Design Optimization of Mono Leaf Spring using Response Surface Method

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Abstract: Leaf springs are used in heavy and medium motor vehicles to absorb shocks due to uneven road surface or bumps. The mono leaf spring is modeled using ANSYS design modeler and FEA analysis is performed using ANSYS static structural platform. Taguchi response surface method is used for design optimization of mono leaf spring. Inner radius, outer radius of mono leaf spring are taken as optimization parameters and 3D responses of equivalent stress, strain energy and deformation are obtained from analysis along with sensitivity analysis. The optimization is carried out to achieve mass reduction of mono leaf spring without much compromise in strength.

Keywords: FEA, Response surface, Mono leaf spring

I. Introduction

Leaf spring are mostly used in suspension of light motor vehicles and heavy motor vehicles like truck, railway locomotives etc. The commonly used material in manufacturing of leaf spring is steel but researches have shown that composite materials perform better as compared to conventional leaf spring material. The function of leaf spring is to absorb energy when vehicle passes through bumps or uneven road surfaces and dissipate later. The energy stored in the form of strain energy. Leaf spring are attached to frame at both ends or at one end. The softness of leaf spring is dependent on length, more the length the softer is leaf spring and vice versa. In general practice the rear leaf spring lengths are longer than front leaf springs.

II. Literature Review

Shishay Amare Gebremeskel et.al [1] investigated leaf spring with a single E-glass/Epoxy material under static loading conditions using FEA simulation studies. The findings have shown that design stresses are much below yield point stresses of material and hence satisfy maximum stress failure criterion and fatigue life from composite material is also lower. The design is best suited for 3-wheeler applications.

Sorathiya Mehul et.al [2] has investigated conventional leaf spring using ANSYS 11.0 and hypermesh software under steady state static loading conditions. The material of leaf spring used were carbon/Epoxy and Graphite/Epoxy. The results from composite leaf spring are compared with conventional steel leaf springs and considerable weight reduction of 78.61% is achieved and 90.09% for mono leaf spring.

D.N Dubey et.al [3] investigated parabolic leaf spring of Maruti Omni car using Finite Element Analysis under static conditions. The materials used for analysis are HM and HS Carbon polymers. The findings have shown that load carrying capacity, stiffness and weight savings achieved from composite leaf spring are much better than conventional steel leaf springs.

Vinkel Arora et.al [4] investigated front end leaf spring of commercial vehicle using ANSYS software using 65Si7 material consisting of 37 parts and findings have shown that design is more effective and safer with equivalent stress 173.5MPa and 85.29MPa for full spring. The results were validated with experimental values.

AnandKumar et.al [5] investigated leaf spring made from 55SI2MN90 for steel leaf and compared with Glass-fiber 7781 leaf spring. The work emphasized on fabrication of leaf spring by hand layup method using wooden made pattern as per leaf spring dimensions. The findings have shown leaf spring made from Glass-fiber 7781 has better strength to weight ratio as compared to 55SI2MN90 leaf spring.
Anil kumar et.al [6] conducted Finite Element analysis on leaf spring made from composite materials Graphite, Carbon, and E-Glass/Epoxy on 10 leaf springs having 2 full leaves and 8 graduated. The findings have shown composite leaf spring outperformed conventional leaf spring in terms of strength with 92.59mm deformation and 35.60mm stiffness.

Senthilkumar Mouleeswaran et.al [7] has reviewed Design, Manufacturing and Testing of Polymer Composite Multi-Leaf Spring for Light Passenger Automobile. A leaf spring put away a potential vitality as strain vitality and scattered gradually. So because of this a support of leaf spring material is likewise an essential factor like limiting the modulus of flexibility longitudinal way and expanding the quality. The work done here comprises of investigation of exhaustion disappointment conduct of composite material under the utilization of burden. All the investigation here is performed with the assistance of exploratory and computational reproduction.

III. PROPOSED WORK

The current research is intended to improve the existing design of mono leaf spring by using response surface method. The optimization parameters are inner radius and outer radius. The responses of equivalent stress, deformation, strain energy and mass are obtained along with sensitivity plot and goodness of fit curve.

