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Performance Enhancement of Leaf Spring Using Design Optimization

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A B S T R A C T

Leaf spring is one of the potential parts for weight reduction as it accounts for 10% - 20% of the unsprung weight and therefore good scope of work lies in its design optimization for weight reduction. This current research investigates the application of Taguchi Response Surface Optimization in optimizing dimensions of mono leaf spring. Initial FEA analysis is conducted using ANSYS software to determine to determine stresses, deformation and strain energy of mono leaf spring. Design of leaf spring is optimized using Taguchi design of experiments scheme generating 3D response surfaces, sensitivities, goodness of fit curves. The optimization parameter considered for analysis are spring inner radius and spring outer radius while the output parameters are equivalent stress, mass and deformation.

Keywords:FEA, mono leaf spring, ANSYS

1. INTRODUCTION

Semi- elliptic leaf springs are almost universally used for suspension in light and heavy commercial vehicles. For cars also, these are widely used in rear suspension. The spring consists of a number of leaves called blades. The blades are varying in length. The blades are usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaf spring is based upon the theory of a beam of uniform strength. The lengthiest blade has eyes on its ends. All the blades are bound together by means of steel straps. The introduction of composites helps in designing a better suspension system with better ride quality if it can be achieved without much increase in cost and decrease in quality and reliability. In the design of springs, strain energy becomes the major factor. In the present scenario the main focus of automobile manufacturers is weight reduction of the automobile. Weight reduction can be achieved mainly by introducing the better material, design optimization and better manufacturing processes.

Mahmood M. shokrieh and Davood Rezaei [1] examined plan, examination and improvement of leaf spring. In their examination they have supplanted a steel leaf spring by a composite one. Essential focus of their examination was to structure a spring that have least weight and is fit for bearing a given static outer power with no disappointment. Using the outcomes acquired for steel leaf spring they planned a composite leaf spring considering spring geometry streamlining made of fiberglass with epoxy tar with pressure and removal as structure requirements. They dissected this spring using ANSYS and checked their outcomes with exploratory outcomes and of limited component arrangement of same measurements. They found that composite leaf spring weigh 80% less and stress created is likewise less contrasted with steel leaf spring. The composite leaf spring common recurrence is observed to be higher that of steel leaf spring.

AjitabhPateriya, Mudassir Khan[2] studied dynamic characteristics of spring loaded using ANSYS. Fluid-solid interaction mesh deformation between the valve disc and surrounding fluid has been used to study the motion of the valve disc for different materials. Different materials have been used considering similar boundary condition for finding the best suitable material. FEM analysis result shows that $La_2Zr_2O_7$ is best suitable material. Maximum shear stress considered is 0.20395 MPa which is greater for Aluminium alloy. For weight and cost comparison the Aluminium alloy material should be preferred.

Pozhilarasu V. furthermore, T Parameshwaran Pillai [3] considered investigation of steel and composite leaf spring. They thought about the customary leaf spring and composite (Glass fiber fortified plastic – GFRP) leaf spring. They utilized ANSYS programming for examining traditional steel leaf spring and composite leaf spring for comparable conditions. They created a glass/epoxy composite leaf spring utilizing hand layup technique. The all-inclusive testing machine has been utilized to test the aftereffects of ordinary steel and composite leaf spring. Under a similar static stacking condition redirection and worry of ordinary steel and composite leaf spring has been acquired and results demonstrates a wide contrast between the outcomes.

Aishwarya A.L., A. Eswarakumar, V.Balakrishna Murthy [4] directed free vibration investigation of composite leaf springs. They created a three-dimensional leaf spring on ANSYS. They examined the impact of variety of width, relative developments of the leaves, grinding between the spring leaves. They saw that grinding coefficient does not influence the outcomes. They saw that leaf width improves the characteristic recurrence.

T.N.V.Ashok Kumar, E. Venkateswara Rao, S. V. Gopal Krishna [5] directed structure and material streamlining of overwhelming vehicle leaf spring. They led their examination to discover the impact on removal, redirection, weight and frequencies. They utilized ANSYS to lead their examination and thought about their outcomes between steel leaf spring and composite leaf spring made of glass/epoxy and Kevlar/epoxy. They utilized layer stacking technique by changing the fortification plotted for 3 layers, 5 layers and 11 layers. They analyzed the weight of regular steel leaf spring with that of composite leaf spring and found a weight decrease of 27.5%.

