SIMULATION FOR OPTIMIZED MODELLING OF EN45A LEAF SPRING

Krishan Kumar¹ & M.L.Aggarwal²

Assistant Professor¹, Professor², Mechanical Engineering Department,

YMCA University of Sc. & Technology, Faridabad-121006, Haryana, India

ABSTRACT

Simulation using CAE tools have been performed using three different models of leaf spring to find out an optimized model considering design and material optimization. To optimise the EN45A leaf spring assembly the conventional flat profile has been changed to parabolic one. In which the thickness of the leaves decreases from centre to edges. This change in design results into elimination of interleaf friction of the mating leaves. For material optimization the material of leaf spring has been replaced from steel (EN45A) to composite materials (GRP). The objective of this work is to produce an optimise model of leaf spring with reduced weight, stresses and improved fatigue life for similar loading conditions.

KEYWORDS

Leaf spring, optimization, parabolic, GRP.

1. INTRODUCTION

Springs are the components which deflect when loaded and stores recoverable energy. Leaf springs are the commonly used springs in the automotive vehicles. A newer design is the parabolic profile leaf spring. In this profile lesser number of leaves whose thickness varies from centre to ends following a parabolic curve is used instead of graduated length leaves of flat profile. Interleaf friction is minimised because of only contact between the leaves at the ends and at the centre where the axle is connected. Spacers prevent contact at other points. This profile results in lesser assembly weight and greater flexibility which interns improved vehicle performance. Aggarwal M.L (2007) concluded that by applying shot peening the fretting fatigue between leaves can be minimised. The strength of EN45A parabolic leaf spring is also higher than the semi-elliptic leaf spring. Ahmet Kanbolat (2011) applied finite element method to obtain fatigue life of the leaf spring assembly against environment conditions. F. N. Ahmad Refngah (2009) described the estimation of fatigue life using FEA and variable amplitude loading. Finite element analysis was performed on the leaf spring and experimental results was compared validate them. Manas Patnaik(2012) analyzed a parabolic leaf spring by applying load and the results as stress and displacement are computed. For optimization camber and leaf span of a spring was considered important factors using Artificial Neural Networks. Manas Patnaik (2012) worked on a mono parabolic leaf spring. The model of the leaf spring was prepared in CATIA software. In this study Design of experiments technique has been used. In which input parameters are to be considered for variation are eye to eye distance & camber and their effect on output results have been recorded. Murathan Soner (2011) considered a leaf spring having five leaves and optimised it change of material and geometrical parameters. The FE model results in reduced weight in comparison to earlier design. Narendra Yadav (2012) analyze a leaf spring whose thickness varies from the centre to the outer side following a parabolic pattern. Using FEA the stress distribution in the leaf spring assembly has been computed and to minimize it by Local

Algorithm for Constants and Priorities. *Pratesh Jayaswal (2012)* considered various techniques for enhancement of productivity by minimizing the rejections. *Ritesh Kumar (2012)* described basic structure, stress characteristics, engineering finite element modelling for analyzing & high stress zones. The equivalent von-misses stresses are plotted for the parabolic leaf spring.

1.1CAE SIMULATION

Leaf springs are used in suspension structure of automobile vehicles. To enhance this system number of modifications has been done. Two modifications like use of parabolic leaf spring and use of composite materials for them are considered in this study. Firstly in this work the two models of steel EN45A leaf springs have modelled and simulated for the purpose of modification in design. The Chemical composition of EN45A spring steel by % weight is 0.61 C, 1.8 Si, 0.79 Mn, 0.02 S, and 0.024 P.

Table: 1 Mechanical Properties of Steel EN45A

Parameter	Value
Material selected- Steel	EN45A
Young's Modulus, E	$2.1 \times 10^5 \text{ N/mm}^2$
Poisson's Ratio	0.266
BHN	400-425
Tensile strength Ultimate	1272 MPa
Tensile strength Yield	1158 MPa
Density	$0.00000785 \text{ Kg/mm}^3$
Behavior	Isotropic

The first model is designed for a flat multi leaf spring and another is designed as parabolic. In flat leaf spring all leaves are having constant thickness throughout the length of leaves. After first full length leaf length of the other leaves decreased & called graduated leaves. The design parameters are as follows: No. of leaves =3, Length of main leaf=940mm, Length of second leaf=670mm, Length of third leaf=550mm, Width of leaves=60mm, Thickness of leaves=8mm, Camber=47mm, Rated load=3600N, Maximum load=7600N

Figure: 1 Conventional Multi Leaf Spring

Figure: 2 CAD Model of Multi Leaf Spring

Figure: 3 Simulations in ANSYS Workbench

Meshing of the model is done in which model is discretized into number of elements and nodes. It represents the structure mathematically. A detailed procedure has been followed to define meshing of the assembly. The geometrical & meshing details are shown in Table-2 below.