IV. METHODOLOGY

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.

Table 1: Dimensions and Material Specifications [7]

S No.	Specification	Value
1	Length of leaves (mm)	965
2	Number of full length leaves	01
3	Width of all leaves (mm)	45
4	Thickness of all leaves (mm)	30
5	Inner radius of the eye(mm)	23
6	Outer radius of the eye(mm)	50
7	Camber (mm)	125
8	Young‟s Modulus (MPa)	$2.1 * 10^5$
9	Poisson‟s Ratio	.33

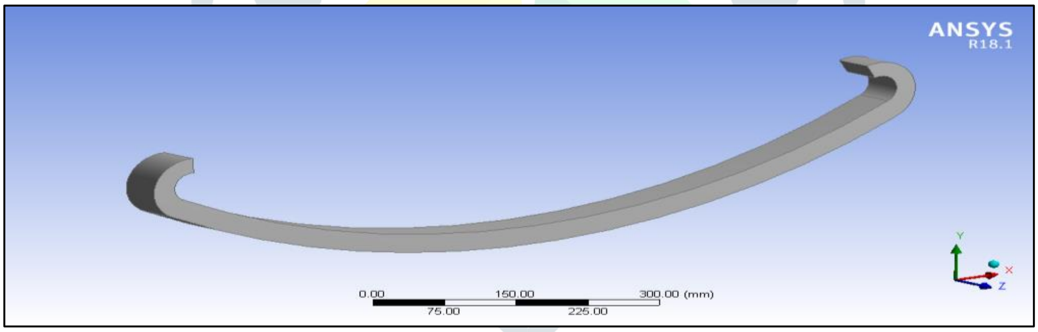

Figure 1: CAD model of mono leaf spring

The parameters are selected as inner radius and outer radius is shown in figure 2 below. The inner radius value for base design is 993.72mm and outer radius value of base design is 1023.7mm.

Name	Value	Type
InnerRadius	993.72 mm	Length
OuterRadius	1023.7 mm	Length

Figure 2: Design parameters for optimization of mono leaf spring

After CAD modeling the model is meshed using brick elements. The total number of elements generated is 474 and number of nodes generated is 3268. The meshed model is shown in figure 3 below.

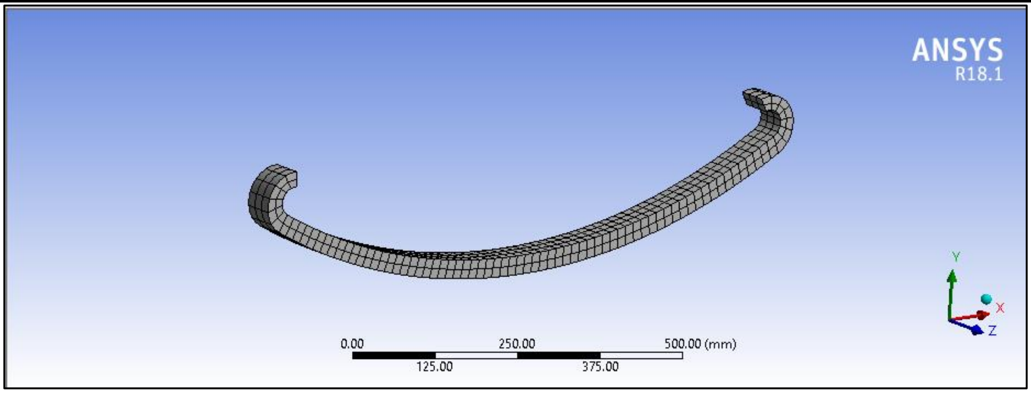

Figure 3: Meshed model of Mono Leaf spring

After meshing the CAD model is applied with appropriated loads and boundary conditions as shown in figure 4 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.

