Analysis of laminated springs and design optimization

Dhaman Bharat[a], Rupinder Singh[a], Ravinder Tonk[a]

[a], Department of Mechanical Engineering,Chandigarh University, Gharuan 140413 Punjab,India.

Abstract
A typical laminated spring with real-world dimensions and loads is the purpose of this study's usage of CAD software. In this paper, the front-end laminated spring of TATA-1109 is examined. Jamna Auto Industries offers the laminated spring design. This model has 37 parts and CATIA creates CAD models for leaf springs. It was imported into SOLID WORKS in *STP format for preprocessing. Establishing the contact reign between various leaves, meshing the model, and setting the revolute joint between pin and eye are some of the preprocessing steps. An analysis of the leaf spring's deflection and stresses using SOLID WORKS was performed. The experimental and CAE test results were then compared for validation. In addition, this study covers the creation and examination of a mono steel leaf spring model. The outcome is compared to the FGER single leaf spring result. Also, in this research, CAD models for riveted and cast eyes were built, and their CAE results were compared to the standard eye design.

Keywords: CAD software, laminated spring, CATIA, leaf springs, SOLID WORKS, FGER single leaf spring

1. INTRODUCTION

A spring is an elastic component used to store mechanical energy. Springs are normally made from solidified steel. Springs, which are small that, can be twisted from pre-solidified stock, while bigger ones are produced using strengthened steel and solidified after manufacture. Springs are different from other machine/structure parts in that they go through substantial change in shape when stacked - their design enables them to stock promptly restorable mechanical energy. [1]. In a vehicle shock absorber, when the wheels encounter a hindrance, the spring action absorbs all the sudden jerks with the compression of springs and slowly releases that force which results to normal positioning of wheels.

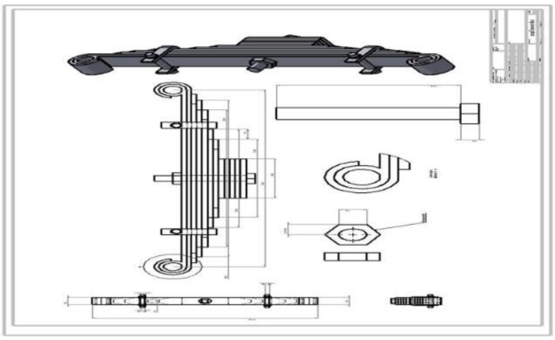

Figure 1. 2D Drawing of Leaf Spring

There are various types of springs. One of these types are leaf springs. The most frequent kind of laminated springs were "curved" laminated springs. The two circular arcs that are joined at their ends give these laminated springs their name "Circular" or "Full Elliptical". [2]. In this case, a powerful front hub was connected to a lower curve's base center, and a higher curve's top focal point to its lower focal point. Laminated springs were widely used in automobiles until the 1970s in Europe and Japan, when the switch to front-wheel drive and increasingly complicated suspension designs saw the usage of curl springs. They are still used on American back-wheel drive cars. Leaf springs are still used in heavy duty commercial vehicles, SUVs, and rail carriages. For large vehicles, they benefit from distributing the load more evenly across the skeleton.

Several past studies have been done in this area of research. Researchers defined and studied four laminated steel springs used in light car rear suspension systems in SOLID WORKS. Existing experimental and logical answers were supported by finite element results demonstrating stress and deflection. [3]. The primary goal was to improve the geometry of the springs. The goal was to acquire a spring with least weight, proficient of absorbing a firm static external force without dislocation. It was found that compared to steel springs, optimized composite springs have significantly lower stresses, higher natural frequency and nearly 80% lower weight of springs without eye elements. In another study, the researchers outlined the process of designing a rail transport composite sheet spring with three composite leaf spring eye mount designs.[4]. Spring characteristics were determined via static and finite element testing. The three designs evaluated had their load deflection curves and strain data displayed against the FEA projected value. The EFA findings indicated this region's interlaminar shear stress concentration. The design also included a transverse bandage over places prone to distinction. Disparities have been minimized but not eliminated.