Table: 2 Details of model

Object Name	<i>Geometry</i>
State	Fully Defined
Definition	
Length Unit	Meters
Element Control	Program Controlled
Bounding Box	
Length X	976. mm
Length Y	78. mm
Length Z	101.18 mm
Properties	
Volume	1.2111e+006 mm ³
Mass	9.507 kg
Statistics	
Analysis Type	3-D
Nodes	3147
Elements	870

For a complete and effective analysis defining proper boundary conditions is very important in which forces, supports, constraints etc. are to be considered as per actual implementation during experimental analysis.

Figure: 4 Boundary Conditions of the model

Defining boundary condition of the leaf spring is fixation of revolute joint and applying displacement support at the other eye end. While loading involves applying a load at the centre of the leaf. As per specifications the spring is drawn at flat condition, therefore the load is applied in downward direction to achieve initial no load condition. The model under defined boundary conditions is shown in Figure-4 & Table-3 here.

Table: 3 Loading conditions of the model

Object Name	<i>Force</i>	<i>Fixed Support</i>	<i>Displacement</i>
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Geometry	2 Edges	2 Faces	
Definition			
Define By	Components		Components
Type	Force	Fixed Support	Displacement
Coordinate System	Global Coordinate System		Global Coordinate System
X Component	0. N (ramped)		Free
Y Component	-7600. N (ramped)		0. mm (ramped)
Z Component	0. N (ramped)		0. mm (ramped)

The multi leaf spring model has been simulated in the defined environment of the ANSYS workbench and the target output like deflection; von-mises stress and fatigue life are achieved as shown in table-4 below and figure-5 & figure-6.

Table: 4 Result table of Multi leaf spring

Object Name	Total Deformation	Equivalent Stress	Directional Deformation
State	Solved		
Scope			
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent (von-Mises) Stress	Directional Deformation
Display Time	End Time		
Orientation			X Axis
Coordinate System			Global Coordinate System
Results			
Minimum	0. mm	0.00028748 MPa	-4.566 mm
Maximum	50.202 mm	1096 MPa	1.7915 mm
Minimum Occurs On	Part23.1	Para 1	
Maximum Occurs On	Para 1	Para 2	Para 1

Figure: 5 Stress contours in the model

Figure: 6 Fatigue Life of the model

On the other hand the parabolic leaves are designed as decreasing thickness from centre to both edges of the leaves. While the length of all leaves are same as of first full length leave. The geometrical specification of leaf springs are; Span length = 940 mm, Seat Length = 100 mm, Number of leaf = 3, Rated load = 3600 N, Maximum Load= 7600 N, Width of leaf=60 mm, Tip Inserts: 50mm Diameter, Centre Rubber Pad=100mmX50mmX5mm

Figure: 7 Parabolic Leaf spring

Figure: 8 CAD model of Parabolic Leaf spring

Figure: 9 Simulations in ANSYS

Table: 5 Details of parabolic model

Object Name	<i>Geometry</i>
State	Fully Defined
Definition	
Length Unit	Meters
Element Control	Program Controlled
Bounding Box	
Length X	972. mm
Length Y	78. mm
Length Z	100.32 mm
Properties	
Volume	1.1039e+006 mm ³
Mass	8.62 kg
Statistics	
Analysis Type	3-D
Nodes	14016
Elements	4179

Figure.10 Boundary conditions of the Parabolic model

Table: 6 Loading conditions of the Parabolic model

Object Name	Force	Fixed Support	Displacement
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Geometry	1 Face	2 Faces	
Definition			
Define By	Components		Components
Type	Force	Fixed Support	Displacement
Coordinate System	Global Coordinate System		Global Coordinate System
X Component	0. N (ramped)		Free
Y Component	-7600. N (ramped)		0. mm (ramped)
Z Component	0. N (ramped)		0. mm (ramped)

Figure: 11 stress contours of the Parabolic model

Figure: 12 Fatigue life of the Parabolic model

Figure: 13 Alternating stress in Parabolic model

Table: 7 Result Table of Parabolic model

Object Name	Life	Equivalent Alternating Stress	Damage
State	Solved		
Scope			
Geometry	All Bodies		
Definition			
Type	Life	Equivalent Alternating Stress	Damage
Design Life			1.e+009 cycles
Results			
Minimum	81150 cycles	5.1297e-004 MPa	
Minimum Occurs On	Part2	Part23.1	
Maximum		705.97 MPa	12323
Maximum Occurs On		Part2	

Secondly in this work two models of parabolic leaf spring has been compared one steel parabolic leaf spring and other is of composite material i.e glass reinforce plastic (GRP). The composite used is Glass Reinforced Plastics in which 48% of glass fibre is present as volume fraction. A knitting machine is used to form a unidirectional glass tape which consists of 97% glass in longitudinal direction & 3% in transverse direction. The material properties of the composite are defined by Institute of Polymer Mechanics in Latvia. So in this present work the GRP is selected as the spring material. The purpose is to achieve an optimise model with change of material.