2. PROCEDURE OF SIMULATION

The CAD model of mono leaf spring is modelled using dimensions as shown in figure 1 below. The CAD model is developed in ANSYS design modeler using sketch and extrude tools as shown in figure 1 below.

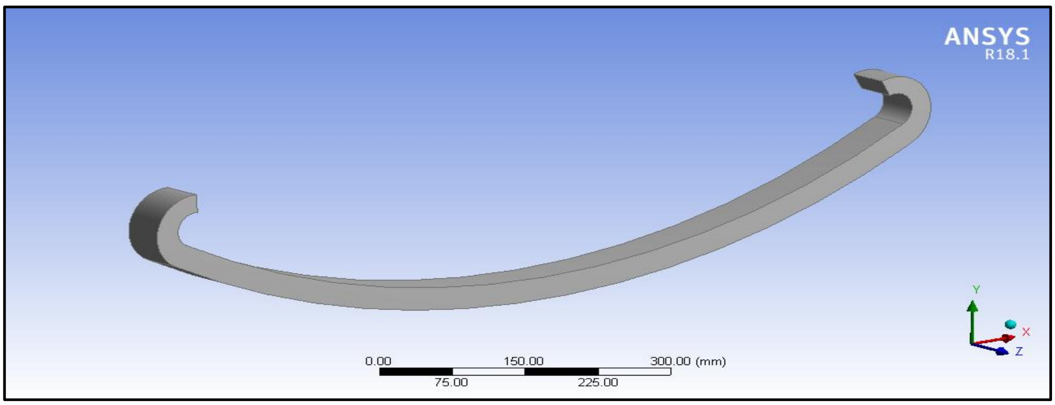

Figure 1: CAD model of mono leaf spring

The CAD model imported in ANSYS is meshed using tetra elements as shown in figure 2 below. The model is meshed using adaptive size function, relevance order 100 and fine sizing. The transition is set to smooth, span angle centre set to coarse

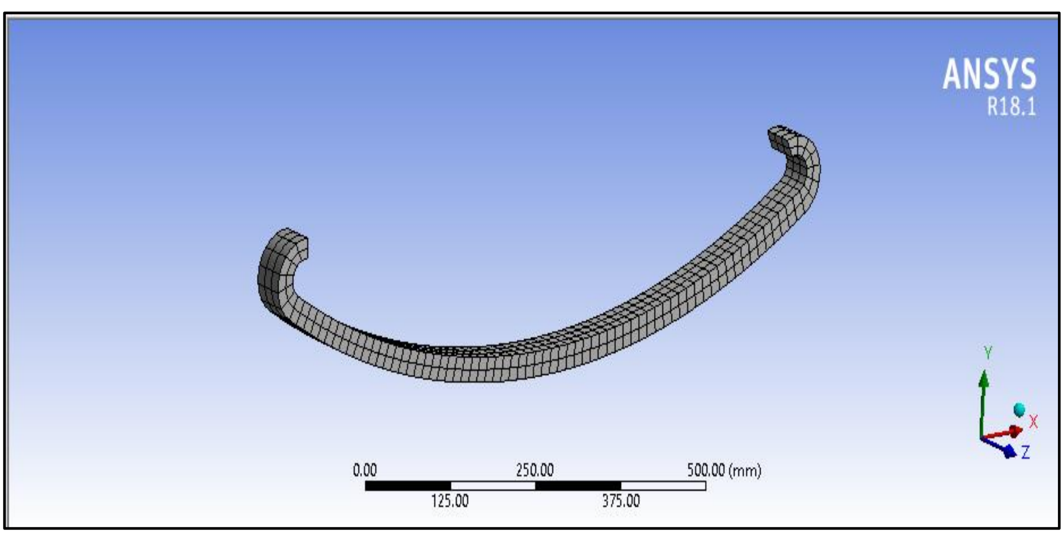

Figure 2: Meshed model of mono leaf spring

The total number of elements generated is 474 and number of nodes generated is 3268. After meshing the CAD model is applied with appropriated loads and boundary conditions as shown in figure 3 below. The left end is applied with displacement support and right end of mono leaf spring is applied with remote displacement keeping Rot_z degree of freedom free and other degree of freedom restricted. The load is applied in mid face of mono leaf spring.