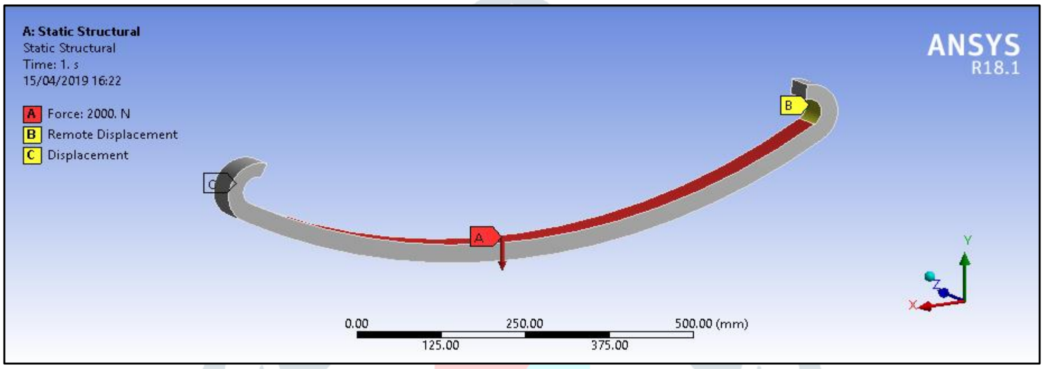

Figure 4: Loads and Boundary conditions of Mono Leaf spring

The next stage is solution stage where software carries out matrix formulations, multiplications and inversions, assemblage of global stiffness matrix and calculations are made at nodes while results are interpolated along entire element edge length. After solving the results of equivalent stress, deformation are generated as shown in subsequent figures.

V. RESULTS AND DISCUSSION

The contour plots of equivalent stress and deformation are plotted and shown in figure 5 below.

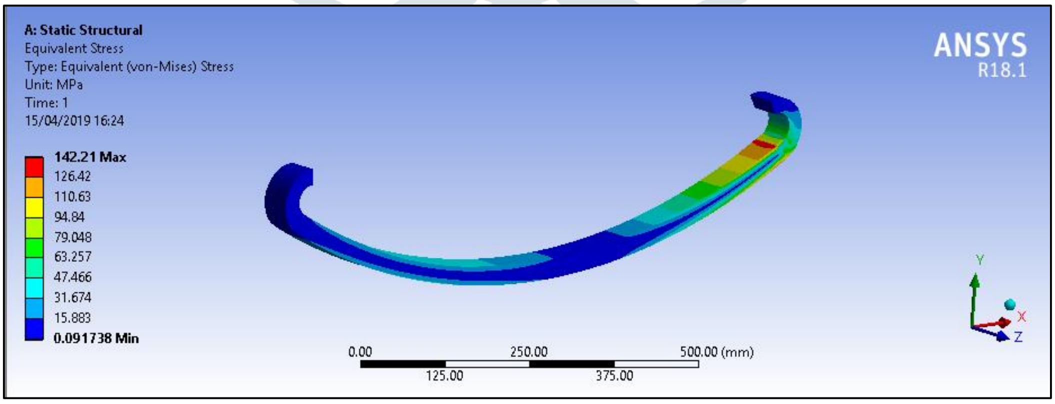

Figure 5: Equivalent stress plot

The equivalent stress plot generated is shown in figure 5 above. The stress plot shows maximum values of equivalent stress near remote displacement support portion of leaf spring with magnitude of 142.21MPa and maximum value of deformation is seen near displacement support with magnitude of 6.5054mm as shown in figure 6 below.

