Mode Shape Analysis of EV-Bus Chassis with Reverse Engineering Method

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Abstract. Universitas Indonesia has developed several electric vehicles, one of which is an electric bus. In order to fulfill the local content of this vehicle, reverse engineering of the R260 ladder frame type chassis is carried out. In this paper, to fulfill the local content, we used material of the ladder frame is type SS400 from PT. Krakatau Steel. After the model was created successfully with finite element software, a dynamic analysis was carried out by taking the 5 lowest frequencies from the simulation results. Loading is carried out evenly over the two main beam ladder frames totaling 14,200 kg. The support placed in the mounting position of the front and rear wheel leaf springs. The distance of the front overhang is 2380 mm, the wheelbase is 6000 mm, and the rear overhang is 3290 mm. The resulting approach is carried out assuming a three-beam and two-overhang beam model. The five lowest frequencies are 11,798 Hz, 21,009 Hz, 23,876 Hz, 30.84 Hz, and 36,473 Hz, respectively.

1. Background
Development of electric cars (Electric Vehicle, EV) in Indonesia, according with Presidential Decree No. 55 of 2019 concerning the Acceleration of the Battery-Based Electric Motor Vehicle Program for Transportation, which is in the context of energy efficiency and energy security and to realize clean air quality. The use of electric cars can increase the efficiency of energy use from batteries to wheels above 77% compared to hybrid cars 38% and cars with internal combustion (ICE) only 25% [1-4]. The high level of efficiency in electric cars because the distribution of energy from the power source to the wheels has a relatively low level of energy loss.

Universitas Indonesia, UI, launched an electric car based on the 52nd anniversary of the Faculty of Engineering UI on Monday (7/18/2017) at the Faculty of Engineering, UI Campus Depok. There were four electric cars displayed at this event, namely Bus Electric Vehicle (EV), Makara Electric Vehicle (MEV) 01, City Car MEV 02, and City Car MEV 03. These electric cars are innovations by FTUI lecturers and students who are members of the UI Molina Team. 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[5].

Car chassis is a significant component and is very important, where the chassis is supporting the axle, steering to adjust the direction of the vehicle, wheels, tires, and brakes to stop the vehicle when walking. The system on the chassis is very directly influential on comfort when driving, stability and others [6,7]. Static analysis on the chassis and dynamic ladder frame chassis has been done [8-15].

In this paper, the author wants to explain the mode shape analysis for the structure of the University Indonesia’s electric bus chassis by reverse-engineering the ladder frame that was installed on this bus with type R260. The goal is to find the first five vibrating modes by simulating chassis material, which is the SS400 type produced by PT. Krakatau Indonesia. This modal analysis is essential to avoid resonance due to some interference from the engine and other rotating components mounted on the chassis having the same frequency as the frequency of the mode shapes.
2. Basic Theory: Vibrate Mode of Continuous Beam System with One or Two Overhangs

The characteristic equation for a Bernoulli overhang beam with density per unit length \( \rho(x) \), with stiffness elasticity, \( r(x) = EJ(x) \) for a range of 0 to 1 can be written in the equation: [16]

\[
[r(x)u^n(x)]^n = \omega^2 \rho u(x)
\]  

where \( \omega \) is a personal frequency, \( u(x) \) is a displacement mode that corresponds superscript is a derivative of \( x \). Footing conditions with three stretches and with two overhangs like the following figure 1.

\[
\begin{align*}
0 & \quad d_1 & \quad d_2 & \quad l \\
\end{align*}
\]

**Figure 1.** Beam with two supports and three spans [16]

The boundary conditions for this beam are: [16]

\[
\begin{align*}
\frac{r(0)u'(0)}{u'(0)} = 0, & \quad \frac{[r(x)u'(x)]'}{x=0} = 0; \\
\frac{r(l)u'(l)}{u'(l)} = 0, & \quad \frac{[r(x)u'(x)]'}{x=l} = 0;
\end{align*}
\]

and

\[
\begin{align*}
& u(d_1^+)) = u(d_1^-) = 0, \\
& u'(d_1^+) = u'(d_1^-), \\
& r(d_1^+)u'(d_1^+) = r(d_1^-)u'(d_1^-), \quad (i = 1, 2; \quad 0 < d_1 < d_2 < l)
\end{align*}
\]

Here are the various vibration mode shapes of one bar with two overhangs.

\[
\begin{align*}
\text{(a)} & \quad \text{First and second modes of mathematical models, (b). First and second displacement modes, (c) first and second rotation modes, (d), first and second bending moment modes, (e) first and second shear force modes [16]}
\end{align*}
\]
3. Methodology

3.1 Reverse Engineering
The University Indonesia’s electric bus, like Figure 3 uses R260 chassis (figure 4), using the reverse engineering method to get the dimensions of this chassis with the main dimensions, as in figure 5. The type of the R260 chassis is a ladder frame with two main beams and four cross member beam and two cross pipe beam.

