Leaf spring type simulation with finite element method approach

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Abstract. The leaf spring is one of the main components of the suspension system which functions as a shock absorber due to uneven road surfaces and a vibration damper from the wheels. Continuous shocks and vibrations can cause the leaf spring to receive high cyclic loads which can cause fatigue failure. The purpose of this article is to determine the differences in equivalent stress, fatigue life and safety factor of different leaf spring types. The types of leaf springs used include the trailing leaf spring, the semi elliptical leaf spring and the parabolic leaf spring. Various types of leaf spring will be designed using solidworks software, while the simulation uses ANSYS 19.2 software. ANSYS engineering data uses SUP 9 material and the load used is 6350 N. After simulation analysis it is concluded that high fatigue life is generated by the parabolic leaf spring with a cycle of $1.996 \times 10^5$ cycles and a minimum safety factor of 1.1336. The safety factor value on the parabolic leaf spring shows that the component will not fail until the life design is achieved.

Keywords: simulation, leaf spring type, finite element method

1. Introduction
Leaf spring is one of the main components of the suspension system used in heavy vehicles because of its low cost, easy maintenance, the ability to accept higher loads and to dampen vibrations well [1], [2]. The vibrations generated from the road surface and wheels are suppressed by the leaf spring so that it is not transmitted to the vehicle body [3].

Leaf springs receive various types of loads when working for a certain period of time which are partly controllable and partly uncontrollable. Uncontrolled loads occur due to environmental changes such as damaged and uneven roads[4]. Types of damaged and uneven roads tend to have a calculated fatigue load. Fatigue is a material weakening caused by repeated loads[5]. Fatigue can cause progressive and localized structural damage that occurs when a material is cyclically loaded. Failure due to fatigue is a fracture mechanism that can be identified by three processes, namely initiation crack, crack propagation and the final stage is final fracture [6]. Leaf spring failures generally involve cracks that can occur during the manufacturing process or in extreme working conditions [7]. The crack will then grow progressively during loading fatigue [8]. The fatigue life
factor of the leaf spring component is very important to study properly because when it reaches a
critical crack length it can cause total damage to the suspension system and can cause catastrophic
accidents with loss of life [9,10].

The leaf spring type consists of various shapes and geometries such as the semi elliptical leaf
spring, the trailing leaf spring and the parabolic leaf spring. Parabolic leaf spring is a conventional
leaf which consists of a single leaf and has varying cross sections while semi elliptical [11]. Each
leaf has a different length but with the same width and thickness. The longest leaf is at the top and
has eyes at both ends. Parabolic leaf spring and trailing leaf spring are usually applied to semi-
trailer trucks which can withstand higher stresses.

Various simulation analysis studies on leaf spring have been studied to increase the strength
and predictability of fatigue life. Kumar et al [11] studied the analysis of fatigue life on leaf springs
with 65Si7 material. The results of the study showed that the fatigue life of leaf springs for the
same stress range would be reduced, if the initial stress was lower. In actual conditions, the leaf
springs will withstand 15-17% longer than predicted by the SAE spring design manual approach.
Kong et al [5] investigated the prediction of fatigue life on parabolic leaf springs under a variety of
different road conditions. Prediction of fatigue life using under variable amplitude loading (VAL).
VAL is collected through measurements from various road conditions such as roads, mountain
roads and potholes. Furthermore, the design life of certain fatigue leaf springs was predicted using
the Finite Element Methods (FEM) stress-strain model. The fatigue life of the lowest leaf springs is
generated on potholes, followed by mountain roads and smooth roads. Solanki et al [12] analyzed
differences through a computational approach to the semi elliptical leaf spring and parabolic leaf
spring. Changes in the ratio of the span length and camber affect the maximum deflection and
maximum stress results.

The purpose of this study was to determine the prediction of fatigue life from the three types
of leaf springs applied to van trucks. Prediction of fatigue life will be simulated using ANSYS
software with the Godman theory approach. The loading conditions will be adjusted to the
specifications of the van truck. The results of the simulation will then be compared with the three
types of leaf springs to determine the difference in fatigue life.