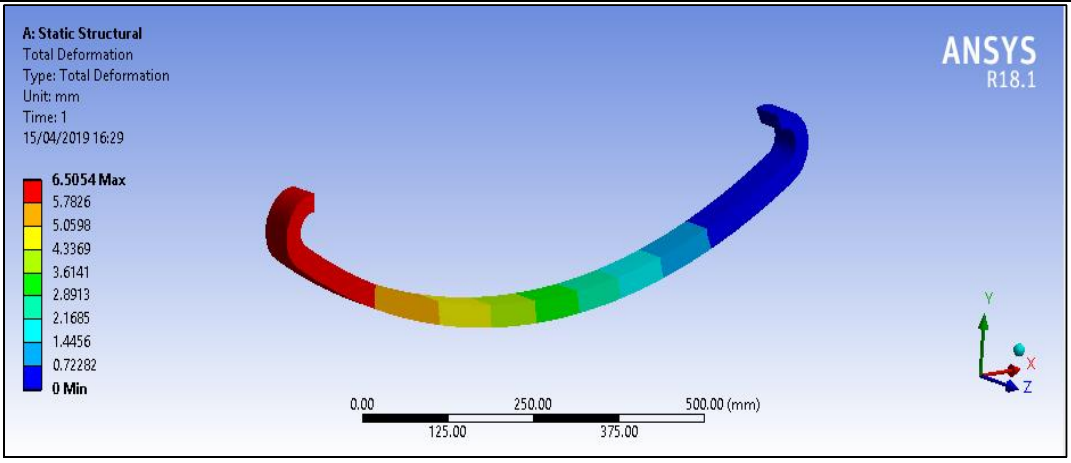

Figure 6: Deformation Plot

After conduction 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 software carries out analysis at these design points and generates equivalent stress, strain energy , deformation and mass as shown in figure 7 below.

	A	B	C	D	E	F	G
1	Name	P8 - InnerRadius (mm)	P9 - OuterRadius (mm)	P5 - Equivalent Stress Maximum (MPa)	P6 - Strain Energy Maximum (mJ)	P7 - Total Deformation Maximum (mm)	P10 - Solid Mass (kg)
2	1	992.5	1025	123.36	55.927	5.2507	13.693
3	2	985	1025	85.668	34.542	3.0585	16.412
4	3	1000	1025	198.29	108.53	10.847	10.954
5	4	992.5	1020	165.71	84.146	8.1805	11.82
6	5	992.5	1030	96.287	40.406	3.6532	15.574
7	6	985	1020	107.67	46.126	4.2481	14.539
8	7	1000	1020	292.01	190.55	20.259	9.0811
9	8	985	1030	67.842	42.909	2.336	18.293
10	9	1000	1030	143.03	69.258	6.6227	12.835

Figure 7: Design Points Generated using Response Surface Method

After response surface optimization the maximum and minimum values of output parameters are generated as shown in figure 8 below. The mass minimization is achieved with magnitude of 9.08Kg and maximization is 18.293 Kg under specified limit of inner radius and outer radius. The minimum strain energy achieved is with magnitude of 33.205mJ and maximum strain energy is 190.55mJ.

1	Name	Calculated Minimum	Calculated Maximum
2	P5 - Equivalent Stress Maximum (MPa)	67.842	292.01
3	P6 - Strain Energy Maximum (mJ)	33.205	190.55
4	P7 - Total Deformation Maximum (mm)	2.336	20.259
5	P10 - Solid Mass (kg)	9.0811	18.293

