Journal of Advances and Scholarly Researches in Allied Education
Vol. 20, Issue No. 3, July-2023, ISSN 2230-7540

Structural Analysis of Leaf Spring

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Abstract - Leaf springs are used in various types of commercial and private vehicles. The objective of current research is to optimize design of leaf spring using design of experiments. The modelling and FEA simulation is conducted using ANSYS simulation package. From the FEA simulation, the structural characteristics of leaf spring is evaluated. Using optimal space filling design techniques, nine different designs were generated with varying inner and outer radii. The smallest equivalent stress among these designs was 88.84MPa, while the highest corresponding stress was 202.14MPa for design point number 2.

Keyword - Leaf Spring, optimization

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1. INTRODUCTION

Leaf springs are a fundamental form of structural support. The structure consists of multiple layers of steel, each with varying sizes, which are vertically stacked. The majority of leaf spring systems are constructed using spring steel material that has been formed into an elliptical shape. The steel exhibits the ability to undergo elastic deformation when subjected to pressure at its ends, followed by a subsequent restoration to its initial shape.

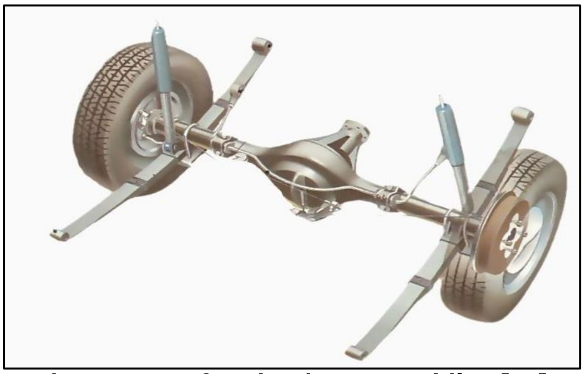

Figure 1: Leaf spring in automobiles [17]

This phenomenon is commonly referred to as "damping." Rectangular pieces of steel are commonly secured using metal clamps positioned at both ends, along with a large fastener located in the center of the leaves. The suspension is secured by affixing robust U-bolts onto the car's axle, thereby immobilizing it. Leaf springs have historically served as a viable alternative to coil springs in the automotive industry. However, their usage has become limited to heavy goods vehicles (HGVs) and military vehicles in recent times. The utilization of spring steel in the suspension system enables enhanced flexibility, thereby facilitating the control and comfortable operation of a moving vehicle. Leaf springs offer substantial support between a vehicle's wheels, frames, and chassis due to their utilization of a significant quantity of metal. Due to their strong interlocking structure, these materials possess exceptional load-bearing capabilities, making them highly suitable for applications in demanding industries that require the handling of substantial vertical forces. In contrast to the concentrated application of force exerted by a small spring and damper, the vertical pressure on the leaf spring is distributed along its entire length. This distribution prevents the suspension from being overwhelmed by a force that is excessively concentrated. Damping plays a crucial role in the functioning of an automobile. Insufficient stiffness in the vehicle's suspension can result in excessive sagging and shaking following encounters with bumps or cracks on the road. Prior to the invention of the shock absorber, one of the primary concerns associated with automobiles equipped with spiral springs was their inability to effectively mitigate the negative effects of driving at reasonable speeds. The enhanced responsiveness of the suspension system following a sharp turn, along with improved controllability, can be attributed to the pressure exerted between the steel plates in leaf springs. Consequently, leaf springs exhibit superior damping characteristics.

