Development of leaf spring design in large vehicles made from material type 65 si7 using static analysis with reverse engineering

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Abstract. University of Indonesia Electric Bus was first developed using Hino R260 chassis. For further development, especially to fill out local content, it must be carried out engineering of its components. One of which will be discussed in this paper is the spring component. Reverse Engineering method is used to redesign in such a way. Measurement of the existing leaf springs in the chassis is done. The dimensions and number of leaf springs for the front and rear wheels of the chassis are produced. With CAD software and finite element analysis, a static analysis is performed on each of these springs. Front axle leaf spring arrangement consists of 8 spring sheets with dimensions of width 80 mm and thickness of 10 mm with stratified length. Rear axle leaf spring arrangement consists of 5 spring springs with dimensions of 90 mm width and 12 mm thickness with evenly distributed length. The theoretical stress on the front leaf springs is 512.74 MPa and finite element analysis is 531.5 MPa. The theoretical stress behind the leaf spring which occurs is 721.67 MPa and elemental analysis up to 728.4 MPa. The material for both of these springs is chosen is 65 si7 or SUP9.

1. Background
Before the issuance of presidential regulation No. 55 of 2019 which contains the acceleration of the battery-based motor vehicle program, Universitas Indonesia has conducted research on electric cars. Some types that have been launched in 2017 are City Car 01 to 03 and Electric Bus. These electric cars are innovations by FTUI lecturers and students who are members of the UI Molina Team. This research is about primary car electric design[1] at the University of Indonesia, energy optimization[2], chassis design[3], brakes[4][5], transmission[6] and steering systems[7][8]. The EV bus is a vehicle with a capacity of 60 passengers with motor power of 120 kW and 300 Ah. In the future this bus is expected to gradually be able to replace the overall function of the UI yellow bus as an internal transportation tool for the UI campus[9].

One of important structure in vehicle is chassis. At chassis is attached to components such as the transmission system, brake system and suspension system. The system on the chassis is very directly
influential on comfort when driving, stability and others[10], [11]. Static analysis on the ladder frame chassis[12][13][14] with any type of material[15] and various thickness [16] with FEA method[17] been done. While research on leaf springs is a static analysis of leaf springs just for light commercial vehicles[18], but for large vehicles still need challenges for research on this leaf spring.

In this paper, the author wants to explain the static analysis for leaf spring of the University Indonesia’s electric bus (large vehicle) by reverse-engineering method. The suspension system that was installed on this bus with type R260 is leaf spring. The goal is to analyze this type of suspension, the leaf spring, with the structure attached to this chassis. The material to be used is the standard material used for leaf spring. The material chosen is to see availability in the country, to fulfill local content as mandated by the president's degree.

2. Basic Theory: Leaf Spring

Leaf springs are springs that focus on strength so they can receive large loads. Springs are used using spring-epic springs; there are 5 springs in each wheel. The thickness of each spring sheet is around 28 mm. of different lengths. The spring sheet is joined using a bolt in the middle of the spring and clamp. At both ends of spring no. 1 or the longest spring made a hole as a mounting place on the frame hanger. Leaf springs are mounted on the side frame using 2 bolts and U plates. At both ends of the spring are given a special rubber coating to eliminate noise due to friction between the plates when the leaf springs are working to take the load, so that the rubber does not come loose then tighten.

![Figure 1. Component of leaf spring [18]](image)

The stress and deflection equation for leaf springs can be used the following formula:

\[
\sigma_{\text{max}} = \frac{pFL}{NBh^2}
\]

\[
\delta_{\text{max}} = \frac{qFL^3}{ENBh^3}
\]

Where the constants p and q are 3 for simple beam and 6 for fixed beam and N is the number of leaf spring sheets. Idealization of this equation is with assumptions like figure 2.

![Figure 2. Ideal for leaf springs[19]](image)
3. Methodology

3.1. Reverse Engineering
The University of Indonesia succeeded in converting conventional buses to electric buses (figure 3) through the National Electric Car (Molina) project in 2013. The chassis used on this electric bus still uses the R260 frame (figure 4) from one of the well-known bus brands today. This chassis frame consists of two main beams with four cross beams and two pipe beams. There are several systems on this bus vehicle that depend on this chassis, one of which is the suspension system.

![Universitas Indonesia’s electric bus](image3)

**Figure 3.** Universitas Indonesia’s electric bus

![Rolling chassis model of electric bus](image4)

**Figure 4.** Rolling chassis model of electric bus

**Figure 5.** Main dimension of EV-bus rolling chassis.

The chassis has a main size is 2380 for front overhangs, 6000 mm for wheel base and 3290 mm for rear overhangs (figure 5)
Figure 6. The leaf spring on rolling chassis parts are measured

The type of suspension system used in this chassis is a leaf spring and a shock absorber (figure 6). Measurement of the main dimensions, number and arrangement of leaf springs for front leaf spring and rear overhang are measured directly is one of the reverse engineering efforts on this suspension system.

3.2. Modeling with CAD software
The process of re-drawing with CAD software is done after all the dimensions of the leaf spring have been obtained. The results of this re-drawing can be seen in Figure 7 below.

Figure 7. Model 3D sub assembly leaf spring (a) front axle (b) rear axle

3.3. Material Selection
One of the mandates of the Presidential Decree No. 55 of 2019 is to increase local supply of electricity. Therefore, materials that will be selected according to code 65 si7 1095 with one of the products from PT. Krakatau Steel is a well-known producer of sheet steel or steel bars in Indonesia. Following are the mechanical and chemical properties of leaf material 65 si7 1095 obtained from various sources[20] (see Table 1).