In other study, the researchers explained that the car sector is increasingly interested in using fiberglass leaf springs to replace steel springs. The plate is composed of single-sided glass fiber reinforced plastic (GRP) with mechanical and geometric qualities comparable to a laminated spring. The content cross-sectional sheet was created using a C language algorithm.[5]. The stress and deflection values from SOLID WORKS software have been confirmed by analytical and experimental data. It was found that composite springs feature lower stresses, higher natural frequencies, and are roughly 85% lighter than steel springs with bonded end joints and entire bore components. Researchers also highlighted those simplified equations and procedures for vibrations and faults are mostly used in the construction of leaf springs.[6]. Study of two-stage multi leaf springs, leaf spring sets and the Hotchkiss suspension using ABAQUS was presented. The effects of varying loads on the stresses and strains were studied. It is possible to foresee the durability of a design prior to development. Wing geometry and anticipated speed may be utilized in comprehensive NVH vehicle models and multi-body dynamic models to verify suspension qualities.

In another study, researchers studied geometric nonlinearity in order to better understand why tapered cantilever beams, also referred to as leaf springs, are more prone to high deflections. It is assumed that a parabolic leaf spring is built of extremely elastic steel in this study. Stress and deflection of the same beam were calculated numerically via the use of small and large deflection theory. Peak load beam response has been shown to be greatly influenced by nonlinear analysis [7].

Study and evaluation of all the above articles by different professionals from different countries, show that CAE is not only a time-saving tool, but also a cost-effective method for design and analysis. CAE has been contributing to the needs of the automotive industry for decades, opening new horizons in analysis and design practice around the world. The majorities of spring manufacturing units in other countries is financially secure and have invested in new technologies via research and development. They focus on fresh spring applications as well. In most nations outside India, the automobile industry accounts for roughly 40% of the total consumption, while other sectors account for 60%. As opposed to this, 60-80% of India's need is for hot coil springs, especially precision springs, in Indian railroads and leaf springs. Therefore, to fill this gap this work is based on the study of the PC-Aided Analysis of the laminated spring and contrast it and standard outcomes using the CATIA software and computer assisted analysis.

2. EXPERIMENTAL SETUP AND TEST

CAE Components and assemblies may be analyzed using CAE tools, for example, to determine their robustness and performance. Simulating, validating and optimizing goods and manufacturing equipment is part of this. The automotive industry makes extensive use of computer-aided engineering (CAE) software. Automakers have been able to in order to cut costs and schedule, while also enhancing the security, convenience, and durability of their cars with its application. Many industries now employ computer-aided design techniques and software to develop drawings and specifications that could previously be done by hand.

2.1 Material and Method

Computer-aided design uses computers to create two-dimensional or three-dimensional representations of physical items. Manufacturers and designers use CAD to test prototypes and pre-release products for optimization, performance, and dependability.[8]. CAD is great for prototyping since it helps designers to foresee issues and save money on the final product. These systems now often include three-dimensional modelling and computer simulation modelling.

Additionally, computational analysis is used to solve partial differential equations in mechanics, and heat transfer using finite elements. The finite element technique and the finite difference approach are the two most used computer-aided analytical methods. To model a part or assembly, we can use the Finite Element Method (FEM) divides its geometry into standard forms and applies loads and restrictions to it. CAD models and finite element analyses may be created using a wide variety of software programs. CATIA V5-R17 and SOLID WORKS are the two-software used in the present study. CATIA is used by several companies in the automotive industry to verify degrees. It excels in creating surfaces and displaying them in a computer-generated manner. [9]. It may be used for a wide range of the manufacturing of aircraft, automobiles and other industrial gear. SolidWorks, is another software which is widely regarded as the industry standard in computer-aided engineering.