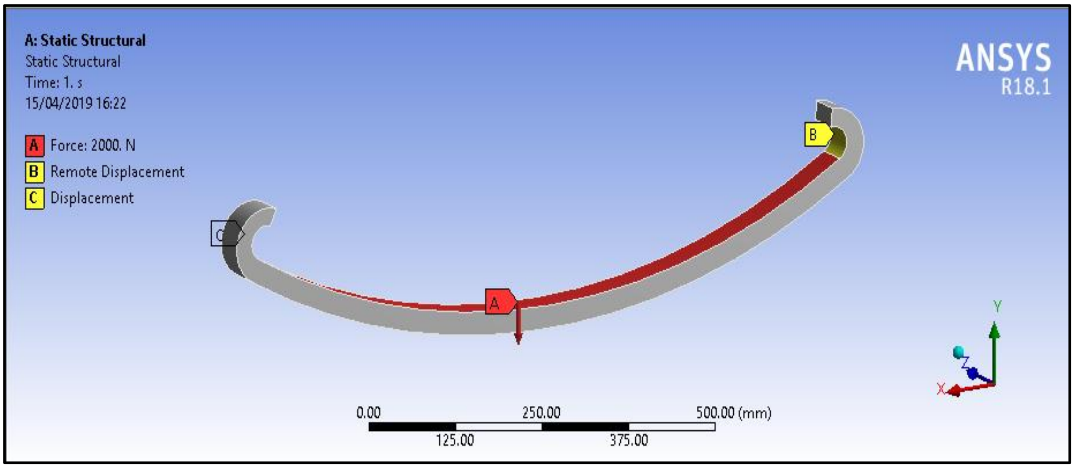

Figure 3: Applied loads and boundary conditions

Software carries out matrix formulations, matrix multiplications, formulation of element stiffness matrices, assembly of global stiffness matrix. Results are calculated at nodes and interpolated for entire element edge length.

Analytical calculation of stress

For "n" number of leaves, the stress can be written as,

$$\sigma = \frac{M}{z} = \frac{6*w*L}{n*b*t^2} \qquad (1)$$

where ,

w is weight of leaf spring

L is span length

n is number of graduated leafs

b is width of leaf spring

t is thickness of leaf spring

After conducting FEA analysis, the dimensions of leaf spring are optimized using response surface optimization which is a collection of mathematical and statistical techniques useful for analyzing problems where several independent variables influence a dependent variable or response, and the goal is to optimize this response. We denote the independent variables by X_1, X_2, X_3, X4……. X_n. The response, 'v' is assumed to be a random variable. RSM is used for the design and analysis of experiments; it seeks to relate an average response to the value of quantitative variables that effect response

The relationship between the dependent variable and independent variables can be represented as

$y = f(X_1, X_2, X_3, X4 \ldots\ldots X_n) + \varepsilon$

where, ε represents the noise or error observed in the response 'y'.

If we denote the expected response by

$E(y) = f(X_1, X_2, X_3, X4 \ldots\ldots X_n) = \eta$

then, the surface represented by

$f(X_1, X_2, X_3, X4 \ldots\ldots X_n) = \eta$

is called the response surface.

The input parameters selected for optimization are shown in table 1 below.

Table 1: Input variables for optimization

X_1 (H12)	Inner radius
X_2 (H14)	Outer radius

3. RESULTS AND DISCUSSION

Afterconduction of FEA analysis the 9 different design points are generated using response surface method. These design points are generated from combination of optimization parameters i.e. inner radius and outer radius. The maximum and minimum values obtained from optimization is shown in figure 4 below.

	A	B	C
1	Name	Calculated Minimum	Calculated Maximum
2	P5 - Equivalent Stress Maximum (MPa)	67.558	276.75
3	P6 - Strain Energy Maximum (mJ)	30.224	172.53
4	P7 - Total Deformation Maximum (mm)	2.8549	17.277
5	P10 - Solid Mass (kg)	9.0811	18.293

