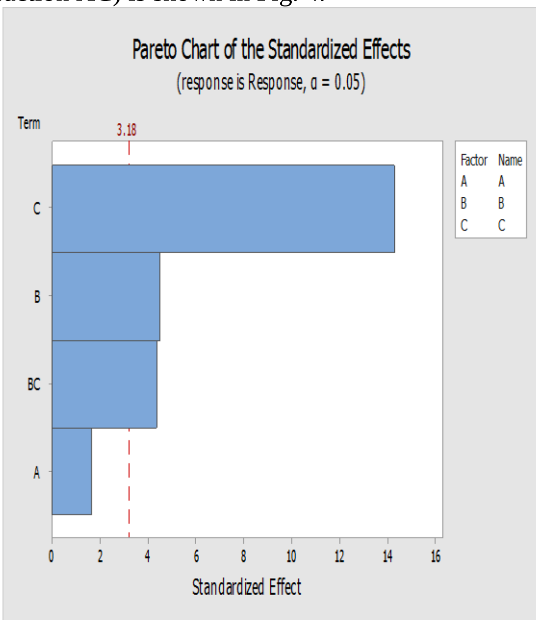

Fig.4. Pareto Chart after omitting interaction AC.

From the main effect graphs depicted in Fig. 5, inference can be drawn that all the three parameters namely spring index (A), number of turns (B) and wire diameter (C) have positive effects on the response variable, weight of the spring. It can also be asserted from the graph that wire diameter has profound effect on the outcome followed by number of turns and spring index.

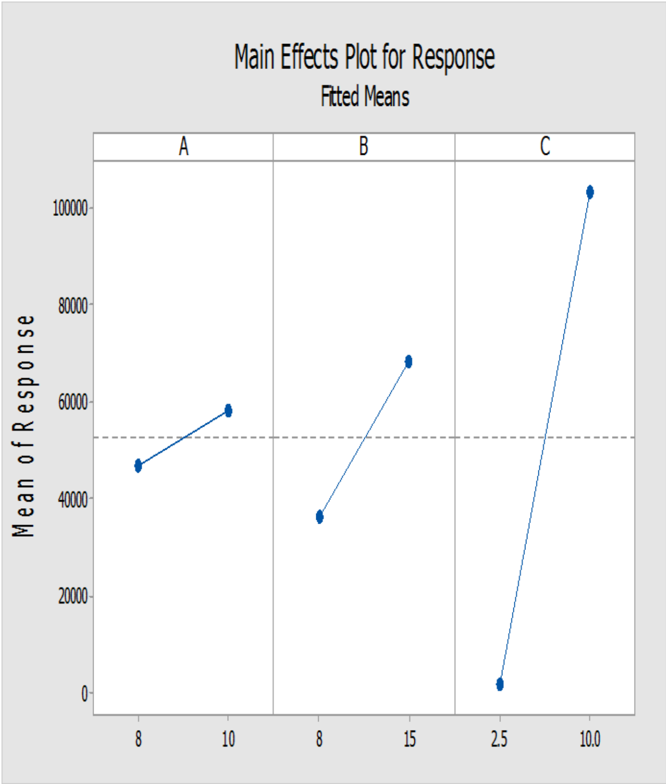

Fig.5. Main effects of parameters on response

The interaction plot in Fig. 6 indicates that the two factors namely number of turns and wire diameter has an interaction and is more significant at higher level of the two factors.

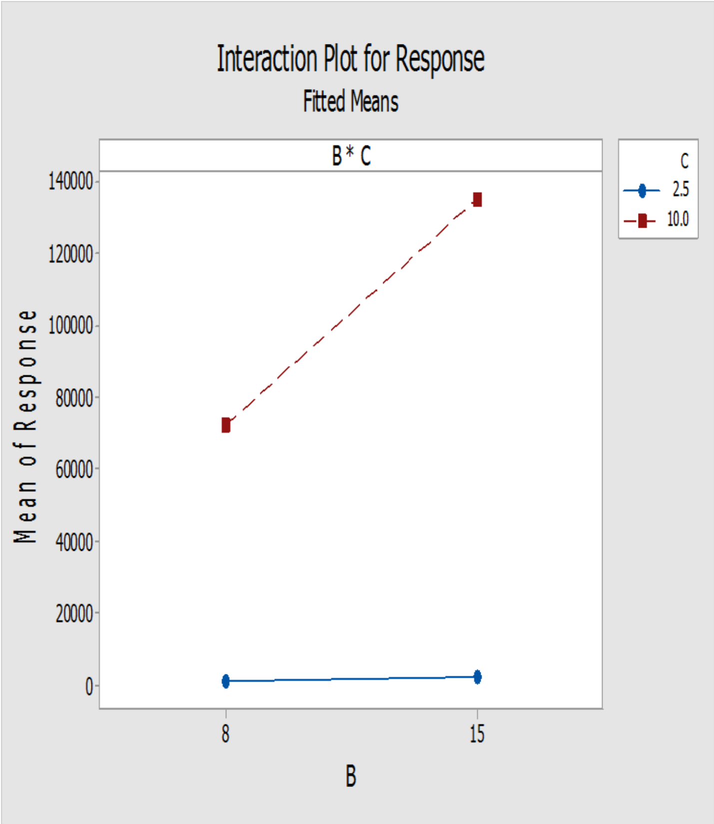

Fig.6. Effect of Interaction BC on response variable

ANOVA results for the problem under consideration are presented in Table 4. The analysis is done for the level of confidence 95%.

Table 4. Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	4	25003014160	6250753540	61.42	0.003
Linear	3	23080045288	7693348429	75.60	0.003
A	1	272830200	272830200	2.68	0.200
B	1	2047000122	2047000122	20.11	0.021
C	1	20760214966	20760214966	203.99	0.001
2-Way Inter-actions	1	1922968872	1922968872	18.90	0.022
B*C	1	1922968872	1922968872	18.90	0.022
S = 10088.1 R-sq = 98.79% R-sq(adj)= 97.19% R-sq(pred) = 91.42%					

From the p-value of this table, it could be concluded that, spring wire diameter is one of the most dominant parameters followed by number of turns affecting the weight of the spring.

After the above analysis, following regression equation was developed between the response variable and the working parameters using Minitab 17 software and is given below:

Regression Equation in Uncoded Units

Response = -52559 + 5840 A - 2812 B + 0 C + 1181 B*C

The optimum values for operating parameters are also found and presented in Table 5.

Table 5. Optimization Result

Parameters	Optimum Values
Spring index(A)	8
Number of turns(B)	8
Wire diameter(C)	2.5

With these values, the minimum value of the objection function (weight of spring) was found as 1000.

4. CONCLUSION

In this study, the effect of factors such as number of turns, spring index and wire diameter on the weight of helical compression spring have been evaluated by applying full factorial experimental approach using Minitab 17 software. From the analysis, it is found that

(i) Wire diameter is the major factor affecting the weight of the spring followed by number of turns and spring index.

(ii) A statistical model has also been developed to predict the value of weight of spring by entering different values for the design parameters.

(iii) The optimal parameters settings to minimize the weight of the spring is:
Spring index = 8;
Number of turns = 8 and
Wire diameter = 2.5 mm.

5. REFERENCES

[1] http://engg-earning.blogspot.in/2011/03/helical-spring.html.

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[3] Bhandari V.B., Design of Machine Elements, Second edition, Tata McGraw Hill Book Co., 2007.