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Optimization of Leaf Spring Parameters Using Taguchi's DoE

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***Abstract*— The design of the leaf spring is the one of the important unit in automotive design. The leaf spring absorbs heavy vertical loads in order to give smooth and comfort ride to the passengers. In the present day, automobile industries have shown an interest to reduce the weight of vehicle components as people are showing interest to have the vehicle with very good mileage. The objective of this present work is to compare the deformation of modified model of leaf spring with conventional leaf spring. Modeling of Leaf Spring is performed with SOLIDWORKS and structural analysis of the leaf spring is carried out using ANSYS 18.1.The light commercial vehicle (TATA ACE) leaf spring is taken for the analysis. In this work, it is decided to vary various design parameters of the leaf spring and to analyze the effects of those parameters in deformation. The various parameters selected are materials, number of leaves and length of leaves. Each parameter is varied to three levels. As per L_9 orthogonal array, the maximum deformation in the leaf spring is obtained from ANSYS analysis for nine test conditions. The best levels of selected leaf spring parameters for minimizing deformation is identified by using Taguchi's Design of Experiments. Analysis of Variance is used to analyze the influence of selected parameters on deformation of leaf spring. The effect of individual parameters as well as interactions between the selected leaf spring parameters on the deformation is analyzed using regression analysis (both linear and non linear). Finally, experiment for validation has been carried out with obtained best levels of leaf spring design parameters and the value of deformation is obtained.**

***Keywords*— Composite Leaf Spring, Deformation, Taguchi's DoE, Regression Analysis, ANOVA.**

I. INTRODUCTION

Leaf Springs are the basic form of suspension made up of layers of steel. It is a simple form of spring commonly used as suspension in the wheeled vehicles. Also it is one of the oldest forms of spring. The advantage of leaf spring over earlier springs is that the design of the leaf spring is simple and cheaper to manufacture.

Mono leaf spring is the simplest design in which only one leaf which tapered from thick in the middle to thin at the edges to distribute the vertical loads. This mono leaf spring is commonly known as parabolic leaf spring. But due to lack of strength within the bar, the single leaf spring setup can only be used for extremely light weight vehicles.

Therefore for heavy duty vehicles, in a multi-leaf steel spring, the number of leaves of spring of varying length is assembled in which the thickness will be greatest at the center and continuously reduced to the ends of spring. For the light and heavy commercial vehicles, semi-elliptic leaf springs are most commonly used for suspension. Also, these springs are used in cars for rear suspension.

Normally the leaf spring is located in between axle housing and chassis of vehicle. This may be well thought-out as the simply supported beam acting with a point load at the middle of it. Due to this, there will be maximum bending moment at the center and continuously reduced towards its ends. Hence selection of spring will be varied from extreme at the center and to minimum at end of spring. The leaves of varying length are placed one above another and they are hold together by means of clamps and a U-bolt at center of leaf spring. The master leaf is the one which is extended to the full length. Both ends of the master leaf are shaped into loops and they are called as eyes. There will be a hole at the center of every metallic leaf through which bolt will be passed to hold the leaves together. In order to hold the shorter leaves outer ends with master leaf, spring clips will be used.

Most commonly used leaf spring in automobile is semi-elliptical assembly. The semi-elliptical leaf spring will be constructed with number of plates. Initial curvature will be given in the leaves so that when load acts on the spring, it will tend to straighten. The leaf spring is clamped together to the housing by means of U-bolts.

The master leaf or the main leaf of the leaf spring will have the shape of an eye at its ends. The bolt will pass through the eye to protect the spring to its supports. Bushings of some antifriction materials rubber or bronze are provided in the hanger or shackle to which the eye of the spring is attached. The master leaf has to bear up the huge vertical bending loads and the loads which act on it while the vehicle takes a turn. The other leaves are called as graduated leaves and the graduated leaves are trimmed to various forms in order to avoid digging in the adjacent leaves. Normally two full leaves and other as graduated leaves will be provided to take up the stresses developed due to loading.

Various models of leaf springs are used in vehicles. They are semi elliptical type, quarter elliptical type, longitudinally located type, transversely located type, tapered type and progressive type leaf springs. The leaf spring will be made of number of steel leaves in the semi elliptical leaf spring. Each leaf will vary in its length. But the thickness and width remains same. The master leaf is the longest leaf which has bushes at its ends and it will be the topmost. The ends of the leaf spring are directly connected to the side member of the vehicle frame. The quarter-elliptic leaf spring is also called cantilever type leaf spring as one end of the leaf spring is fixed to the side member of the frame of vehicle and the other end is connected freely to the front axle. In this type of spring, the camber will be given on the upper side so that when the front axle beam is subjected to any load, the leaves tend to straighten. In the transversely mounted semi-elliptical inverted leaf spring, the leaf spring is placed and connected transversely along the width of vehicle. The springs are mounted inverted so that longest leaf will be at the bottom. The use of two shackles is the specialty of this arrangement.

