Design and static testing of electric vehicle chassis trike front-wheel drive

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Abstract. Compared to conventional vehicles, the advantages of electric vehicles are more significant acceleration, no exhaust emissions, making electric vehicles more environmentally friendly, minimal maintenance because there are not many components used in electric cars. This research method is used to develop the chassis design of an electric trike, and then the chassis design is analysed using Solidworks software. The chassis with a thickness of 2.4 mm weights 29.6 kg with a maximum value of stress, displacement, strain, and other factors. Safety as follows: 7,582 x 10^7 N/m^2, 2,567 mm, 3,368 x 10^-4 and 3.5, 2 mm thick chassis weighs 25 kg with maximum stress, displacement, strain, and safety factor values as follows: 1.079x10^8 N/m^2, 3.160 mm, 3.981 x 10^-4 and 2.5 then the chassis thickness of 1.6 mm weights 20.3 kg with the maximum stress, displacement, strain, and safety factor values as follows: 1.809 x 10^8 N/m^2, 4.190 mm, and 9.388 x 10^-4. Chassis with a thickness of 2 mm using a rectangular tube and ASTM A53 material has a safety factor value that is by the requirements and the maximum stress value on the chassis does not exceed the allowable stress value and weight.

1. Introduction
An electric car is a car that is driven by an electric motor using a source of electrical energy stored in a battery. Amjad stated that electric cars have received a lot of attention in the modern world because of their economic and environmental advantages [1]. Compared to conventional cars, the advantages of electric cars are more excellent acceleration, no exhaust emissions, making electric cars more environmentally friendly, minimal maintenance because there are not many components used in electric cars. In Indonesia, many electric car products have been made, such as the Tucuxi electric car, made in 2012 (Electric Car manufacturer, LLC). Electrical Car, LLC is an electric transportation development company in Michigan, America. Selo electric car made in 2013 (designer Ricky Elson), Genghis electric car made in 2013 (butterfly night manufacturer). PT developed the electric bus. MAB (PT. Mobil Anak Bangsa), the company, is developing an electric bus that is expected to be used as public transportation that is environmentally friendly and has zero pollution (no pollution).

The design of an electric car for limited lines is made as efficient as possible by considering the availability of user materials on the market, the capacity of the electric car, the strength of the chassis design, and the safety factor. The electric car design will be made into a trike model, namely a three-wheeled car with only one wheel. The trike model was chosen as the suitable model because it will use a wheel motor placed on the front wheel, an uncomplicated construction design, and better maneuverability. The wheel drive system that is applied uses the FWD (Front Wheel Drive) system because the wheel motor is placed in front; the FWD system is a driving system for vehicles with the front wheels as the driving force. The drive system will use in-wheel motor technology, the latest
technology as a wheel drive component of electric cars. An in-wheel motor is a motor that has become an integral part of the wheel so that it does not require other mechanics to connect the electric motor to the drive wheel. The use of in-wheel motor components in FWD trike electric cars is one of the superior technologies in FWD trike electric cars. The motor wheel can reduce the power lost due to shifting the transmission on the vehicle. The specifications of the components in the motor wheel are a maximum power of 800 watts, a maximum speed of 60 km/h, which is equipped with a battery as a power input with a Lithium-ion battery type (60v 20AH).

The design and chassis size are taken from measurements adjusted to the number of passengers and the components installed in the electric trike car. The materials used in the design of the chassis are rectangular iron tubes measuring 40 mm 80 mm with variations in the thickness of 1.6 mm, 2 mm, and 2.4 mm and rectangular tubes measuring 40 mm 60 mm with variations in the thickness of 1.6 mm, 2 mm and 2.4 mm made of carbon steel. The chassis design of the FWD electric trike car only has a capacity for two people. The design results will be tested statically using software to determine the strength of the chassis design and the factor of safety. Before designing the chassis, several things must be considered as a design reference; here are some general considerations described by Dahlan [2], (1) Types of loads and stresses caused by loads, (2) Types of component movement, (3) Type of material, (4) Shape and size of components, (5) Ergonomics, (6) Safety of operation, (7) Cost.