2. LITERATURE REVIEW

Mahmood et. al. [1] The investigation encompassed the development and examination of cast eye ends and conventional eye ends for conventional single leaf springs. The CAD models were generated using CATIA software, and subsequent analyses were conducted using ANSYS software, all under the same load conditions. This was conducted in order to consider the effects of displacement von-Mises stress, normal stress, and various other parameters. The researchers reached the determination that substituting regular eyes with cast eyes leads to a 5.4% augmentation in deflection magnitude when subjected to identical static loads. Von Mises exhibited a reduction in stress levels by 3% compared to its previous level of responsibility. Nevertheless, there has been a notable 19.08% rise in the mean level of stress, juxtaposed with a corresponding decline of 13.1% in the minimum level of safety. It has also been found that the utilization of computer-aided engineering (CAE) tools necessitates a reduced expenditure of both time and financial resources in contrast to conducting tests in real-world settings. Furthermore, the employment of CAE tools yields results that align with predetermined parameters.

Mahdi et. al. [2] utilised a traditional multi-leaf spring made of SUP9 steel. This spring consisted of “two full-length leaves, one of which had eye ends, as well as seven leaves of different lengths” [2]. After the completion of the finite element design using the CATIA V5 R17 software, a finite element analysis was conducted using ANSYS11. The results obtained from the experiments were compared to the bending stress and deflection observed under full and half loads through the utilisation of finite element analysis. There was a slight discrepancy observed in the deflection values, with a 0.632% difference noted in full load application and a 10.11% difference observed in bending stress. Similarly, the amount of bending stress exhibited a modest variation, with a 0.632% difference observed in half load application and a 17.95% difference noted in full load. The researchers reached the conclusion that the design would not experience failure when subjected to the stress conditions they had imposed. Additionally, they found that computer-aided engineering (CAE) technologies yield more precise results with reduced variability in the outcomes.

Santhosh et. al. [3] focused on “the design and development of hybrid leaf springs specifically intended for application in light vehicles. The main aim of this study is to evaluate the stress resistance of steel and composite leaf springs, as well as their respective weight-saving capabilities” [3]. In this particular instance, standard steel is employed instead of the three materials that were initially under consideration, namely “glass fibre reinforced polymer, carbon epoxy, and graphite epoxy. The steel leaf spring was utilized to ascertain the suitable design variables” [3]. The results suggest that replacing a steel leaf spring with a composite material alternative could potentially lead to a significant decrease in weight by approximately 92%, along with a reduction in stress levels. The results obtained from the extensive and prolonged investigation reveal the maximum displacement achievable by a steel leaf spring. Among the three hybrid leaf springs composed of graphite and resin, it is observed that one exhibits greater strain compared to a steel leaf spring, whereas the remaining two do not demonstrate such strain. Based on the research results, it has been determined that a “monolithic leaf spring composed of E-Glass/Epoxy material exhibits a weight reduction of 81.22% compared to a steel leaf spring” [3]. Similarly, a monolithic leaf spring constructed from Graphite/Epoxy material demonstrates a weight reduction of 91.95%, while a monolithic leaf spring utilizing Carbon/Epoxy material exhibits a weight reduction of 90.51%. When comparing steel leaf springs to hybrid leaf springs composed of E-glass and epoxy, it has been found that the latter exhibit superior strain and stiffness characteristics.

Saini et. al. [4] In the research they opted to substitute the “steel leaf spring with a hybrid spring” and subjected it to an identical battery of stress tests as the initial spring. The researchers reached the determination that composite circular springs exhibit superior resistance to wear and tear compared to steel springs due to their inherent characteristics. The researchers employ the ANSYS software to examine the long-term durability and potential weight reduction of steel elliptic springs. The researchers are examining the durability and long-term performance of the subject under investigation. The “aim of this study is to assess the performance of the steel leaf spring and the composite leaf spring in terms of their load-bearing capacity, wear resistance, and ability to reduce the overall weight of the spring system. Furthermore, the researchers compared the results obtained from the finite element analysis” regarding wear life and weight loss with the conclusions derived from previous theoretical and experimental studies. The attainment of the customary weight reduction is attainable when utilising steel leaf springs.

3. OBJECTIVES

The objective of current research is to optimize design of leaf spring using design of experiments. The modelling and FEA simulation is conducted using ANSYS simulation package. From the FEA simulation, the structural characteristics of leaf spring is evaluated.