Figure 8: Maximum and minimum values of Output Parameters

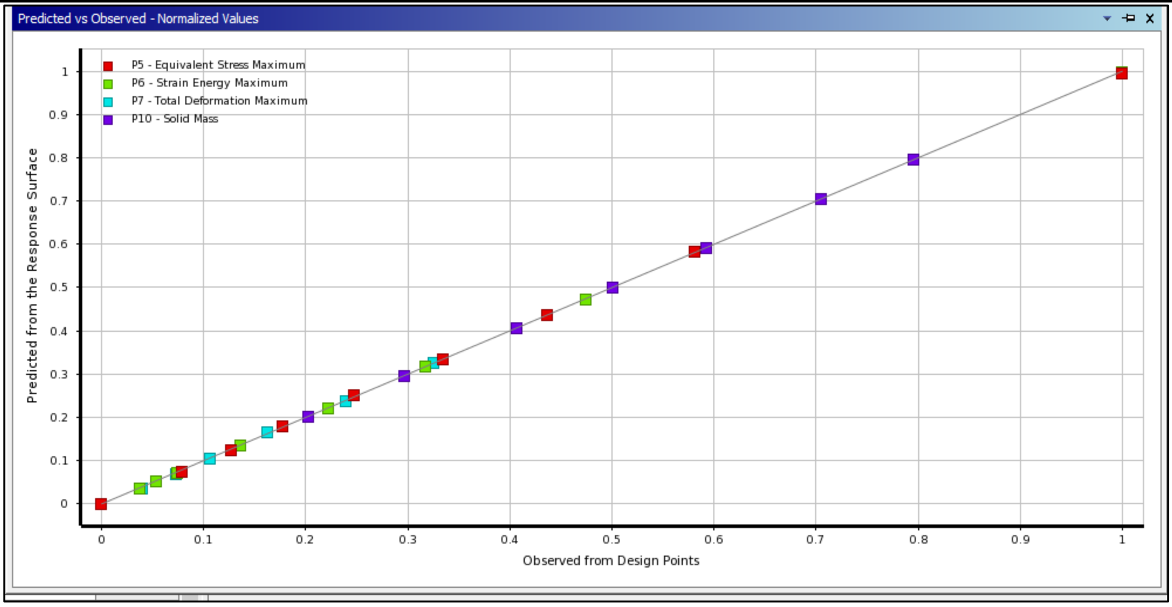

Figure 9: Goodness of Fit Curve

The goodness of fit curve shown in figure 9 above shows close proximity between observed values and predicted values values of equivalent stress, strain energy, total deformation and mass. The sensitivity plot of different variables are shown in figure 10 below. 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 50.57% positive for equivalent stress and outer radius shows 31.24% negative for equivalent stress. The sensitivity of inner radius is 47.02% positive for strain energy and outer radius shows 27.8% negative for equivalent stress. The sensitivity of inner radius is 43.57% positive for deformation and outer radius shows 25.51% negative for deformation. The sensitivity of inner radius is 59.24% negative for mass and outer radius shows 40.75% positive for deformation.

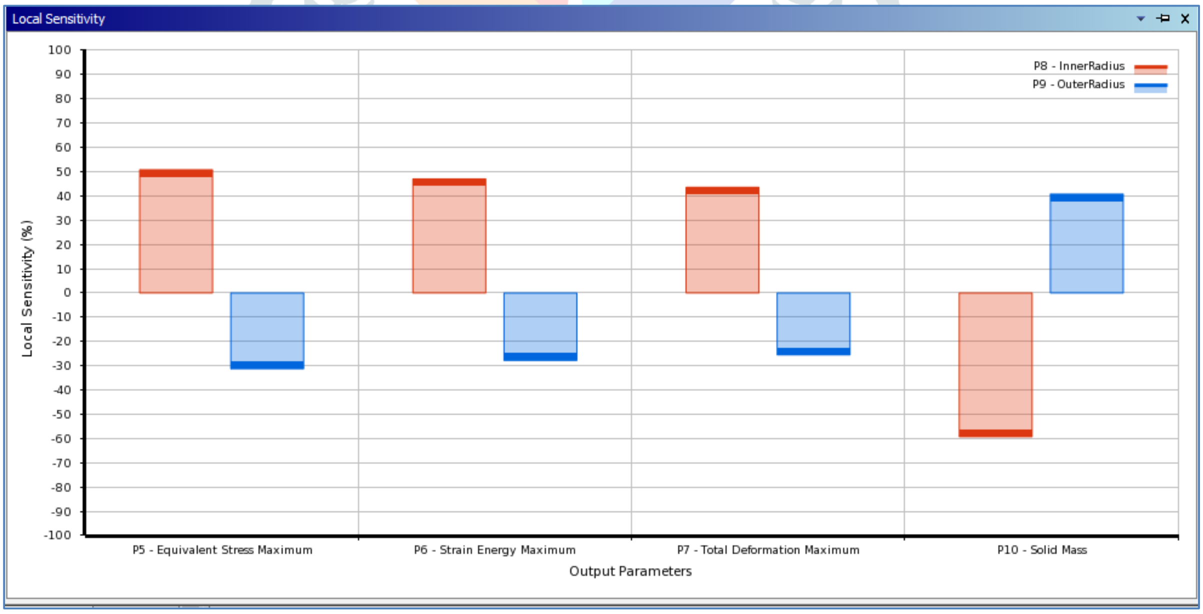

Figure 10: Sensitivity plot of different parameters

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.. The responses are shown in figure 11 for equivalent stress.