It is necessary to reduce the unsprung weight of the vehicle by considering the vehicle dynamics. When the weight reduction of any amount is achieved in the unsprung weight will lead to increased fuel efficiency. Leaf spring, road wheel and driving shaft constitute the unsprung weight. Among that leaf spring constitute maximum of 25% of unsprung weight while others such as road wheel and drive shafts amounts to minimum. Hence many researches are going on by using different materials for the leaf spring to minimize the weight of leaf spring which in turn the unsprung weight. At the same time the materials selected for the leaf spring should have high elastic strain energy storage capacity, good corrosion resistance, high strength to weight ratio, high fatigue strength and good damping capacity.

Weight reduction in leaf spring is achieved by introducing leaf spring with optimized material properties, optimized design and optimized manufacturing processes. This causes the vehicle with increased fuel efficiency and better riding comfort. Through various researches it is found that the use of composite materials in the leaf spring causes reduction of weight. This made possible to reduce the weight of the leaf spring without compromising the stiffness and load carrying capacity of the spring.

The optimally designed composite leaf spring will provide weight reduction to a maximum of 85% when compared to leaf spring made of conventional steel which in turn will increase the fuel efficiency. Hence proper design optimization technique should be used for the selection of proper material for the leaf spring and for the selection of optimized thickness and length of leaf spring so that the deflection due to the load on the spring will be minimized.

II. Literature Review

A. Arther Clive [1] made the analysis on leaf spring with composite materials. The deflection of the leaf spring for various composite materials and conventional steel has been obtained by analysis using ANSYS. Carbon Epoxy, Carbon Fiber, E glass epoxy were the composite materials selected and the deflection obtained using ANSYS is compared with the result obtained for conventional leaf spring. It is found from the result that leaf spring with Carbon Fiber cause minimum value of deformation when compared to other materials.

Syambabu Nutalapati [2] designed the leaf spring for Mahindra Ommander 650 Di and calculated the weight of the leaf for conventional steel and for the chosen Eglass/epoxy composite materials. It was found that 84.66% of weight is saved for the composite material when compared with conventional steel. He modeled the leaf spring using Pro/E 5.0 and imported the model in ANSYS. The static and modal analysis were carried out for the selected both the materials. It is found from the result that the deformation and the von-mises stress are very much less for the composite material when compared to conventional steel.

Ajay. B.K, Mandar Gophane and Baskar P [3] performed the design and analysis on a multi-leaf spring. The steel material was replaced with glass fiber reinforced plastic material. The factor of safety was kept as 2.5 and analysis was carried out using ANSYS. It is found from the result that the leaf spring with composite material has the stress value lower than leaf spring with steel.

Anandkumar A. Satpute and Prof. S. S. Chavan [4] carried out experimental tests in order to justify composite material will be the alternative over the conventional steel spring. Maruti Omni multi leaf spring with conventional leaf spring is tested analytically and experimentally for the static condition. Then the conventional steel is replaced with mono composite leaf spring.

The composition of fibers and matrix were used for the fabrication of composite spring. Glass fiber and Epoxy were used as a resin. It is found from the result that there is a weight reduction of 88% when composite material is used.

AshishV.Amrute, Edward Nikhil karlus [5] carried out the static analysis on multi leaf spring of a light commercial vehicle with conventional steel and with composite materials. E-Glass/Epoxy has been selected as composite materials. Analysis is carried using ANSYS and the stress and deformation were obtained for steel and composite materials. Element type of SOLID 45 and CONTA 174 has been chosen for analysis. Force of 4169 N is applied at both eye ends. It is found that there is weight saving of 67.88% when composite material is used. Also it is found that both bending stress and deformation of leaf spring with composite material is very much lesser while comparing with conventional steel leaf spring.

Anup P. Patil and B.G. Marlapalle [6] used PRO-E wildfire 5 for modeling the leaf spring with steel as material and with composite material. E-Glass Epoxy was the composite material chosen for the analysis. ANSYS 14.5 software was used for the analysis of leaf spring with steel and with composite materials. The deflection and the bending stress of leaf spring for both materials are obtained from the analysis and compared. It is found that there is material saving up to 64.12% when composite material is replaced with steel.

Joo-teck Jeffrey KUEH and Tarlochan FARIS [7] investigated with the use of ANSYS, the static and fatigue characteristics of conventional steel leaf spring and multi-leaf spring made of composite materials. The design parameters of existing conventional 7 leaf spring made of steel has been taken from analysis. The two composite materials such as E-glass fiber/vinyl ester and E-glass fiber/epoxy were used by keeping the dimensions same for design. Static and fatigue results were obtained and analyzed. It is found from the analysis that the fatigue life of composite materials selected for the leaf spring is 2 and 4 times higher than that of steel multi-leaf spring.

Bandi Manasa and R. Lokanadham [8] designed the standard elliptical leaf spring using CATIA and made the analysis using ANSYS for various materials. The conventional leaf spring 55 Si 7 is replaced with composite leaf spring. Analysis was performed with various loads. The stress, strain and deformation of leaf spring for different materials like E-Glass/ Epoxy and Jute/ E-Glass/ Epoxy were obtained and the results are compared.

Also the reduction in weight due to the use of composite materials with conventional steel are also compared.