Table: 8 Mechanical Properties of the GRP

Parameter	GRP
Nature	Orthotropic
Young's Modulus, E_{xx}	38000 MPa
Young's Modulus, E_{yy}	13000 MPa
Young's Modulus, E_{zz}	13000 MPa
Poisson's Ratio, ν_{xy}	0.31
Poisson's Ratio, ν_{yz}	0.05
Poisson's Ratio, ν_{zx}	0.31
Modulus of Rigidity, G_{xy}	1000 MPa
Modulus of Rigidity, G_{yz}	16 MPa
Modulus of Rigidity, G_{zx}	60 MPa
Mass density	0.00000185 kg/mm ³
Tensile strength Yield	900 MPa

Table: 9 Details of GRP Model

Object Name	<i>Geometry</i>
State	Fully Defined
Definition	
Length Unit	Meters
Element Control	Program Controlled
Bounding Box	
Length X	972. mm
Length Y	78. mm
Length Z	100.56 mm
Properties	
Volume	1.3e+006 mm ³
Mass	2.782 kg
Statistics	
Bodies	22
Active Bodies	12
Nodes	6398
Elements	2233

The geometrical & meshing details of GRP leaf spring are shown here table-9 and boundry conditions of the model are shown in figure-14 here.

Figure: 14 Boundary Conditions of GRP Model

Figure: 15 Fatigue Life of GRP model

Figure: 16 Alternating stress in GRP model

Table: 10 Result table of GRP model

Object Name	Life	Equivalent Alternating Stress	Damage
State	Solved		
Scope			
Geometry	All Bodies		
Definition			
Type	Life	Equivalent Alternating Stress	Damage
Design Life			1.e+009 cycles
Results			
Minimum	84180 cycles	2.4313e-004 MPa	
Minimum Occurs On	Part1.1.2	Part23.1	
Maximum		724.8 MPa	11879
Maximum Occurs On		Part1.1.2	

2. RESULTS & DISCUSSIONS

From the results obtained by simulating the three models i.e conventional multi leaf spring of steel and parabolic leaf spring of steel & composite GRP, a comparative analysis has been done as in table-11 & table 12

Table: 11 Result comparisons after design optimization

Models	Flat Multi Leaf spring (EN45A)	Parabolic Leaf Spring (EN45A)	Variation % age
Parameters
Von-Mises Stress, MPa	1096	1083.2	1.16
Fatigue Life, cycles	77410	81150	4.83
Weight, Kg	9.507	8.62	9.32
Displacement, mm	50.202	56.806	13.15

Table: 12 Result comparisons after material optimization

Models	Parabolic Leaf Spring (EN45A)	Parabolic Leaf Spring (GRP)	Variation % age
Parameters
Alternating Stress, MPa	705.97	724.8	2.66
Fatigue Life, cycles	81150	84180	3.73
Weight, Kg	8.62	2.782	67.72

3. CONCLUSION

When design of conventional multi leaf spring is changed to parabolic leaf spring it has been concluded that;

1. For same boundary & loading conditions, a decrease of 1.16% of stress developed is experienced in the parabolic model due to elimination of interleaf friction between the leaves.
2. The fatigue life of the parabolic design is 4.83% more in comparison to conventional leaf spring which makes it more reliable.
3. The weight of the whole assembly is also decreased by 9.32% in parabolic model which makes it lighter in comparison to conventional multi leaf assembly.

And when material of the parabolic leaf spring is replaced with a composite one i.e glass reinforced plastic, it has been concluded;

1. The alternating stress level remains in the required limits and a variation of 2.66 % is noticed which is acceptable.
2. The fatigue life of the GRP model is 3.73% more in comparison to steel parabolic model which makes it more reliable.
3. The weight of the whole assembly is also decreased by 67.72% in GRP parabolic model which makes it lighter in comparison to steel parabolic model.

Finally it can be concluded that the parabolic leaf spring made of composite material is better in all respect in comparison to conventional steel multi leaf spring and proved to be an optimised model.

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AUTHORS

Krishan Kumar is working as Assistant Professor in the Deptt of Mechanical Engineering at YMCA University of Science & Technology Faridabad with a total experience of nine years. Currently a research scholar of Ph.D at the same university. He has completed his M.Tech in CAD/CAM from NIT Kurukshetra in 2009 and B.Tech in Mechanical Engineering from Kurukshetra University in 2004. He had published many research papers in International journals and National, International conferences.

Dr. M.L. Aggarwal is working as Professor in the Deptt of Mechanical Engineering at YMCA University of Science & Technology Faridabad. He has done B.Sc. (Engg) in Mechanical Engg. from REC Kurukshetra in 1988, M.Tech. and PhD. from IIT Delhi in 2003 and JMI New Delhi in 2007 respectively. He has been working in YMCA University of Science & Technology Faridabad, Haryana, India since 1989. He has published approx. 50 papers in International / National Journals in the relevant areas of design engineering. His research areas of interest are materials and mechanical design.