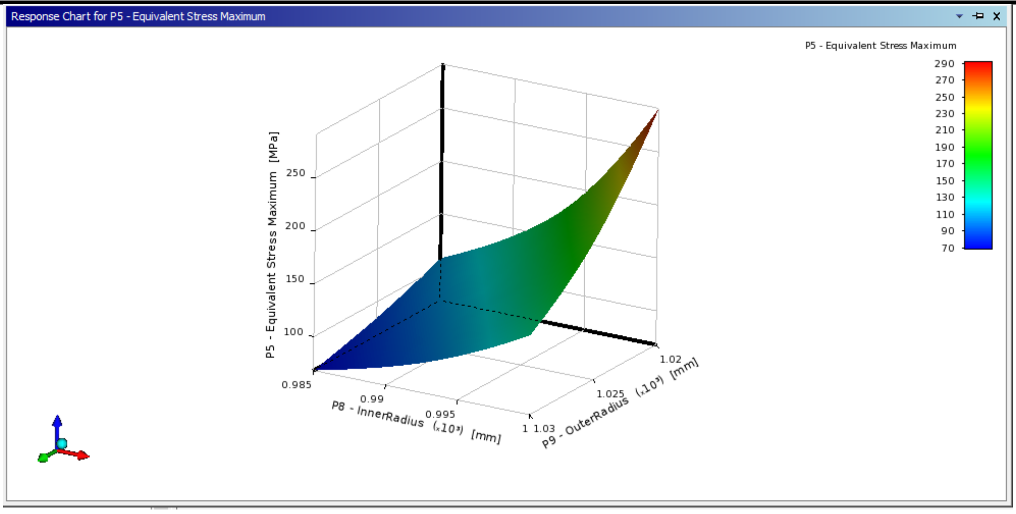

Figure 11: Response chart of equivalent stress

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.

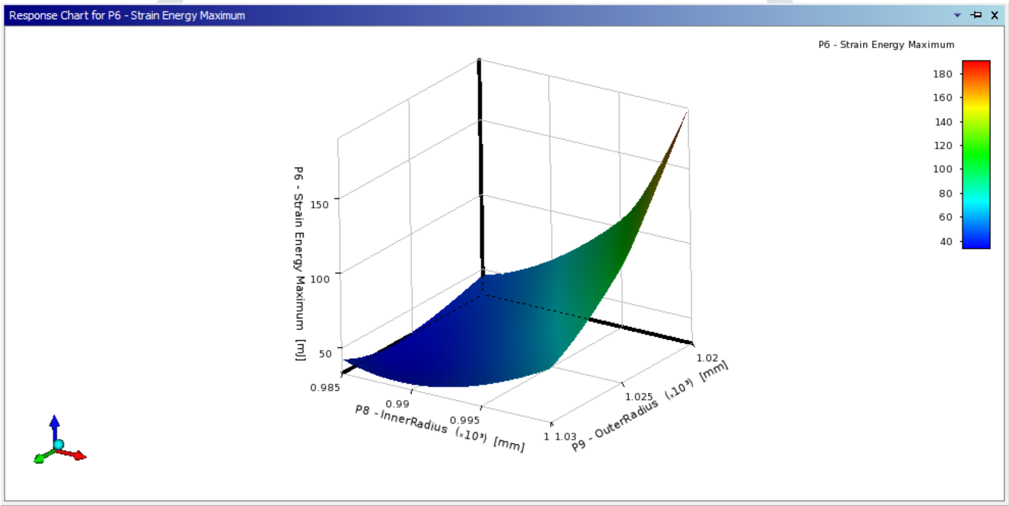

Figure 12: Response chart of strain energy

The response of strain energy shows highest magnitude of 180mJ 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.