4. METHODOLOGY

The structural analysis of leaf spring is conducted using FEA simulation technique. The process involves modeling of leaf spring using extrude tool of design modeler. The developed leaf spring model is shown in figure 2.

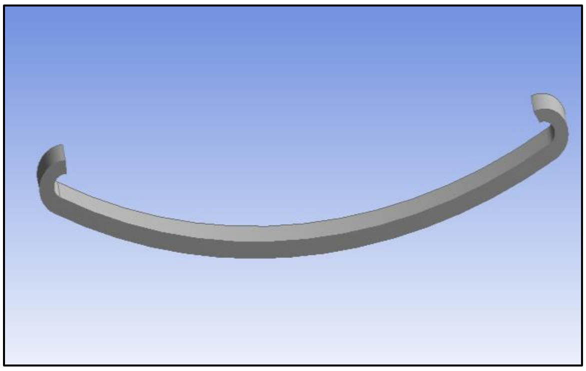

Figure 2: Leaf spring model

After modeling of leaf spring, the discretization process is conducted wherein the model of leaf spring is converted into elements and nodes (figure 3).

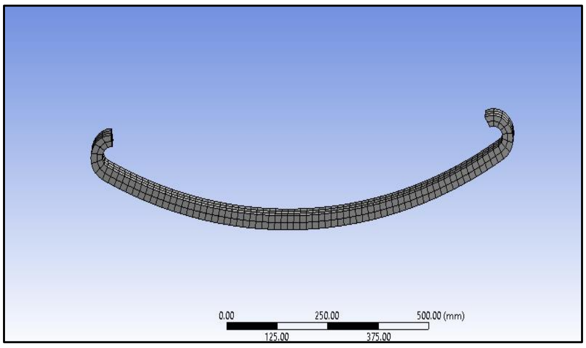

Figure 3: Leaf spring meshed model

After meshing, the structural loads are applied on the mono leaf spring. The applied structural loads include displacement support and remote displacement support as shown in figure 4 The FEA analysis is conducted at 2000N force.

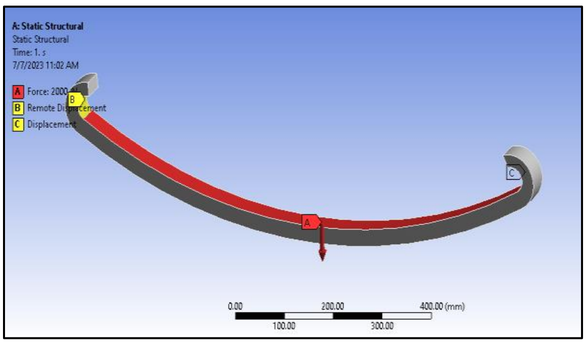

Figure 4: Structural loads and boundary conditions

After defining structural boundary conditions, the simulation is run. The FEM solves the system of equations derived from the assembly stage. Various numerical techniques, such as direct methods to obtain the solution. The FEM utilizes numerical integration techniques, such as Gaussian quadrature, to approximate the integrals involved in the element-level calculations. The accuracy of the solution is influenced by the choice of element types, mesh refinement, and the convergence criteria used in the solution process.

4. RESULTS AND DISCUSSION

A finite element analysis (FEA) simulation is conducted to identify areas of elevated induced stress and deformation on a leaf spring. The region highlighted in red represents the specific portion of the leaf spring that experiences the highest levels of stress. (figure 5).