Figure 4: Maximum and minimum values obtained from optimization

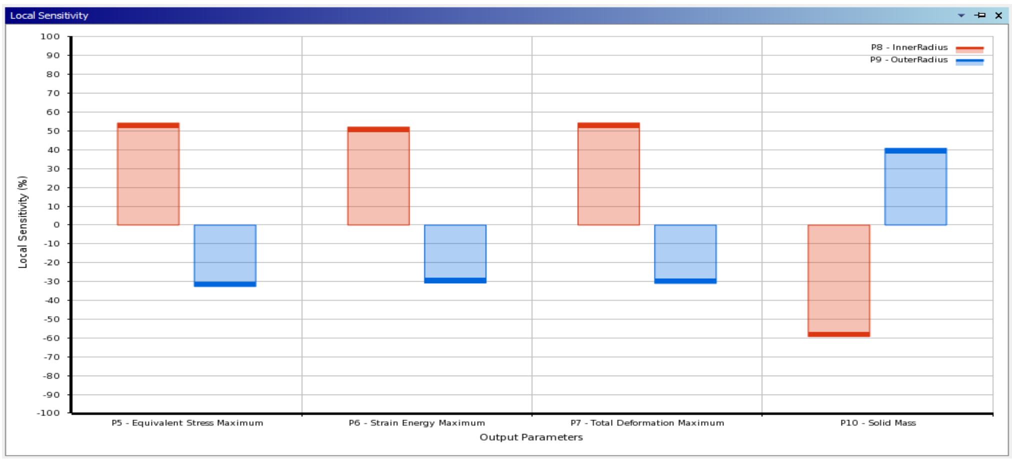

Figure 5: Sensitivity plot

The sensitivity plot of different variables are shown in figure 5 above. The sensitivity plot shows positive sensitivity of inner radius for equivalent stress, strain energy and total deformation while shows negative sensitivity for solid mass. The sensitivity of inner radius is 54.19% positive for equivalent stress and outer radius shows 32.65% negative for equivalent stress. The sensitivity of inner radius is 52.064% positive for strain energy and outer radius shows 30.78% negative for strain energy. The sensitivity of inner radius is 54.255% positive for deformation and outer radius shows 30.997% negative for deformation. The sensitivity of inner radius is 59.24% negative for mass and outer radius shows 40.75% positive for mass. The 3D response surfaces are generated for different output variables i.e. equivalent stress, deformation and mass and input variables for analysis are inner radius and outer radius.

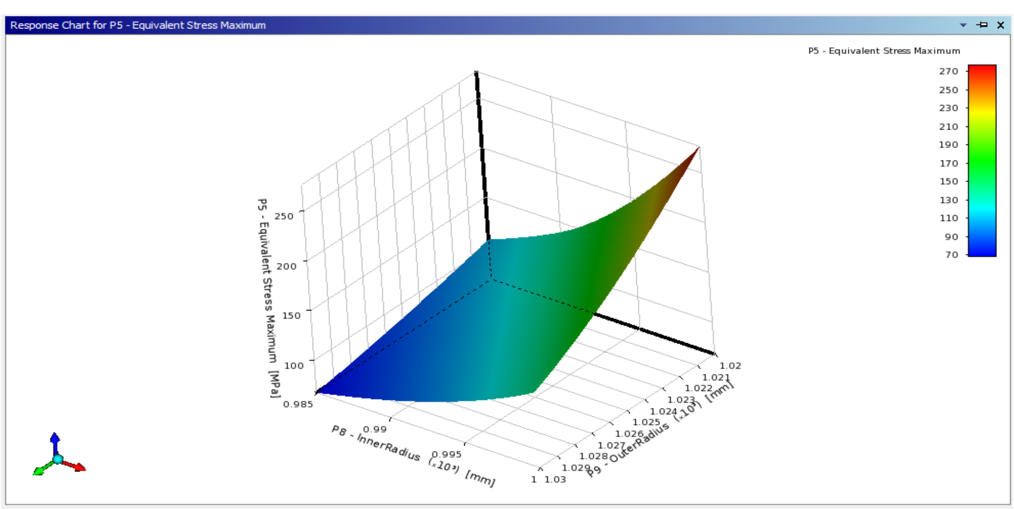

Figure 8: Response chart of equivalent stress

The response of equivalent stress (figure 8 above) shows highest magnitude of 270MPa for outer radius range from 1020 mm to 1025mm and inner radius above 995mm. The minimum equivalent stress with magnitude of 70Mpa is attained at outer radius range of 1103mm to 1025mm and inner radius range from 985mm to 990mm.

