ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 4, April 2017

Application of Design of Experiment (DOE) Method for Optimum Parameters of "Mahindra Bolero" Leaf Spring

[1] Chaitali Chaudhari [2] Supriya Chaudhari, [3] Akshay Dalvi [4] Mayuri Deshpande, [5] Prof. Sachin Shinde
[1], [2], [3], [4] BE Research Scholar, [5] Professor, Research Scholar
[1], [2], [3], [4], [5] Datta Meghe College Of Engineering, Airoli, Navi Mumbai

Abstract: **The Automobile Industry has shown keen interest for replacement of steel leaf spring with that of composite leaf spring, since the composite material has high strength to weight ratio, good corrosion resistance and tailor-able properties. The study aim's in the rear leaf spring analysis of "Mahindra Bolero". In this study, the authors attempt is to maximize the stiffness in the leaf spring by application of the DOE (Design of Experiments) method. Experiments have been conducted using standard L-8 orthogonal array by Taguchi. The statistical methods of signal to noise ratio (S/N) and analysis of variance (ANOVA) are applied to investigate the effects of four design parameters (material, width, thickness, number of leaves) on stiffness. A combination of optimal design parameters is also identified.**

Index Terms— **DOE, Mahindra Bolero Leaf Spring, Composite Material, Taguchi method, ANSYS 14.5, Minitab 17.**

I. INTRODUCTION

A leaf spring is a beam of cantilever design used to absorb the shock loads. Mostly, used in passenger and commercial vehicles as a part of the suspension system that connects the wheel base and the chassis of high criticality in terms of safety of the vehicles. The advantage of leaf spring over helical spring is that the ends of the leaf spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device [1]. In the present work, the 3D model of Mahindra Bolero leaf spring is created in CREO 3.0. Fig. 1 explains the construction features designed in CREO parametric by varying its width, thickness and number of leaves. The model with different combination of parameters has been analyzed considering material like Carbon Steel, E-glass Epoxy, Boron/ Aluminium, Kevlar using Ansys 14.5. The variation of bending stress and displacement values are computed. To add on the different combinations of input for Design of Experiment(DOE), parameters such as material, width, thickness and number of leaves have been taken into account & its influence on bending stress and maximum deflection has been studied.Experimental analysis is carried out based on DOE, and the obtained experimental data are analyzed using ANOVA (Analysis of variance) are discussed in section V.DOE (Design of Experiments) provides a powerful means to achieve breakthrough improvements in product quality and process efficiency. From the viewpoint of manufacturing fields, this can reduce the number of required experiments when taking into account the numerous factors affecting experimental results [2]. DOE can show how to carry out the fewest number of experiments while maintaining the most important information. DOE exhibits in determining the independent variable values at which a limited number of experiments will be conducted. For this purpose, Taguchi proposed an improved DOE. This approach adopts the fundamental idea of DOE, but simplifies and standardizes the factorial and fractional factorial designs so that the conducted experiments can produce more consistent results. The major contribution of the work has been in developing and using a special set of orthogonal arrays for designing experiments. Orthogonal arrays are a set of tables of numbers, each of which can be used to lay out experiments for a number of experimental situations. The DOE technique based on this approach makes use of these arrays to design experiments. Through the orthogonal arrays, it is possible to carry out fewer fractional factorial experiments than full factorial experiments [2].

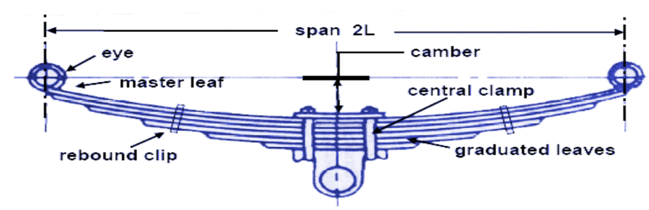

Fig 1: Schematic representation of Leaf Spring [3]

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ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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II. OBJECTIVES

i) Change in material properties will yield high strength as compared to the old material, hence material optimization will be observed.
ii) The weight of the complete stack assembly of the leaf will have optimised weight as compared to the earlier one.
iii) Reduced stresses and increased stiffness will insure better suspension and a comfortable ride.
iv) The advance methodology of experimental design using computer simulation will be studied.
v) Optimum condition of semi-elliptical leaf spring design in case of stiffness, deflection and stress based on regression analysis will be obtained.

III. LEAF SPRING PARAMETERS

A Cause-and-Effect diagram is also known as Ishikawa diagram or fishbone diagram as shown in Fig. 2 is used in the brainstorming session to identify the cause-effect between factors related to cause [4]. The main purpose of the Cause-and-Effect diagram is to generate a comprehensive list of possible causes at the first step in problem solving.