Malaga. Anilkumar, T. N. Charyulu and Ch. Ramesh [9] replaced multi-leaf steel spring by mono spring made of composite material for the same stiffness and load carrying capacity. The multi steel leaf spring and the mono leaf spring made of composite were modeled by taking the dimensions of a leaf spring of light weight vehicle. The static and modal analysis was carried out using ANSYS. Analysis was carried out with three different composite materials with mono leaf spring and compared with multi leaf steel leaf spring. It is found from the result that, mono leaf spring made of composite minimizes the weight by a minimum of 85% when compared with conventional leaf spring.

Pankaj Saini, Ashish Goel and Dushyant Kumar [10] worked on analysis of leaf spring made of composite material for light vehicles. For the capability of mass production, constant cross section design method is alone selected. The materials selected are plain carbon steel, Carbon/Graphite fibers and Glass fibers. The solid modeling of multi leaf steel spring and mono-composite leaf spring were modeled by considering the dimensions of leaf spring of light weight commercial vehicle. Static analysis and simulation has been carried out using ANSYS by applying the boundary conditions. It is found from the analysis that when composite material is used there is a weight saving of minimum of 81.72% over the conventional steel leaf spring. Also it is noticed that the Von Mises stress for the composite material comes to a maximum value of 300.3 Mpa while for conventional steel comes to be 453.92 Mpa.

Y. N. V. Santhosh Kumar, M. VimalTeja [11] discussed the various benefits of composite materials over conventional metallic structures. Mono composite leaf spring is replaced instead of conventional steel spring. The main objective is to minimize the weight of leaf spring made of composite material over the leaf spring made of conventional steel. Design of the spring with constant thickness and constant width has been considered for the analysis. Static analysis of the spring has been performed for the master leaf and the deflection and X component of stress has been obtained. It is proved from the result that there is a weight reduction of 60.48% is obtained using composite leaf springs when compared with steel.

V. Trivedi Achyut and R.M. Bhoraniya [12] performed static analysis conventional leaf spring and composite leaf spring using ANSYS 14.0.

The load carrying capacity and savings of weight with the use of composite material in the leaf spring with the regular steel leaf spring is compared in this work. The dimensions used in the conventional steel leaf spring have been used for composite multi leaf spring. The composite materials selected are Carbon/Epoxy and Graphite/Epoxy. The output parameters selected are stress and deformation and weight of spring. The stress and deformation for the conventional steel leaf spring and for selected composite materials were obtained in the analysis using ANSYS. It is finally concluded in the work that the composites have 400% less weight than conventional steel. Also the modal analysis has been carried out and it is found that use of composite material is not producing resonant effect and its use will be safe.

Yogesh Nikam, Dr.Avinash Badadhe [13] designed mono leaf composite leaf spring that replaces the 7 leaf steel leaf spring. The leaf spring is modeled using CATIA and the modeled design has been imported as IGES format in ANSYS. The deformation of the conventional 7 leaf spring has been obtained using ANSYS and the deformation obtained for the leaf spring made of composite is compared. It is found that the equivalent stress and the deformation obtained for the leaf spring with composite material is lesser when compared to steel leaf spring.

A.P. Ghodake and K.N. Patil [14] replaced the use of conventional steel with the introduced new material, glass fiber rein forced plastic (GFRP) and the polyester resin (NETPOL 1011) for the leaf spring. 65Si7 is the material selected for the steel leaf spring and E-Glass/Epoxy is the material selected for the composite. The geometry of the leaf spring is modeled using SOLIDWORKS and imported in ANSYS for analysis. Loading and boundary conditions were given as per the standards available during analysis. The deflection, stress and strain energy for the conventional steel leaf spring and for composites were obtained. It is found from the result that there is weight reduction of 84.94% with the use of composite than the conventional steel.

Manjit Lakra, Mukesh Sahu, A K Khandelwal and S P Shrivas [15] analyzed and compared the load carrying capacity and weight reduction with the use of composite material instead of steel spring. The model is designed using SOLIDWORKS and the static analysis was carried out using ANSYS 14.5. The output obtained from ANSYS is compared with the experimental results. Grey Relational Analysis is the techniques used for optimization.

It is concluded from the analysis that Carbon epoxy material gives minimum stress and deformation when compared with conventional steel leaf spring.

D. Lydia Mahanthi and C. Venkata Siva Murali [16] introduced the use of fiber reinforced plastics to decrease the weight of the product without any compromise on load carrying capacity and spring rate. The leaf spring has been modeled using CATIA and analyzed using ANSYS by feeding the entire boundary and loading conditions. EN 47, KEVLAR, S-Glass Epoxy and E-Glass Epoxy were used as material for the leaf spring. It is found from the analysis that KEVLAR material seems to be better when compared with steel and other composite materials.

Gayatri J. Abhyankar, Vaibhav Holkar, Bhiva Malkar, Ganesh Sutar and Rajesh teli [17] designed, modeled and analyzed the leaf spring of Mahindra Bolero with different materials such as conventional steel and E Glass/Epoxy composite. Static analysis has been carried out the modeled design of leaf spring. The deformation and equivalent stress of leaf spring for the selected two different materials has been obtained. It is found from the result that the mass of composite leaf spring is reduced by 41.07% over steel. Also the deflection and maximum stress developed found be lesser for composite leaf spring while comparing with conventional steel leaf spring.