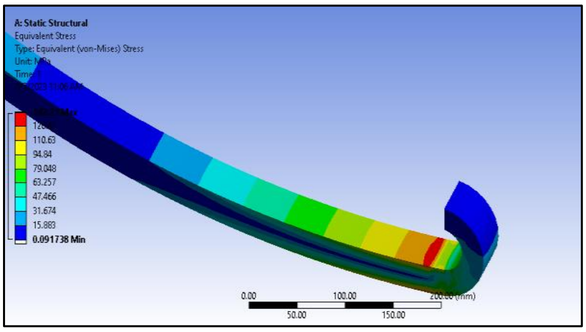

Figure 5: Equivalent stress distribution plot

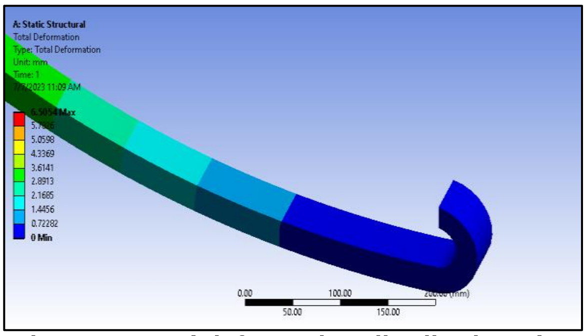

Figure 6: Total deformation distribution plot

The displacement plot for a leaf spring is depicted in Figure 6. The region of greatest deformation in the leaf spring is observed at its displacement support, whereas the area of least deformation is found in the region in dark blue color.

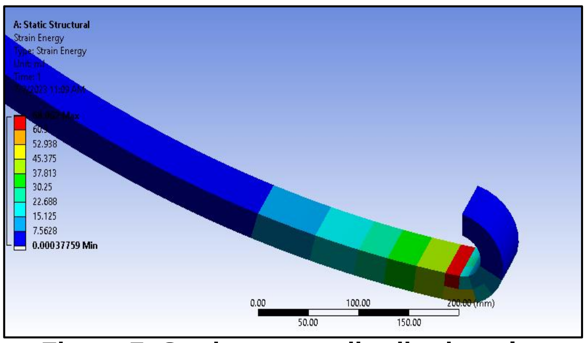

Figure 7: Strain energy distribution plot

Figure 7 presents a graphical depiction of the spatial distribution of strain energy within a leaf spring. The support zone is characterized by a significant accumulation of strain energy exceeding 45.37mJ. After conducting an assessment of a leaf spring, the most suitable arrangement is determined by considering the spring's comparative stress, overall displacement, and solid mass.

Table 1: Design Points

Design Points	Inner Radius (mm)	Outer Radius (mm)	Equivalent Stress Maximum (MPa)
1	995.83	1021.66	185.90
2	999.16	1023.88	202.14
3	989.16	1027.22	93.75
4	994.16	1026.11	127.34
5	987.5	1020.55	119.19
6	990.83	1022.77	126.94
7	992.5	1029.44	98.78
8	997.5	1028.33	135.95
9	985.83	1025	88.84

The design points are generated using the optimization techniques. Optimal space filling design refers to a design approach aimed at achieving efficient and effective coverage of a given space or region. It involves the placement or arrangement of elements within the space to maximize coverage while minimizing gaps or overlaps between the elements. The goal is to achieve a design that fills the space as uniformly and evenly as possible. The optimization table is generated as shown in table 1. In total 9 different designs are generated with different values of inner radius and outer radius. In contrast to the entirety of the design, design elements 3 and 7 exhibited the lowest degree of shear stress with other design elements. The minimum equivalent stress occurs at design point number 9, measuring 88.84 MPa, whereas the maximum equivalent stress is observed at design point number 2, measuring 202.14 MPa.

4. CONCLUSION

The findings demonstrate the effectiveness of the FEA simulation technique in analyzing the structural behavior of the leaf spring and optimizing its design. By identifying critical stress and deformation areas, it provides valuable insights for improving the performance and reliability of leaf spring designs. Future research could explore additional optimization techniques and further refine the design to enhance its efficiency and durability. Using optimal space filling design techniques, nine different designs were generated with varying inner and outer radii. The smallest equivalent stress among these designs was 88.84MPa, while the highest corresponding stress was 202.14MPa for design point number 2.

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