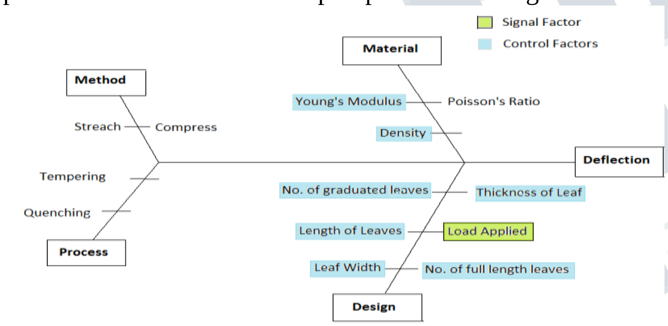

Fig 2: Cause and effect diagram of leaf spring [4]

From the brain-storming session, the main causes of the problem are identified. These causes can be categorized into control factors, noise factors, and signal factors [5]. A parameter diagram studies all those factors which contribute to the output by a graphical way.

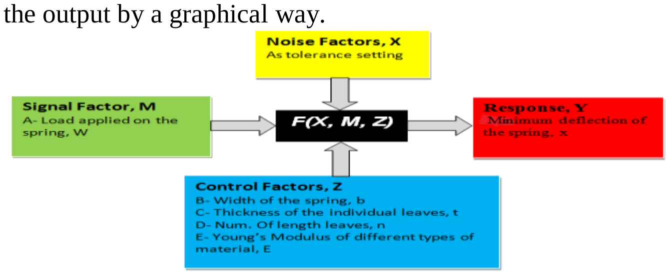

Fig 3: Factors affecting the output

IV. SELECTION OF ORTHOGONAL ARRAY

Design of experiment (DOE) methodology was used to plan the experiment. Before finalizing a particular OA, the following two things must be established,
(a) The number of levels for the parameters of interest.
(b) The number of parameters and their interaction of interest.
In the present study four different process parameters have been selected as already discussed. The width, thickness, number of leafs have two levels and material has four levels i.e.4^1 2^3 as tabulated in Table 1. In present case, according to above two conditions mentioned, L8orthogonal array was selected for this study and is given in Table 3.

Table 1: Process parameters with their values

Factors	Design Parameters	Level 1	Level 2	Level 3	Level 4
A	Materials	Carbon Steel	E-glass Epoxy	Boron/ Al	Kevlar
B	Width	70	60	-	-
C	Thickness	8	6	-	-
D	No. of Leaf	6	5	-	-

Experimental analysis

In multi leaf spring, the maximum stress and deflection is as follows,

$S_{max} = 6PL / nbt^2$

$D_{max} = 12PL^3 / Ebt^3(3n_f + 2n_g)$

[3]

Where,
P = load applied= 5150 N (Load acting on each spring)
L =length of spring
E= modulus of elasticity
b= width of leaves
t = thickness of leaves
n= number of leaves

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International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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Table: 2 Mechanical Properties of standard Material [6-7]

Material	Ultimate tensile (MPa)	Yield tensile (MPa)	Young's modulus (MPa)	Poisson's ratio	Density (kg/m^3)
Steel	800	572.3	20000	0.285	7860
E-glass/ epoxy	900	205	24000	0.300	1520
Boron/ Al	-	120	144400	0.315	1020
Kevlar	1800	1380	76000	0.360	1440

In this study, larger-the-better principle is considered to maximize the stiffness. The corresponding loss function is expressed as follow [8]:

$$S/N_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

Where n is the number of observations and y is the observed data.

The S/N ratios were computed using Eq. for each of the 8 trials and the values are reported in Fig. 5 which gives the reflection of each level on the response.

Table: 3 L_8 Orthogonal Array generated in Minitab

Trials	Factors				Stiffness N/mm
	A (Material)	B (Width)	C (Thickness)	D (no. of leaves)	
1	1	1	1	1	48.488
2	1	2	2	2	41.358
3	2	1	1	2	49.150
4	2	2	2	1	42.547
5	3	1	2	1	42.671
6	3	2	1	2	47.109
7	4	1	2	2	51.223
8	4	2	1	1	53.027

VI. SCATTER PLOT FOR MATERIAL

Composite materials have far more strength than that of steel and hence becoming the trending research issue in industry. The following scatterplot shows the relationship between material and stiffness as shown in Table 3.

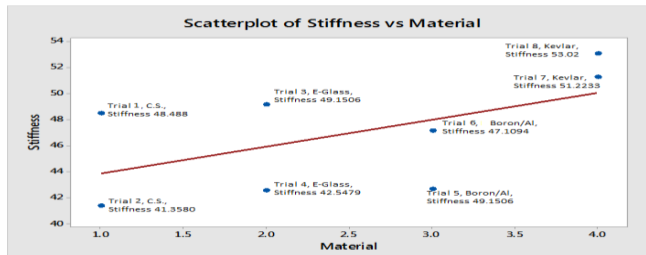

Fig 3: Scatter plot of Stiffness vs. Material

Main effect plot

In order to access the influence of factors on a response of stiffness, the means and signal-to-noise ratio(S/N) for each control factor must be calculated. In Taguchi analysis, the main effect plot shows how each factor level affect the response characteristic. A main effect is present when different levels of a factor affect the characteristic differently. Assistant tool creates the main effects plot by plotting the characteristic average for each factor level.