D V Ramanareddy, B. Subbaratnam, E. Manoj Kumar and Perala Kalyan Praneeth [18] carried out a work on analysis of a composite leaf spring and compared with leaf spring made of standard steel. Design of leaf spring was carried out using CATIA V5. The various materials selected for analysis are Epoxy glass, Epoxy carbon, Aluminum Alloy, Titanium Alloy and the output result of the analysis is compared with conventional steel leaf spring. The theoretical and experimental results of stress and deformation for the selected materials are compared and tabulated. Also the comparison of weight for the various materials of leaf spring has been tabulated. Finally it concluded that the composite materials used in the leaf spring gives the better result in deformation, stress and also in weight reduction.

Prasad P. Kunzarkar and Tushar V. Gukrathi [19] carried out a review on use of various materials in automobile leaf spring. Review on the usage of different materials like S2-glass fiber/Epoxy and E-Glass/Epoxy, E glass fiber with two layer bidirectional fabric, E-Glass Epoxy and Carbon fiber/Epoxy etc., were carried out.

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Finally it is concluded that the use of composite materials in the leaf spring instead of conventional steel is of more efficient and much beneficial for the light weigh vehicles.

It is found from the literature review that the analysis has been carried out by varying only one parameter by keeping other parameters constant. In this work, it is decided to vary various design parameters in the single leaf spring and to analyze it for the minimization of deformation of leaf spring.

III. METHODOLOGY USED

The various methodologies used in this study are, Taguchi's Design of Experiments and Regression Analysis for developing empirical models.

A. *Taguchi's Design of Experiments*

The objective function is formulated using Taguchi's Design of Experiments in order to identify the optimal levels of selected leaf spring parameters. The various leaf spring parameters selected are materials, no. of. leaves and length. Each parameter is varied to three levels. The effect on deformation of leaf spring by varying the material (carbon epoxy, graphite epoxy and conventional steel) and number of leaves (3, 4, 5) and length (870mm, 880mm and 890mm) in the existing design are studied. When number of parameters and their levels increased, it is required to conduct more number of experiments. Exclusively designed orthogonal array is used to study and to analyze the entire parameter levels by conducting minimum number of experiments. The minimum number of experiments to be conducted is calculated as,

$[(L – 1) \times P] + 1 = [(3-1) \times 3]+1=7 \approx L_9$

where,

P – Number of parameters and

L – Number of levels of parameters

In order to normalize the obtained data, Signal-to-Noise (S/N) ratio values of deformation of leaf spring are calculated as,

$$S/N Ratio = -10\, log_{10} \frac{1}{n} \sum \overline{y^2} \qquad (1)$$

where, n is the number of serials and $\overline{y}$ is the sum of squares of measured values.

The main aim of this study is to minimize the deformation of leaf spring. Hence lower-the-better category is selected in calculating the S/N ratio.

Larger value is normally taken as better performance characteristic, as the S/N values are used. Therefore, the highest value of S/N ratio gives the optimal level of the particular parameter. Finally, a experiment for validation is conducted with all the optimal levels of parameters identified, to confirm the optimality.

B. *Regression Analysis*

The purpose of Linear Regression is to obtain prediction equations that express any output as a function of various independent variables. If those variables are measured, the prediction for the output can be obtained. The extension of Linear Regression is the Non Linear Regression which allows more than one independent variable. That is, instead of using only one independent variable 'x' several independent variables can be used. By using more than one independent variable, the accuracy in prediction of 'y' is possible [20].

In order to obtain the prediction of deformation of leaf spring and to develop the linear and cross product empirical models based on deformation of leaf spring values for the different test conditions, Regression Analysis is used in this study. The values of deformation of leaf spring predicted by the Linear and cross product Regression models are compared and correlated with the deformation values of leaf spring obtained using ANSYS and the relative trend is analyzed.

Often analysis-of-variance (ANOVA) approach will be handled to analyze the quality of predicted regression line. It is a method in which the total variation in the dependent variable will be further divided into meaningful components and they are then observed and treated in a proper fashion [21]. Fnides [22] used ANOVA technique and states that a low P value which is less than 0.05, analysis-of-variance indicates an arithmetic significance to the source on the corresponding response which is 95% of confidence level. Kazancoglu et al. [23] used ANOVA technique and obtained the significance of the factors quantitatively on the whole quality characteristics of cutting process.

IV. EXPERIMENTAL DETAILS

The leaf spring of a TATA ACE vehicle is taken for the analysis. Materials of the leaf spring, number of leaves and length of leaf spring were selected as parameters and the deformation of the flank wear was selected as performance quality characteristic. The values of various parameters selected and their ranges are presented in Table 1.

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TABLE I
THE DIFFERENT VALUES OF PARAMETERS SELECTED AND THEIR LEVELS

Parameters	Levels		
	L_1	L_2	L_3
Materials g/cm^3	1.6	2.26	7.87
Master Leaf Length (mm)	870	880	890
Number of Leaves	3	4	5

Modeling using SOLIDWORKS, Analysis in ANSYS was carried out as per the test conditions shown in Table 2.