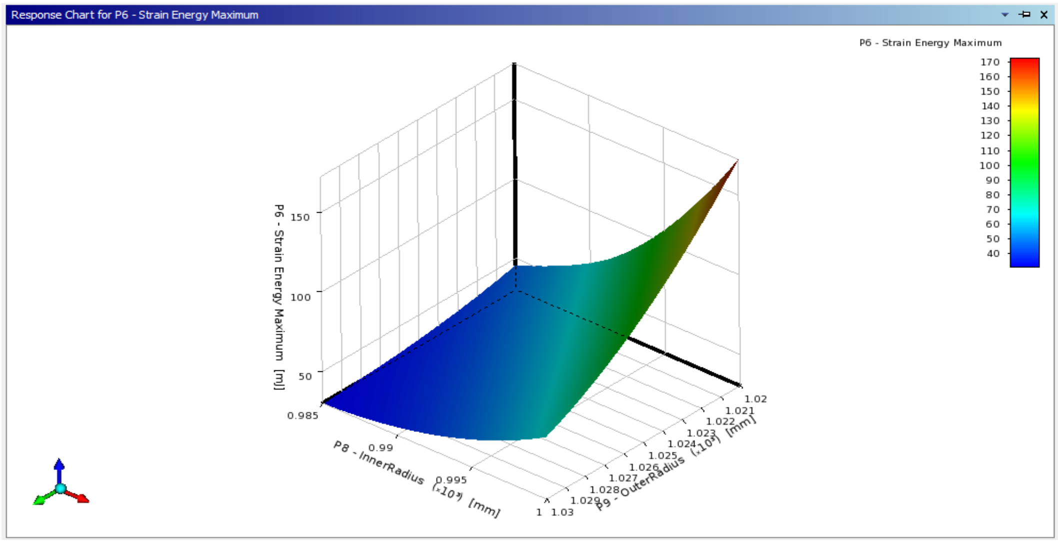

Figure 9: Response chart of strain energy

The response of strain energy (figure 9) shows highest magnitude of 170mJ for outer radius range from 1020 mm to 1025mm and inner radius above 995mm. The minimum strain energy with magnitude of 40Mpa is attained at outer radius range of 1103mm to 1025mm and inner radius range from 985mm to 990mm.

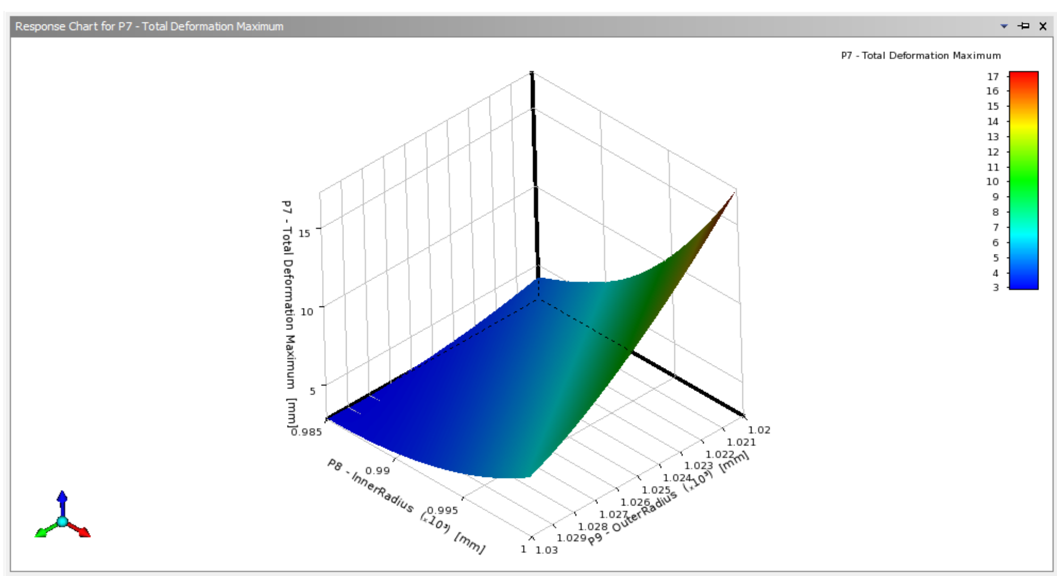

Figure 10: Response chart of total deformation

The response of total deformation (figure 10) shows highest magnitude of 17mm for outer radius range from 1020 mm to 1025mm and inner radius above 995mm. The minimum deformation with magnitude of 3mm is attained at outer radius range of 1103mm to 1025mm and inner radius range from 985mm to 990mm.