In this work, 4 means and 4 S/N ratios were calculated. The results were presented in Figs. 4-5, which were obtained by means of a statistical software MINITAB. 'Larger is better' is criteria for optimum stiffness. Rank is assign on the basis of distance of the point from the mean line. Delta is the measure of stiffness variation from mean line as in Table 4.

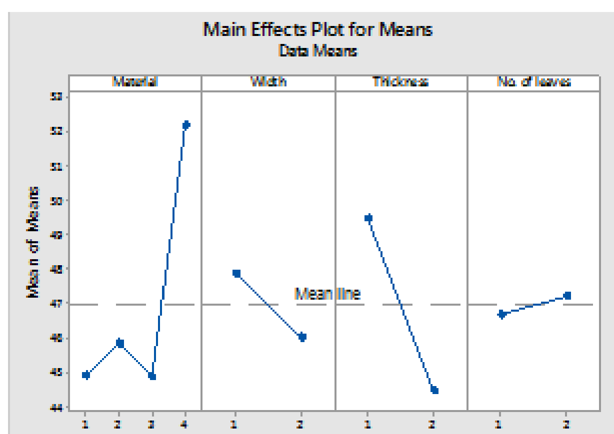

Fig 4: Effect of process parameters on stiffness(Raw data)

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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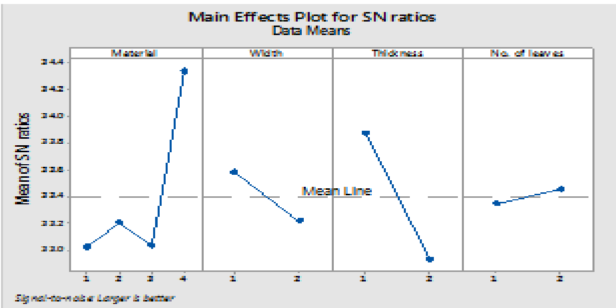

Fig 5: Effect of process parameters on stiffness (S/N data)

Table: 4 Response Table for S/ N Ratios, Larger is better

Level	Material	Width	Thickness	No. of leaves
1	33.02	33.58	33.87	33.35
2	33.20	33.22	32.93	33.45
3	33.03	-	-	-
4	34.34	-	-	-
Delta	1.32	0.37	0.95	0.11
Rank	1	3	2	4

The data in Table 4 shows that the largest contribution to the total stiffness is of factor 'A' followed by factor 'C', 'B' and then 'A'. The larger is the delta value and rank of the particular factor, the larger is its ability to influence the stiffness.

VIII. ANOVA RESULTS

According to the reading of this diagrams proposed from Taguchi, all the four parameters have a significant effect on the stiffness of leaf spring. The best combination of levels was given by the levels (4, 1, 1, 2) for both the effect on means and for S/N ratio. The optimal result is confirmed with a superior ultimate stiffness value of55.8217N/mm.

Fig 6: Optimal Predict graph

From the above analysis, the processing parameters, such as material, width, thickness and no. of leaves diameter can be obtained, its value were Kevlar material, 70mm, 8mm and 5, respectively. According to the S/N ratios, this solution can be considered robust against noise.

IX. ANSYS RESULTS

The static analysis of the Leaf Spring is carried out using ANSYS workbench 14.5 to find out maximum deflection and von Mises stress when maximum static load of 5150N acts at the centre of the leaf spring [9]. The spring behaves like a simply supported beam. The obtained displacement contour and von Mises stress distribution for the Conventional Steel (width: 70mm, thickness: 8mm and no. of leafs: 6) and Kevlar (width: 70mm, thickness: 8mm and no. of leaves: 5) are shown in Fig. (7) to (10) respectively.