TABLE II
EXPERIMENTAL TEST CONDITIONS AND PARAMETER VALUES

Sl. No	Material (d)	Length of Master Leaves (l)	No.of. Leaves (n)
1	Carbon Epoxy (1.6 g/cm^3)	870	3
2	Carbon Epoxy (1.6 g/cm^3)	880	4
3	Carbon Epoxy (1.6 g/cm^3)	890	5
4	Graphite Epoxy (2.26 g/cm^3)	870	4
5	Graphite Epoxy (2.26 g/cm^3)	880	5
6	Graphite Epoxy (2.26 g/cm^3)	890	3
7	Conventional steel (7.87 g/cm^3)	870	5
8	Conventional steel (7.87 g/cm^3)	880	3
9	Conventional steel (7.87 g/cm^3)	890	4

Modelling of the chassis as per the dimensions was done using 3D model software SOLIDWORKS and the modelled leaf spring for the test condition 7 is shown in Figure 1.

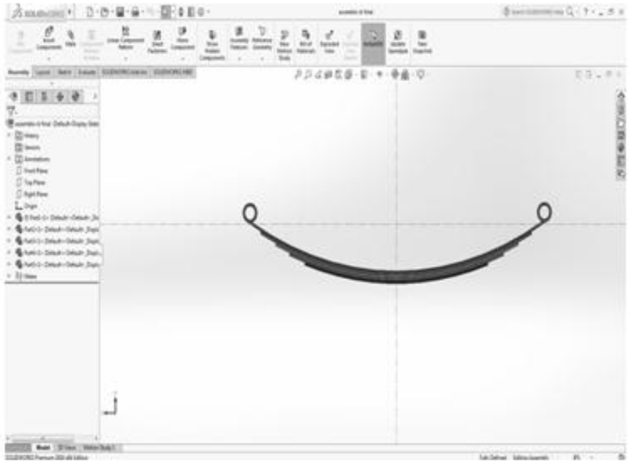

FIGURE 1 LEAF SPRING MODELLED USING SOLIDWORKS FOR TEST CONDITION 7

Modeled leaf spring for all the test conditions were imported to ANSYS 18.1 software. The analyzing part of the leaf spring was done by using FEA in ANSYS for all the test conditions by feeding all the material properties required during analysis. The meshed leaf spring during the analysis for test condition 3 is presented in Figure 2.

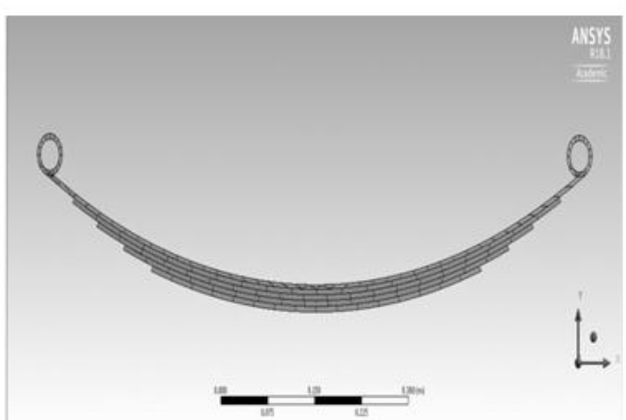

FIGURE 2 MESHED LEAF SPRING FOR TEST CONDITION 3

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V. RESULT AND DISCUSSIONS

According to the orthogonal array obtained using Taguchi's DoE, analysis was carried out using ANSYS for all the combinations of parameters tabulated in Table 2 and the value of deformation of leaf spring is obtained. The snapshot of the output of deformation for test condition number 1 is presented in Figure 3.

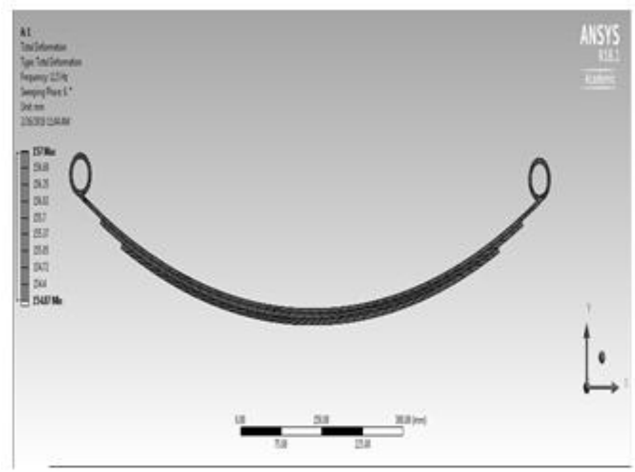

FIGURE 3 SNAPSHOT OF THE OUTPUT OF DEFORMATION FOR TEST CONDITION NUMBER 1

The experimental test conditions and the values of deformation of leaf spring obtained using ANSYS for all the combinations of parameters tabulated in Table 3 (both actual obtained from ANSYS and S/N ratio values of deformation) are presented in Table 3. The value of S/N ratio for deformation was calculated using (1) for the serial number 5 as,

$$S/NRatio = -10\log_{10}(75.3x75.3) = -37.539$$

TABLE III
VALUES OF DEFORMATION OF LEAF SPRING OBTAINED USING ANSYS FOR ALL THE TEST CONDITIONS

Test Condition Number	Material density (D) (Kg/m^3)	Length (L) (mm)	No. of. Leaves (N)	Deformation (mm)	S/N Value of Deformation
1	1600	870	3	157	-43.917
2	1600	880	4	124.4	-41.898
3	1600	890	5	106.4	-40.539
4	2260	870	4	88	-38.889
5	2260	880	5	75.3	-37.539
6	2260	890	3	111.5	-40.918
7	7870	870	5	21.6	-26.721
8	7870	880	3	32	-30.102
9	7870	890	4	25.4	-28.117