![Figure 3. Universitas Indonesia’s Electric Bus](image)

![Figure 4. Rolling Chassis Model of Electric Bus](image)

![Figure 5. Primary Dimension of Rolling Chassis Electric Bus.](image)

From Figure 5, it can show that dimensions of the front overhangs are 2380 mm, the wheelbase is 6000 mm, and the rear overhang is 3290 mm.
The reverse engineering process is carried out by measuring the main parts of this electric bus chassis as shown in figure 6.

3.2 **Modeling with CAD software**
After all, dimensions have obtained, a redrawing using CAD software is carried out with the following results, as can be seen in figure 7.

3.3 **Material Selection**
As a commitment to increase the local content of Indonesian electric cars, the material selection is carried out in such a way by using the production of PT. Krakatau Steel with SS400 code. Following are SS400 material properties from PT. KS and from several other sources.
Figure 8. Material SS400 from PT. Krakakatau Steel
Process of inputting material properties into the material menu in the CAD software can be seen in figure 9.

![Material Input of CAD Software](image)

**Figure 9. Material Input of CAD Software**

### 3.4 Chassis Model of Ladder Frame

From the CAD rolling chassis model in Figure 5, an analysis is carried out on the ladder frame chassis with the shape as shown in figure 10.

![Model Ladder Frame Chassis Electric car Universitas Indonesia](image)

**Figure 10. Model Ladder Frame Chassis Electric car Universitas Indonesia**

### 4. Result and Discussion

#### 4.1 Determination of Load and Support in Chassis

In Figure 5, where the support was placed on the mounting front-wheel springs and rear-wheel springs. While the load was given in the form of an even distribution along the two main beams of the chassis for a total Gross Vehicle Weight (GVW) = 14200 kg, which is in accordance with the specifications of the R260 rolling chassis. The following form of the support and the load on CAD modeling.
4.2 Meshing on Chassis Ladder Frame
After modeling of support and loading and material selection in the previous stage, before finite element analysis is carried out to determine the vibrational mode of Universitas Indonesia's electric car chassis meshing is performed on the CAD software. The meshing results can show in the following figure.

Figure 11. Support and Load Mode of Universitas Indonesia’s Electric Bus

Figure 12. The meshing of Chassis Frame (Front Section)  Figure 13. The meshing of Chassis Frame (Middle Section)

Figure 14. The meshing of Chassis Frame (Rear Section)

4.3 Mode Shape Analysis
The next step can be performed mode shape analysis from dynamic analysis on CAD software. The following 5 first vibrate mode are displayed.
The shape mode as shown in Figure 15, up to Figure 19 has been equivalent to the theoretical mode shapes as shown in Figure 2. In the first mode seen in Figure 14, the rear overhang experience deflection first, because the rear overhang distance is 3290 mm longer than front overhang distance is 2380, where there is no cross member beam as a stiffener between that distance. The second module
that experiences more significant deflection is the distance between the two axes (wheelbase) with a distance of 6000 mm, although there is already a cross member beam in between. The third vibration mode occurs in the front overhang, with the most significant deflection in the forward direction upwards. The fourth vibration mode occurs again in the rear overhang with deflection downward direction, while the fifth vibration mode occurs in the rear overhang in the form of a twist between the two main beams of the ladder frame. Further research can be done by adding a cross member beam at the rear overhang because, in this section, mounting will be made to the holder of the electric motor as the rear-drive of this electric bus.

5. Conclusion
The conclusion that can be obtained from the mode shape analysis of the Universitas Indonesia’s electric ladder frame bus chassis are:
1. The material used is Krakatau Steel SS400 type steel with ladder frame structure model
2. The total workload distributed to the chassis structure with a total of 14,200 kg
3. The model approach used is a beam with two overhangs.
4. Front overhang distance is 2380 mm, wheelbase 6000 mm, and rear overhang 3290 mm.
5. The mode shapes from 1 to 5 with the lowest frequency of 11.798 Hz, 21.009 Hz, 23.876 Hz, 30.84 Hz, 36.463 Hz.

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