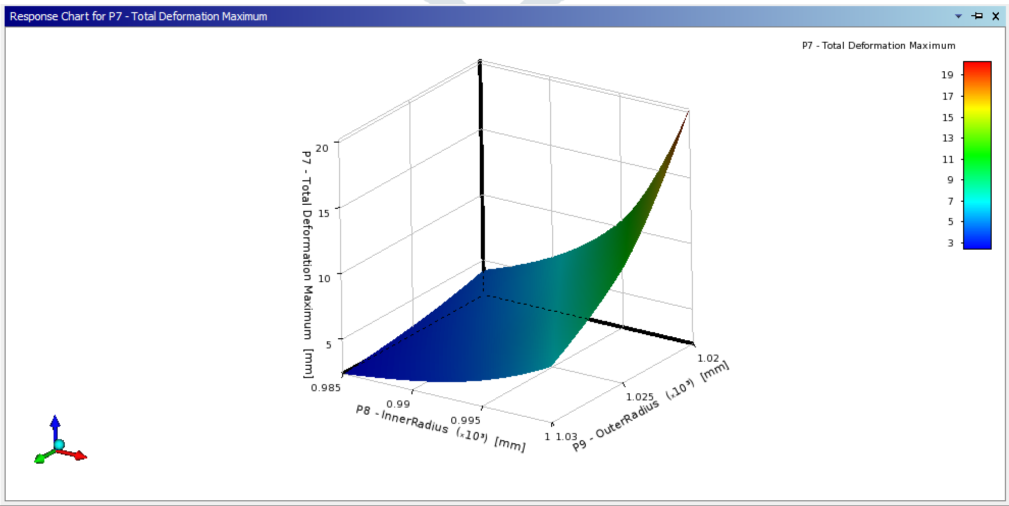

Figure 13: Response chart of total deformation

The response of total deformation shows highest magnitude of 19mm 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.

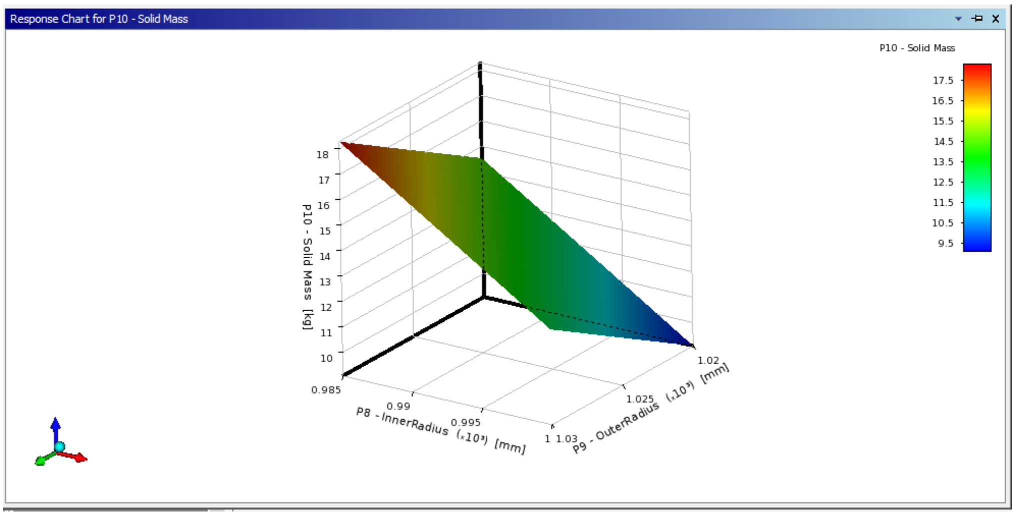

Figure 14: Response chart of solid mass

The response of solid mass 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.

VI. CONCLUSION

The FEA analysis conducted predicted the equivalent stresses and deformation at specified load applied to mono leaf spring. The Taguchi response surface method has aided in minimizing the mass of mono leaf spring to a considerable extent using design of experiments scheme. The responses of different output parameters i.e. equivalent stress, deformation, strain energy and mass are plotted. The minimized mass of mono leaf spring achieved using design optimization is 9.08Kg.

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