2. Method and material

The types of leaf spring that are designed include the trailing leaf spring, the semi elliptical leaf
spring and the parabolic leaf spring. The design dimensions parameters of the leaf spring are as
follows (Table 1). The analysis of the finite element method on leaf spring aims to analyze
the equivalent stress, fatigue life, fatigue damage and safety of the factor. The load parameter is
adjusted to the leaf spring capacity of the van truck, which is 6350 N.

| Type Leaf Spring | Span Length | Camber | Inner Diameter Eye | Thickness | Width |
|------------------|-------------|--------|-------------------|-----------|-------|
| Trailing Leaf Spring | 1370 mm     | 120 mm | 40 mm             | 8 mm      | 65 mm |
| Semi Elliptical Leaf Spring | 1370 mm     | 195 mm | 40 mm             | 8 mm      | 65 mm |
| Parabolic Leaf Spring | 1370 mm     | 195 mm | 40 mm             | 8 mm      | 65 mm |
2.1 Material properties
The material from Leaf Spring in this study is the material spring steel SUP 9 [13]. SUP9, Mn-Cr steel, exhibits good heat deformability and good hardening for application to large size stabilizers, torsion rods and coil springs

| Properties       | Metric          |
|------------------|-----------------|
| Tensile Strength | $\geq 1225 \text{ MPa}$ |
| Yield Strength   | $\geq 1080 \text{ MPa}$ |
| Poissons Ratio   | 0.266           |
| Density          | 7850 $\text{ kg mm}^3$ |

2.2 Meshing and boundary condition
The meshing technique is used to divide the model into a number of small parts for better analytical accuracy[14]. In both cases, meshing was carried out at an element size of 5 mm for the leaf geometry in direct contact with the loading. The meshing results of several leaf spring type designs are as shown in Table 3

| Type Leaf Spring          | Element   | Nodes   |
|---------------------------|-----------|---------|
| Trailing Leaf Spring      | 206514    | 347825  |
| Semi Elliptical Leaf Spring | 156799    | 281190  |
| Parabolic Leaf Spring     | 70958     | 195772  |

![Figure 1 - Meshing Results](image)

**Figure 1**. Meshing Results a) Trailing Leaf Spring, b) Semi Elliptical Leaf Spring and c) Parabolic Leaf Spring
The boundary conditions used in the finite element analysis method lie in the geometry of the two ends of the eye on the leaf spring (Figure 2). The eye tip of the leaf spring used consists of an input parameter where all data has been fixed under a coordinate system that determines the location of the section axes.

![Boundary Condition](image)

**Figure 2. Boundary Condition**

3. Results and discussion

3.1 Equivalent stress

Figure 3 shows the simulation results of the equivalent stress of four different types of leaf spring. The stress equivalent of the trailing leaf spring is 121.45 MPa, the semi elliptical leaf spring is 182.79 MPa and the parabolic leaf spring is 76.042 MPa. The greatest stress value is generated in the semi elliptical leaf spring in the eye geometry. The eye geometry of the semi elliptical leaf spring requires increasing thickness to reduce stress levels on the surface[7]. The stress on the semi elliptical leaf spring lies in the geometry of the arm of the master leaf, this happens because the master leaf arm is the support for the stress concentration of the resulting load. Meanwhile, the parabolic leaf spring has the lowest equivalent stress because each leaf has a different length. The length of the spring affects the stiffness, as the length of the leaf increases, the stiffness of the spring decreases while the bending deflection increases[15]. Selection of good stiffness is related to the selection of an appropriate geometric structure. The geometry with which the long section is rolled must be chosen precisely, as it determines the stiffness of the spring[7]. In addition, it also affects the level of stress, which in turn has an influence on the strength of the fatigue leaf spring which is given. The right way of the right rolling process can significantly increase fatigue strength[16].

The selection of rolling lengths should be carried out in such a way as to obtain a relatively uniform stress distribution over the longest section [15]. In the rolling process, it should be noted that the rapid stress changes in the area result in stress consequences becoming fatigue cracks on the leaf spring[17].