The optimized level of parameters which is maximum value of S/N ratio were identified as,

Material density = 7870 kg/m^3(D_3)
Length = 890 mm (L_3)
No. of. Leaves = 5 (N_3)

Validation experiment has been conducted in ANSYS to obtain deformation with the above identified best value of the parameters. The result of deformation with the best level of leaf spring parameters is shown in Figure 4.

FIGURE 4 THE RESULT OF DEFORMATION WITH THE OBTAINED BEST LEVELS OF PARAMETERS

The value of deformation of leaf spring with identified best levels of parameters is 19.919 mm which is lower than all the tabulated values in Table 3. The respective S/N ratio value of deformation in the experiment for validation is -25.9853.

From Table 3, the percentage contribution of the selected parameters on S/N-deformation of leaf spring is calculated as,

$$\text{Material Density} = \frac{-28.313}{-28.313-36.524-34.933} = 28.37\%$$

Length of Leaf Spring = 36.608%
Number of Leaves = 35.01%

It is confirmed from the calculations that the material density of leaf spring is less significant on the S/N-deformation of leaf spring followed by other parameters. The length of leaf spring has high significant on S/N-deformation of leaf spring.

For verifying the validated result using linear regression analysis, the estimated mean of the deformation is calculated as,

$$D_{em} = D + L + N - 2D_m \qquad (2)$$

Where,
D_{em} = Estimated mean of deformation
D = Mean of deformation corresponding to Material density
L = Mean of deformation corresponding to Length
N = Mean of deformation corresponding to No. of leaves
D_m = Overall mean of deformation

From the table, the average values for the selected parameters are calculated and substituted in equation (2) and estimated mean of deformation is determined as,

D_{em} = -28.31378437-36.06066926-34.9333979 – 2(-36.51607769)
= -26.274

For the linear regression model, confidence interval for the prediction of average deformation on a validation test is calculated as,

$$CI = \sqrt{F0.05\,(2, fe)Ve\left[\frac{1}{n} + \frac{1}{R}\right]} \qquad (3)$$

Where,
f_m = error degrees of freedom
$F_{0.05}(2,f_e)$= F ratio necessary for risk (2,5) = 5.79 [24]
V_e= error variance (0.718224) from Table (4)
R = Number of repetitions for validation test = 1
N = Number of experiments in total = 9
n = effective number of replications
= N/(1 + dof associated with deformation)
= 9/(1+8)
= 1

The value of confidence interval for the deformation of linear regression model using the above relation is calculated as,

CI = {5.79 x 0.578146 [1/1 + 1/1] }^1/2
= 2.587456411

The linear regression table for deformation of leaf spring is presented in Table 4.

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TABLE IV
LINEAR REGRESSION TABLE FOR DEFORMATION

Regression Statistics	
Multiple R	0.994
R Square	0.989
Adjusted R Square	0.982
Standard Error	0.847
Observations	9

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	330.02	110.00	153.16	2.44E-05
Residual	**5**	3.5911	**0.718**		
Total	8	333.61			

	Coeff.	*Std. Error*
Intercept	**-51.1579**	30.481
X D	**0.002287**	0.0001
X L	**-0.00077**	0.0345
X N	**1.689831**	0.345

The 95% confidence interval of the optimal deformation in confirmation test is

$$(D_{em} - CI) < D_{con} < (D_{em} + CI)$$
$$(-28.861) < (-25.985) < (-23.687)$$

The result of conformation test shows that the deformation is -25.985which lies between (D_{em} - CI) and (D_{em} + CI) i.e., -25.985 is in between -28.861 and -23.687. Thus the validated deformation is confirmed by the above calculations.

Empirical equation on the basis of Linear Regression model for the deformation of leaf spring is developed as,

$$D_{LR} = -51.157 + (0.0022xD) - (0.00076xL) + (1.689xN) \quad (4)$$

Where,

D = Material density in kg/m^3
L = Length in mm
N = No. of leaves in mm.

The Experimental S/N value of deformation for the test condition 1 is-43.917

Empirical value of deformation

= -51.1579 + (0.002287 x 1600) – (0.00077 x 870) + (1.689831 x 3) = -43.099

The percentage error between empirical and experimental deformation value is obtained as,

= ((Predicted value – Experimental value) / Predicted value) x 100
= ((-43.0992619 - 43.91799305)/ -43.0992619) x 100
= 1.8996%

The S/N ratio of deformation values, predicted S/N values of deformation using linear regression and percentage deviation of predicted values from the experimental values of deformation are presented in Table 5.