The foundation of every endeavour is CAD modeling. Finite Element software will take into account any CAD model's shapes. All 3D modeling tasks, from sketching to rendering, are handled by a single piece of specialized software, known as CAD modeling software. Additionally, the model of the many leaf spring structures includes several intricate pieces that are not easily modelled with ordinary CAD tools. Surface generation tools in CATIA allow the creation of standard surfaces, which are then transformed into solid models. The CATIA design modulation software not only permits the CAD modeling but also the drafting feature which enables us to view the sectioned and oblique projections of the assembly. Our problem's CAD model is made up of 41 unique pieces that are assembled into a multi-leaf spring form, built from various 2D designs. A multi-leaf spring CAD model for examination (Fig. 2).

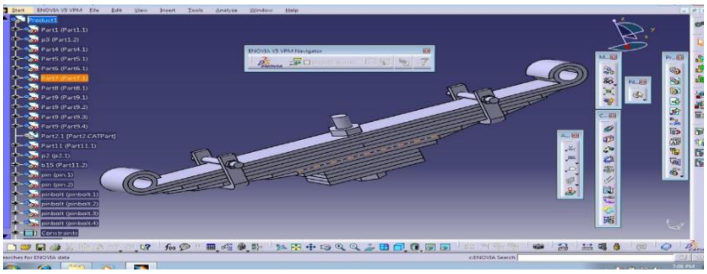

Figure 2. Multi Leaf Spring Assembly

Part Modeling

Part modeling is the basic tool used by CAE Engineers in CATIA. Creating a drawing is the first step in developing a new component from scratch. This is done on the sketcher workbench, which is integrated into the design process. Part model of a component used in the assembly of multi leaf spring is shown in the Fig. 3 below.

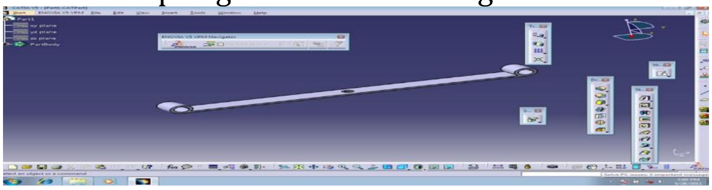

Figure 3. Part modelling of main leaf

Some part of the model are created using part modeling, depending upon the thickness and shape of the component. Parts like clamps, rivets and shims are made by part modeling.

Surface Modeling

Extruding, lofting, and sweeping are just a few of the surface modeling methods available in Wire frame & Surface Modeling. FIG.4 depicts the multi-leaf spring wire frame model.

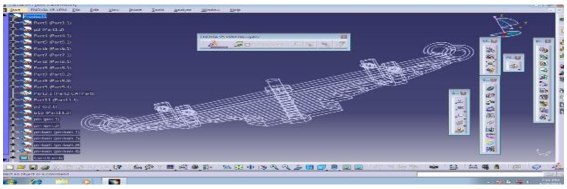

Figure 4. Wire frame model

Assembly Design

The fig-5 shows the assembly of some parts of the multi leaf spring. Assembly design provides us more convenient and more accurate way of positioning all the parts made by part modeling/Surface Modeling.

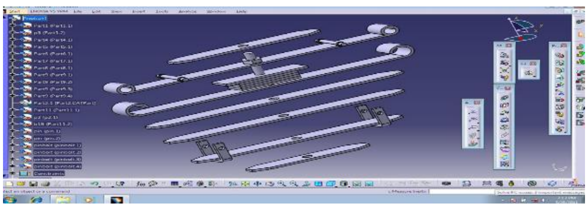

Figure 5. Assembly of Leaf spring parts

3. RESULTS AND DISCUSSION

This section of this paper includes a brief description of all the experimentation done. The practical application result for the normal static loading are considered for comparison using SOLID WORKS. The result involves the determination of the stresses and deflections induced underneath the static loading circumstances. The load and defection curve is useful in describing the behavior of the spring under normal static load. The load deflection curve behavior is studied by using under 2 conditions which are for loading and unloading of the leaf spring. From the loading and unloading curve, mean value of lad and deflection can be determined. Figure 6 shows the results of the leaf spring static loading experiment.