Table 1. Mechanical and thermal properties of SUP9 material.

| Mechanical Properties | Thermal Properties |
|-----------------------|--------------------|
| Elastic modulus       | 190 GPa            |
| Poisson ratio         | 0.29               |
| Tensile strength      | 1225 MPa           |
| Yield strength        | 1080 MPa           |
| Shear modulus         | 73 GPa             |
| Melting point         | 1450 °C            |
| Specific heat capacity| 470 J/kg-K         |
| Thermal conductivity  | 48 W/m-K           |
| Thermal expansion     | 13 µm/m-K          |
The values of these 65 si7 material properties will be made as custom materials in finite element analysis with software computers.

![Material properties](image)

**Figure 8.** Input new material in CAD software

4. Result and Discussion

4.1. Determination of Load on Leaf Spring

For chassis analysis, it is modeled with a beam with two overhangs. The support of the chassis is on front and rear wheels. So the Chassis is a beam that is only supported with evenly distributed loads. The load acting on the entire beam range is 69651 N (from R260 data specifications). The length of the beam is 11670 mm, the uniformly distributed load is $69,651 / 11,670 = 5.9684$ N / mm. Now taking the reaction around the front wheels is 29,543.89 N and the rear wheels around 40,107.71 N[3]. Modeling of these forces on the front leaf spring and rear leaf spring can be seen in Figure 9 and Figure 10. The support model for leaf springs is modeled as a fixed support[19].
4.2. Meshing on Leaf Spring

Conducting the process of determining the type and size of loading and type of support on leaf springs has been completed at an early stage. Before conducting static analysis, the meshing process is an absolute thing to do to be able to do the finite element process properly and correctly. The form of meshing results for the rear leaf spring and front leaf spring can be seen in the following two figures (figure 11 and figure 12).
4.3. Static Analysis of Leaf Spring with CAD Software

The next step can be performed static analysis on CAD software. Contact modeling between leaf springs is assumed to be global in contact only. Looping is needed in this analysis, where if the comparison with the results of theoretically differs greatly, then the model of each leaf spring sheet will be improved. The following result for front and rear axle are displayed (see figure 13 and figure 14).
Figure 13. The results of finite element analysis of the front axle leaf spring

Figure 14. The results of finite element analysis of the rear axle leaf spring
The stress that occurs theoretically in the front leaf spring and the rear leaf spring can be calculated with the equation number (1) as follows:

\[ \sigma = \frac{pFL}{Nbh^2} = \frac{3Pl}{nbt^2} = \frac{3 \times 14.772 - 759}{80 \times 10^2} = 512.74 \text{ MPa (Front Axle Leaf Spring)} \] (3)

\[ \sigma = \frac{3Pl}{nbt^2} = \frac{3 \times 20.054 \times 777.3}{590 \times 12^2} = 721.67 \text{ MPa (Rear Axle Leaf Spring)} \] (4)

And the deflection that occurs theoretically in the front leaf spring and the rear leaf spring can be calculated with the equation number (2) as follows:

\[ \delta_{\text{max}} = \frac{qFL^3}{ENbh^3} = \frac{3 \times 14.772 - 759^3}{2 \times 10^{11} \times 80 \times 10^2} = 0.15 \text{ mm (Front Axle Leaf Spring)} \] (5)

\[ \delta_{\text{max}} = \frac{qFL^3}{ENbh^3} = \frac{3 \times 20.054 \times 777.3^3}{2 \times 10^{11} \times 590 \times 10^3} = 0.31 \text{ mm (Rear Axle Leaf Spring)} \] (6)

So, the safety factor that occurs theoretically in the front leaf spring and the rear leaf spring can be calculated with the equation as follows:

\[ F_s = \frac{\sigma_u}{\sigma} = \frac{1470}{512.74} = 2.87 \quad \text{(Front Axle Leaf Spring)} \] (7)

\[ F_s = \frac{\sigma_u}{\sigma} = \frac{1470}{721.67} = 2.04 \quad \text{(Rear Axle Leaf Spring)} \] (8)

From the calculation results above, the theoretical and analytical results using finite element software are not much different (see Figure 12 and Figure 13, as well as the two calculation results). The maximum deflection that occurs is relatively small at 0.15 mm for front axle leaf spring and 0.31 mm for rear axle leaf spring. The smallest safety factor that occurs is quite safe above number 2 for both leaf springs. Dimension results from both leaf springs with reverse engineering method, such as number of leaves, width and length from the results of direct measurement by reverse engineering can be used. By taking standard leaf spring material, the appropriate material is 65 si7 or SUP9. Hopefully this analysis can be used as a reference for domestic production of leaf springs for electric buses such as those owned by the University of Indonesia.

The development of further research is the possibility of developing the use of other types of springs for electric cars, especially buses. Air suspension is a more challenging type for this type of large bus. Air spring flexibility is better because the stiffness can be regulated in such a way as the air pressure contained therein. Researchers are very interested in continuing this research in the direction of air springs and may also be produced domestically.

5. Conclusion

After a static analysis of the two leaf springs (front and rear leaf spring), as one of the results of the reverse engineering process, it can be concluded several things, namely:

1. Front axle leaf spring arrangement consists of 8 spring sheets with dimensions of width 80 mm and thickness of 10 mm with stratified length.
2. Rear axle leaf spring arrangement consists of 5 spring springs with dimensions of 90 mm width and 12 mm thickness with evenly distributed length.
3. The theoretical stress on the front leaf springs is 512.74 MPa and finite element analysis is 531.5 MPa.
4. The theoretical stress behind the leaf spring which occurs is 721.67 MPa and elemental analysis up to 728.4 MPa.
5. The material for both of these springs is chosen is 65 si7 or SUP9.
6. The smallest safety factor that occurs above number 2.
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