The greater the stress that occurs, the lower the guarantee of safety and the greater the deflection. Deflection is a change in the position / shape of a material from its original form due to stresses [10]. Therefore, the magnitude of the stress and the point of loading affect the amount of deflection that occurs. This equivalent stress value suggests that the leaf spring can still support the large load for all designs[4]. Leaf springs of all types can withstand style and retain their original form and function.
3.2 Fatigue life

A constant amplitude load on stress life analysis by looking at the number of leaf spring cycles until fatigue failure occurs. Figure 4 shows the simulation results of fatigue life using the Godman theory approach. The trailing leaf spring has a minimum cycle of 35660 cycles, the semi elliptical leaf spring is 1,5897 $10^5$ cycles and the parabolic leaf spring is $10^6$ cycles. Parabolic leaf spring has high fatigue life because based on fatigue sensivity (Figure 5) it has passed the endurance limit value so that it can be concluded that it will not experience failure, whereas semi elliptical has a low fatigue life along with the results of the highest stress level [18].

Figure 5 presents the variation in the fatigue sensitivity value as a function of loading at critical locations on the leaf spring. Sensivity is generally used in finding life, damage or a factor of safety [4]. Figure 5 shows how the fatigue results change as a function of loading at the critical location in the model. This simulation aims to see the sensitivity of the model life if the load changes from 50% of the load to 150% of the current load. It can be seen from the figure that when the load is
increased by 150%, the lifespan of the trailing leaf spring is reduced to 36107 cycles, 8689.3 cycles of trailing leaf spring and $1.996 \times 10^6$ parabolic leaf spring cycles.

As can be seen, the greatest stress is on one of the first three leaves. This is not surprising since such leaf springs must withstand the greatest work stresses because they change shape the most when the springs are under bending loads [19]. In addition, in Figure 4 d the lowest fatigue life lies in the eye geometry. The eye is known to function as a stressor [6]. High stress with continuous fatigue load can lead to nucleation cracks[20]. The large difference in fatigue behavior among specimens due to the effect of eye geometry should be noted.

**Figure 4.** Fatigue liferesults a) trailing leaf spring, b) semi elliptical leaf spring and c) parabolic leaf spring
3.3 Safety of Factor

The safety factor is used to evaluate so that the safety of machine components is ensured evenly even though the dimensions used are minimum [14]. The safety factor in this study was based on the maximum equivalent stress. The use of maximum von Mises stress aims to identify the stress combination, namely the main stress (x, y, and z axes) and the maximum stress. The safety factor of the simulation calculation (Figure 6) shows that the minimum safety factor for the trailing leaf spring is 0.70977, the semi elliptical leaf spring is 0.47158 and the parabolic leaf spring is 1.1336. Semi elliptical has the smallest safety of factor value, this is in accordance with the largest generated stress. The greatest stress lies in the geometry of the eye so that the position has the lowest fatigue.
The results of the fatigue life design show the contour plot of fatigue damage. Fatigue damage is defined as design life rather than available life [21]. The resulting fatigue life is a safety factor against failure of fatigue. The resulting safety factor for the maximum value reaches 15, while the safety of factor value less than <1 indicates a failure before the design life is reached [4]. A safety of factor value > 1 is generated in the parabolic leaf spring, so it can be concluded that the parabolic leaf spring has a safe design and a higher fatigue life value.

4. Conclusion

Based on the simulation that has been done, it can be concluded that the high fatigue resistance is produced by the parabolic leaf spring with a cycle of $10^6$ cycles. Based on the graph of fatigue sensitivity, the value of fatigue life has exceeded the endurance limit so that the component will not experience failure before the design life is reached, this is also supported by the simulation results of the smallest stress generated and the safety factor value of 1.1336. A safety factor value that is > 1 indicates that the parabolic leaf spring has a relatively safe design.

Fatigue sensitivity in all three types shows that the cycle decreases when the load changes from 50% to 150%. The lowest cycle reduction is produced by the parabolic leaf spring with 1.996 $10^5$ cycles.

Trailing and semi-elliptical leaf springs have a relatively low fatigue life and based on the results of the safety factor, they are prone to failure. Failure is prone to occur in eye and master leaf geometry because the stress levels are the highest. The addition of thickness to the eye and master leaf geometry is necessary to reduce stress levels on the surface.
5. Reference

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