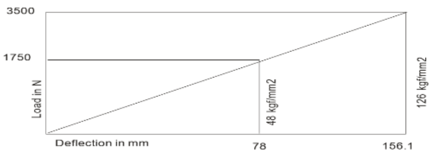

FIGURE 6: Actual load deflection curve

Analysis using Solid Works

Leaf spring CAD models have been imported into Solid Works. Mild steel is employed in the examination of the leaf springs, which is comparable with almost similar behaviour and isotropic properties SUP9.

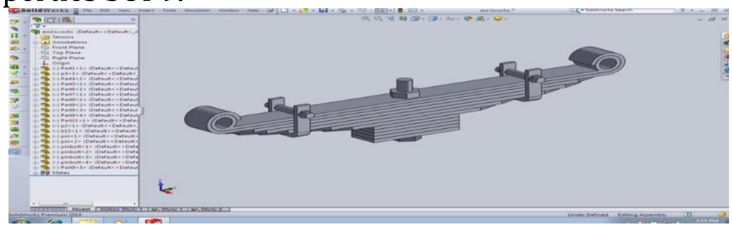

FIGURE 7: CAD modeling in solid works

Table – 1: Model - Static Structural - Solution - Results

Object Name	Total Deformation	Directional Deformation	Directional Deformation 2	Equivalent Stress	Bending Stress
State	Solved				
Scope					
Geometry	All Bodies				
Definition					
Type	Total Deformation	Directional Deformation		Equivalent (von-Mises) Stress	Bending Stress
Display Time	End Time				
Orientation		X Axis	Y Axis		Y Axis
Coordinate System		Global Coordinate System			Global Coordinate system
Results					
Minimum	0 mm	-10.946 mm	-155.94 mm	0.185 MPa	-2210.9 MPa
Maximum	156.15 mm	27.45 mm	11.02 mm	172.5 MPa	1415.6 MPa
Minimum Occurs On	Part1	Part2	Part1.3	Part3.1	Part2
Maximum Occurs On	Part2			Part1.5	Part3.1

Analysis for Static load of 17.5 KN: Results

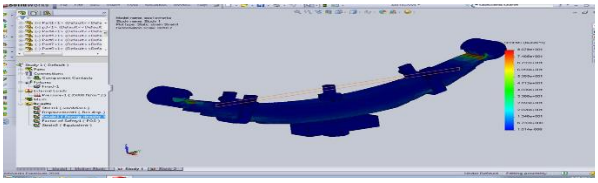

FIGURE 8: Total Deformation in leaf spring (17.5 KN)

Table 2: Results for Static load of 17.5 KN

Object Name	Total Deformation	Directional Deformation	Directional Deformation 2	Equivalent Stress	Bending Stress
State	Solved				
Scope					
Geometry	All Bodies				
Definition					
Type	Total Deformation	Directional Deformation		Equivalent (von-Mises) Stress	Bending Stress
Display Time	End Time				
Orientation		X Axis	Y Axis		Y Axis
Coordinate System		Global Coordinate System			Global Coordinate system
Results					
Minimum	0 mm	-5.4731 mm	-77.97 mm	0.0927 MPa	-479.31 MPa
Maximum	78.078 mm	13.725 mm	5.5099 mm	86.29 MPa	537.73 MPa
Minimum Occurs On	Part1	Part2	Part1.3	Part3.1	Part2
Maximum Occurs On	Part2			Part1.5	Part3.1

Optimization and Analysis of Leaf Spring

Steel springs are being replaced with glass fibre reinforced composite sheet metal springs in the automobile industry. Steel alloys, which are rather homogenous, are replaced with inhomogeneous fibre-reinforced plastic (FRP). The stresses developed in the critical area of the leaf spring fabric can also be reduced by changing the leaf spring fabric design.