TABLE V
LINEAR REGRESSION MODEL VALUES

Test Condition Number	Deformation (mm)	S/N ratio deformation	LR deformation	% LR Deviation
1	157	-43.917	-43.099	1.899
2	124.43	-41.898	-41.417	1.162
3	106.41	-40.539	-39.7349	2.025
4	88	-38.889	-39.900	2.532
5	75.33	-37.539	-38.218	1.775
6	111.15	-40.918	-41.605	1.651
7	21.68	-26.721	-26.525	0.737
8	32	-30.102	-29.912	0.635
9	25.46	-28.117	-28.239	0.402

Comparison between experimental S/N ratio of deformation and predicted values of deformation using linear regression are shown in Figure 5.

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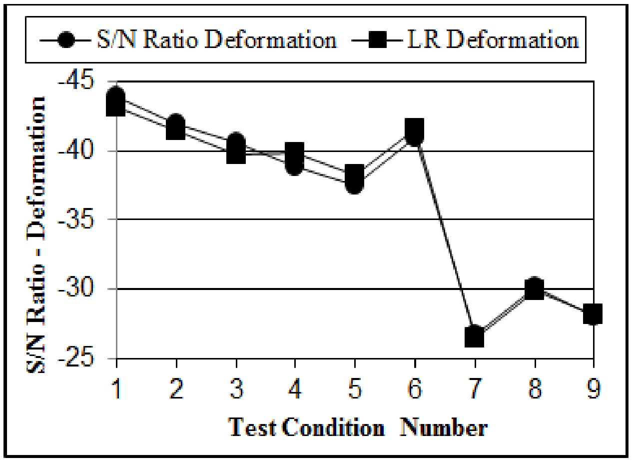

FIGURE 5 COMPARISON BETWEEN S/N RATIO OF DEFORMATION WITH LINEAR REGRESSION MODEL VALUES

In order to verify the validated results of deformation of leaf spring on the basis of Non Linear Regression model, the estimated average of deformation has been already found as, $D_{em} = -26.274$

For the non linear regression model, confidence interval for the prediction of average deformation on a validation test is calculated as,

$$CI = \sqrt{F0.05\ (2, fe)Ve\left[\frac{1}{n} + \frac{1}{R}\right]} \qquad (5)$$

Where,
f_m = error degrees of freedom
$F_{0.05}\ (2,f_e)$= F ratio necessary for risk (2,2) = 19 [24]
V_e= error variance (**0.389178**) from Table 6
R = number of repetitions for validation test = 1
N = Number of experiments in total = 9
n = effective number of replications
= N/(1+dof associated with deformation)
= 9/(1+8)
= 1

The value of confidence interval for the deformation of non linear regression model using the above relation is calculated as,,

CI = {19 x 0.389178[1/1 + 1/1]}^1/2 = 3.8456

The non linear regression table for deformation of leaf spring is presented in Table 6.

TABLE VI
NON LINEAR REGRESSION TABLE FOR DEFORMATION

Regression Statistics	
Multiple R	0.993
R Square	0.997
Adjusted R Square	0.990
Standard Error	0.623
Observations	9

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	332.83	55.47	142.53	0.0069
Residual	**2**	0.778	**0.389**		
Total	8	333.61			

	Coeff.	*Std Error*
Intercept	-387.48	139.08
X D	-0.0150	0.010
X L	0.37849	0.1572
X N	106.006	39.33
X (DxL)	2.03E-05	1.25E-05
X (DxN)	-0.00015	0.00015
X (LxN)	-0.11768	0.0443

The 95% confidence interval of the optimal deformation in confirmation test is

$(D_{em} - CI) < D_{con} < (D_{em} + CI)$
$(-26.274 - 3.8456) < D_{con} < (-26.274 + 3.8456)$
$(-30.1196) < (-25.985) < (-22.4284)$

The result of conformation test shows that the deformation is -25.985 which lies between (D_{em} - CI) and (D_{em} + CI) i.e., -25.985 is in between -30.1196 and -22.4284. Thus the validated deformation is confirmed by the above calculations.

Empirical equation on the basis of non linear regression model for the deformation of leaf spring is developed as,

= -387.483-(0.01509xD) + (0.378493 x L) + (106.0063 x N) + (2.03E-05 x D x L) - (0.00015 x D x N) - (0.11768 x N x L)

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The percentage error between empirical and experimental deformation value is calculated as,

= ((Predicted value – Experimental value) / Predicted value) x 100

= ((-43.943 - 43.917)/ -43.943) x 100

= 0.0586%

The S/N ratio of deformation values, predicted S/N values of deformation using non linear regression and percentage deviation of predicted values from the experimental values of deformation are presented in Table 7.

TABLE VII
NON LINEAR REGRESSION MODEL VALUES

Test Condition Number	Deformation (mm)	S/N ratio deformation	NLR deformation	% NLR Deviation
1	157	-43.917	-43.943	0.0586
2	124.43	-41.898	-41.146	1.828
3	106.41	-40.539	-40.701	0.398
4	88	-38.889	-39.256	0.933
5	75.33	-37.539	-37.597	0.154
6	111.15	-40.918	-41.1305	0.516
7	21.68	-26.721	-26.696	0.0910
8	32	-30.102	-30.061	0.139
9	25.46	-28.117	-28.110	0.0236

Comparison between experimental S/N ratio of deformation and predicted values of deformation using non linear regression are shown in Figure 6.