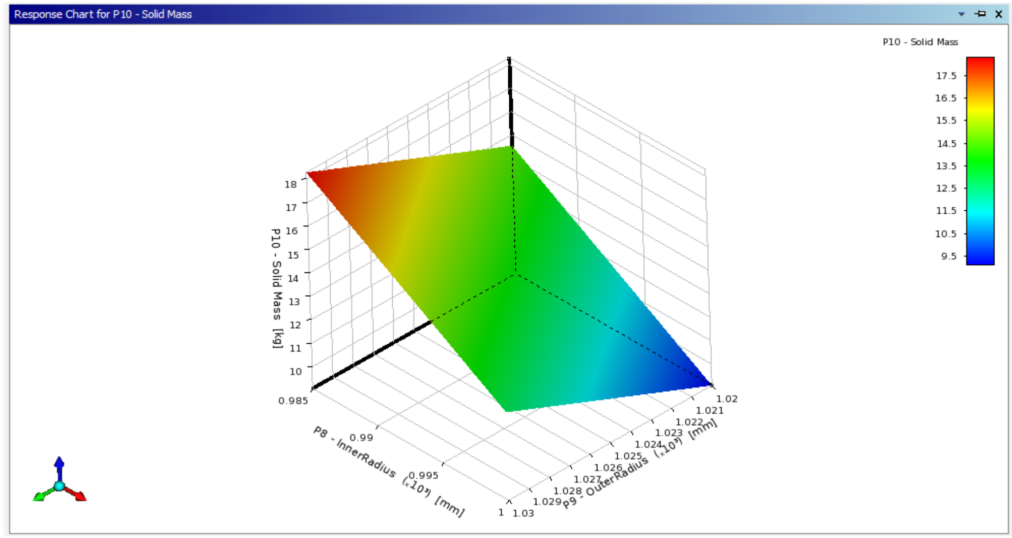

Figure 11: Response chart of solid mass

The response of solid mass (figure 11) lowest magnitude of 9.5Kg and below for outer radius range from 1020 mm to 1025mm and inner radius above 995mm. The maximum solid mass with magnitude 17.5kg and more is attained at outer radius range of 1103mm to 1025mm and inner radius range from 985mm to 990mm

4. CONCLUSION

The FEA analysis of leaf spring is conducted using ANSYS software and results are analytically verified. For design optimization using response surface method inner radius and outer radius of leaf spring are selected as parameters for optimization. The response surface plots are generated for deformation and equivalent stresses and strain energy. From response surface plots the range of magnitude of parameters (inner radius and outer radius) can be determined for maximum and minimum values of equivalent stress and deformation. The details are as follows:

1. The equivalent stress plot as shown above shows the maximum value of 142.2MPa near vicinity of joints. While the remaining portion of leaf spring has almost same value of stress.

2. The maximum deformation is seen on the end portion of leaf spring with value of 6.50mm and minimum deformation is seen on the other end of leaf spring near to supports.

3. From design of experiments the sensitivity plot is generated shows positive sensitivity of inner radius for equivalent stress, strain energy and total deformation while shows negative sensitivity for solid mass.

4. The sensitivity of inner radius is 54.19% positive for equivalent stress and outer radius shows 32.65% negative for equivalent stress.

5. The sensitivity of inner radius is 52.064% positive for strain energy and outer radius shows 30.78% negative for strain energy.

6. The sensitivity of inner radius is 54.25% positive for deformation and outer radius shows 30.99% negative for deformation.

7. The sensitivity of inner radius is 59.24% negative for mass and outer radius shows 40.75% positive for mass.

8. The response of equivalent stress shows highest magnitude of 290MPa for outer radius range from 1020 mm to 1025mm and inner radius above 995mm. The minimum equivalent stress with magnitude of 70Mpa is attained at outer radius range of 1103mm to 1025mm and inner radius range from 985mm to 990mm.
9. Using response surface optimization, nearly 27.7% weight reduction of leaf spring is observed.

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