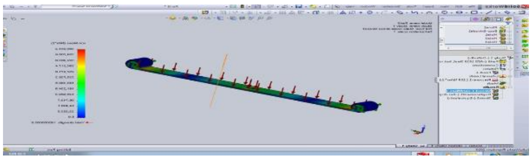

FIGURE 9: Deformation in single steel leaf spring (50 KN)

Table 3. Results Comparison

Parameters	Exp. Results	CAE Results	Variation
Normal Static Load	35000 N	35000 N	Nil
Deflection	158 mm	156.15 mm	1.17%
Bending Stress	126 kgf/mm^2	141.56 kgf/mm^2	12.30%
Spring Rate	221.5 N/mm	224.5 N/mm	1.35%

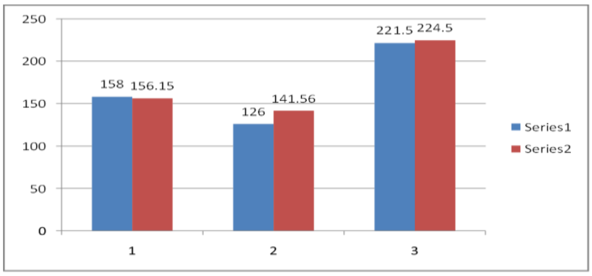

FIGURE 10: Bar chart for experimental and CAE results

According to the above bar-chart, under the identical static loading circumstances, experimental deflection is 158mm and CAE deflection is 156.15mm. The variance in deflection and bending stress for experimental and CAE data is 1.17 percent and 12.30 percent, respectively. The value of equivalent stress (von-mises stress) is 17.2kgf/mm2.

Table 10: Comparison of single steel leaf & single FGER leaf spring results

Parameter	Steel	FGER	Variation
Load	50 N	50 N	Nil
Deflection	97.9508 mm	95.476 mm	2.0%
Mass	10.198 kg	3.78 kg	62.9%
Bending stress	25.9 kgf/mm2	4.5 kgf/mm2	82.62%

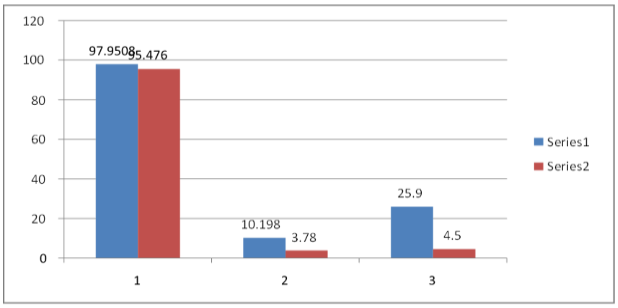

FIGURE 11: Bar-chart for single steel & FGER leaf spring

From the above shown bar-chart, it has been observed that when a single steel leaf and a single FGER leaf is analysed in CAE, for the same static load and similar boundary conditions, the deflection is reduced by 2.0% the mass of the steel leaf spring is 10.198 kg and that of FGER is 3.78 kg Bending stress for steel and FGER is 25.9 kgf/mm2 & 4.5 kgf/mm2 respectively.

4. CONCLUSION

In this research paper, many observations were based on the SOLID WORKS findings, and it was observed that when the leaf spring was fully/half filled, a 1.17 percent difference in deviation between experimental results and CAE was noticed, which verified our model and CAD analysis. The flexural stress in the full load situation rose by 2.30 percent in the CAE analysis compared to the experimental circumstances, whereas it increased by 12.02 percent in the semi-loaded state. The highest equivalent stress values were 172.5 MPa and 86.29 MPa. Below the yield point, completely and half-filled leaf springs, i.e. (250 MPa).

There is a reduction in weight when a single steel leaf spring is replaced with a composite material (FGER).There is a slight variation in deflection, i.e., 2.0% while the bending stress was reduced by 82.62%. Replacing FGER single leaf springs with steel leaf springs saves 62.9% in weight. On replacing complete steel leaf spring with FGER, there is a mass reduction of 65.8%, reduction in bending stress by 62.62% while the variation in deflection is 4.26% The Value of maximum equivalent stress in case of FGER spring is 24.01 MPa, which is below the yield stress (900 MPa).

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