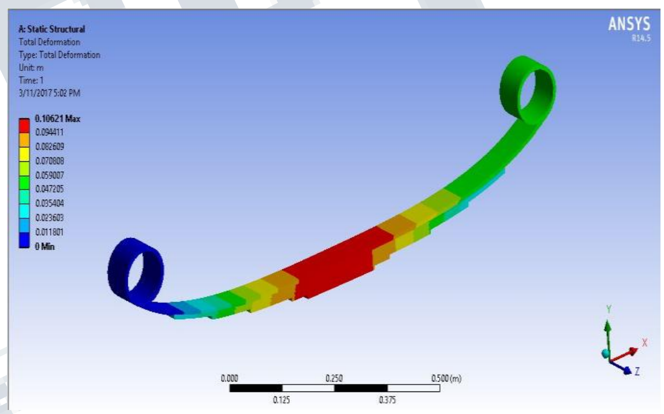

Fig 7: Displacement Contour for Steel Leaf Spring

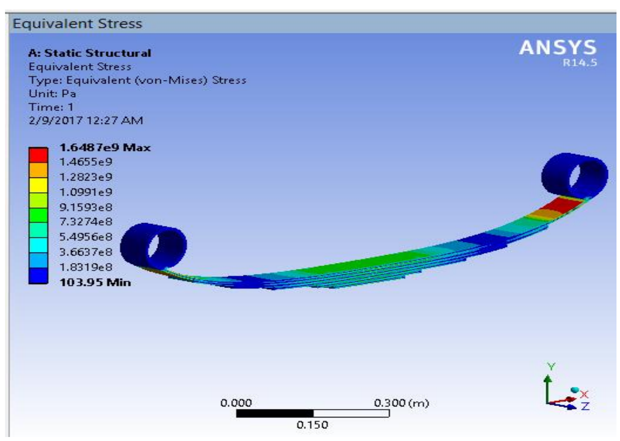

Fig 8: Von Mises Stress Distribution for Steel Leaf Spring

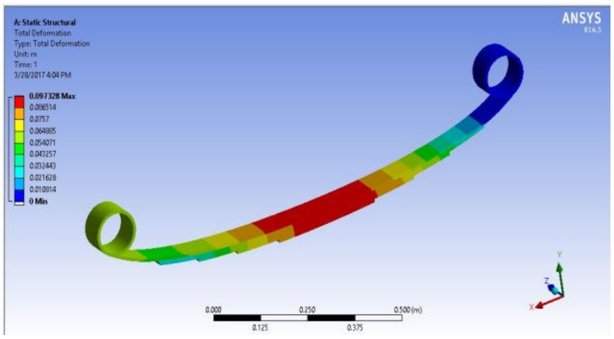

Fig 9: Displacement Contour for Kevlar Leaf Spring

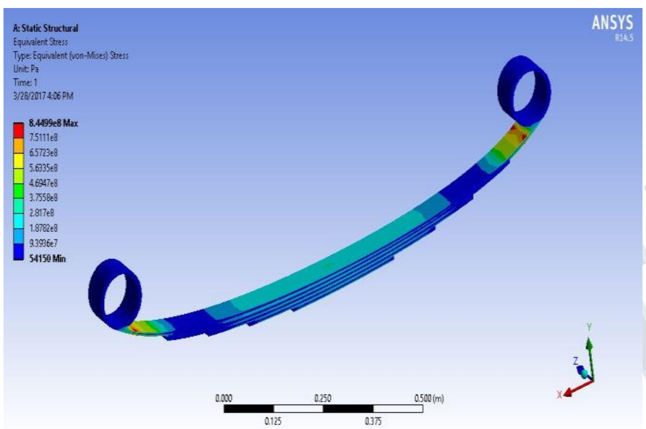

Fig 10: Von Mises Stress Distribution for Kevlar Leaf Spring

X. CONFIRMATION OF EXPERIMENT

The confirmation of experiment was conducted in the computer simulation at the optimal specifications recommended by the investigation. The average value of deflection as found to be reduced by percent and confirms minimum amongst all other combinations.

Table: 5 Comparison of optimum results

	Material	Signal (N)	Deflection (mm)	Stress (MPa)	Stiffness (N\mm)
Before	Carbon Steel	5150	106.2	1.6619e3	48.48
After	Kevlar	5150	97.00	8.4492e2	53.09

XI. CONCLUSION

i) A new method of stress analysis is proposed and studied which is a combination of design of experiments method (Taguchi method) and computer aided spring simulation technique for analysis of stress induced in the leaf spring due to the effect of factors like material of leaf spring, width of leaves, thickness of leaves and number of leaves.

ii) Using Ansys it is found that, Stress induced in composites leaf spring is much less than that of one made up of steel

iii) Material found to be most influential among the factors. Number of leaves had the least effect on the stiffness of leaf spring.

iv) The optimized levels of selected design parameters obtained by Taguchi method are: (Material): Kevlar, (Width): 70mm, (Thickness): 8mm, (No. of leaves): 5

v) With Taguchi optimization method, the stress induced in the leaf spring can be reduced from 1.6619e3 MPa to 8.44922e2 MPa and stiffness is increased from 48.488 N/mm to 53.09 N/mm.

vi) By theoretical calculation, the weight of Steel leaf spring is 211.28N and that of Kevlar leaf spring with optimum combination is 33.88N. Hence weight reduction of 83.96% is obtained.

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