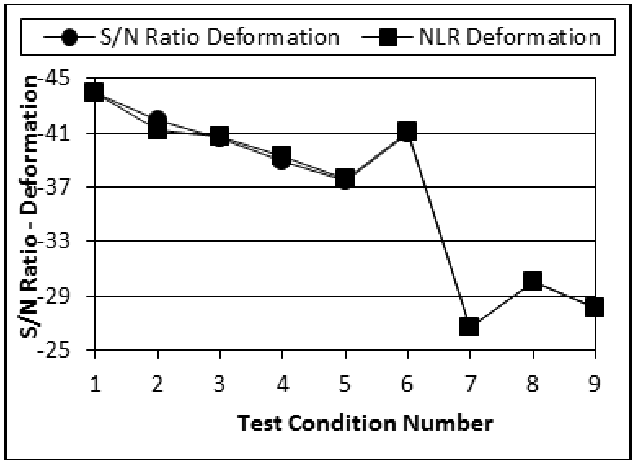

FIGURE 6 COMPARISON BETWEEN S/N RATIO OF DEFORMATION WITH NON LINEAR REGRESSION MODEL VALUES

Figure 7 shows the comparison between percentage deviations of deformation values using Linear Regression model with percentage deviations of deformation values using Non Linear Regression model.

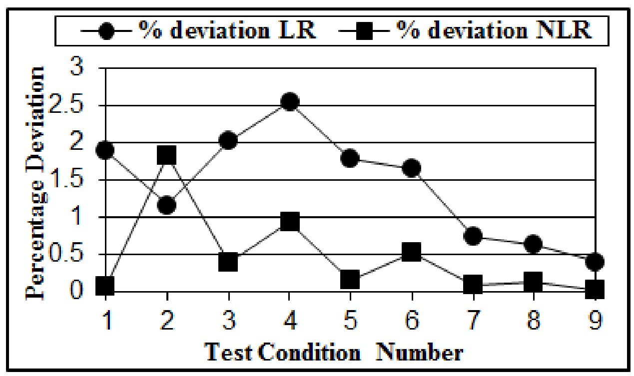

FIGURE 7 COMPARISON BETWEEN PERCENTAGE DEVIATIONS OF DEFORMATION VALUES USING LINEAR REGRESSION MODEL WITH PERCENTAGE DEVIATIONS OF DEFORMATION VALUES USING NON LINEAR REGRESSION MODEL

Figure 8 shows the comparison between the average percentage deviation of S/N ratio of deformation values of leaf spring using linear regression analysis with average percentage deviation of S/N ratio of deformation values of leaf spring using non linear regression.

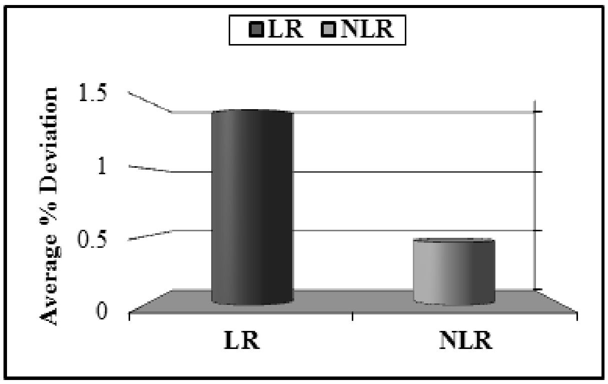

FIGURE 8 THE AVERAGE PERCENTAGE DEVIATION OF S/N RATIO OF DEFORMATION VALUES OF LEAF SPRING USING LINEAR REGRESSION ANALYSIS WITH AVERAGE PERCENTAGE DEVIATION OF S/N RATIO OF DEFORMATION VALUES OF LEAF SPRING USING NON LINEAR REGRESSION

VI. CONCLUSIONS

In this analysis, the value of deformation of leaf spring for various selected parameters has been analyzed for various test conditions. The following conclusions were drawn:

1. The lowest value of deformation obtained in the confirmation experiment with the use of Taguchi's DoE is 19.919 mm which is lower by a least of 8.122% than all the obtained experimental values.
2. It is noticed from Fig 5 that the tendency of experimentally obtained S/N ratio values of deformation of leaf spring is uniform with the values of deformation predicted using Linear Regression. Hence, it is fact that this model can be used for the prediction of deformation of leaf spring for all test conditions.
3. Also it is observed from Fig. 6 that the trend between experimental S/N ratio values of deformation of leaf spring is almost same with the predicted values of deformation using Non Linear Regression model. Therefore the prediction using Non Linear Regression model is also possible to be used for the prediction of deformation of leaf spring for all test conditions.
4. It is clear from Fig. 7 that percentage deviations of deformation values predicted using Non Linear Regression model shows a very minimal deviation while comparing to percentage deviations of deformation values predicted using Linear Regression model for all test conditions.
5. Also it is well proved from Fig. 8 that, the non linear analysis better predict the deformation of leaf spring than linear regression.

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