The manufacture of the "Ababil" prototype electric car chassis was carried out using an aluminum alloy 6036-T6 square tube material. Chassis static design and simulation using Solidworks premium 2016 software. From the design results, the overall dimensions of the "Ababil" prototype electric car chassis are obtained, namely length = 2300 mm, width = 620 mm, height = 538 mm, and a total load of 1059.48 N. Stress simulation results analysis obtained maximum stress = 2.15 107 N/m2, maximum deflection = 1.31mm and factor of safety = 2.6.

Then the design of the electric car made by Setyono and Gunawan, used the Autodesk Inventor software [3], namely the "Smut Abang" electric car. In Setyono, the data obtained from the design are the dimensions of the chassis of the electric car [3] "Smut Abang" ITATS (Adhi Tama Institute of Technology Surabaya), which has a length = 2134 mm, width = 623.5 mm, height = 711.5 mm. Then the results of stress analysis obtained maximum stress of 108.8 Mpa. The maximum displacement value that occurs is 0.7136 mm, and the factor of safety is 2.53.

A trike is a vehicle that has three wheels, where the front wheel has only one wheel. Trike models are often found in tricycle designs that are usually used for children. This design has a good balance and is easy to ride, which is why this design is often found in children's bicycle models. A UNNES student used the trike model to manufacture a microcar, which is significantly superior to the trike design, namely the design of the steering system construction, which is not complicated.

A reverse trike is a vehicle with three wheels where the front wheel has two wheels, and this design is the opposite of the Trike model. This design has a nice balance. It is just that the steering will feel different because, in this model, we will control two wheels. The Reverse Trike model can be found in electric cars made by Toyota, which are named i-Road. Toyota's i-Road electric car has a sleek model that is expected to get through traffic jams. The drawback of this model is the design of the steering system, which is more complicated than the trike model because, in this model, the steering system moves two wheels. Here is a picture of the Toyota i-Road, which is a 3-wheel reverse trike car. The chassis is an essential part because it works as a support for the load vehicle [4]. According to Setyono and Gunawan, the right chassis design will provide optimal results between the level of security and construction size [3].

2. Methods
This research method is used to develop an electric trike chassis design. research and development methods are research methods used to produce certain products and test the effectiveness of these products [5]. Then the chassis design is analysed using Solidworks software. In the early stages of design, a plan will be produced by the specified specifications. The next stage will be an analysis of stress, strain, displacement, and factor of safety resulting from the static test of the Solidworks software, which then obtains the characteristics that match the requirements. The chassis design designed on the
FWD trike electric car is the trike model, where the car only uses one wheel for the front and two wheels for the rear. Solidworks is software that solves problems through the application of the Finite Element Method (FEM) [6]. FEM is used to predict or analyse stresses and deformations in a structure due to loading [7-9]. The size of the chassis is based on the needs and capacity of the user and the adjustment of the components to be installed on the chassis. The constituent material on the chassis uses carbon steel material with a rectangular tube type. The following is a specification of the size and type of material used in the chassis.

The material used in the chassis design is a rectangular tube with variations in the thickness of 2.4 mm and sizes 40 mm, 80 mm, and 40 mm 60 mm. The type of material used is ASTM A53, the material used in the chassis design is a rectangular tube with variations in the thickness of 2 mm and sizes 40 mm, 80 mm, and 40 mm 60 mm. The type of material used is ASTM A53, and the material used in the chassis design is a rectangular tube with variations in the thickness of 1.6 mm and sizes 40 mm, 80 mm, and 40 mm 60 mm. The type of material used is ASTM A53. Each chassis is illustrated in Figure 1 to Figure 3.

![Figure 1. Chassis material with a thickness of 2.4 mm](image1)

![Figure 2. Chassis material with a thickness of 2 mm](image2)

![Figure 3. Chassis with a thickness of 1.6 mm](image3)

The flow chart in the study aims to facilitate the implementation of research by clarifying the stages of the investigation, shown in (Figure 4). This study aims to develop an electric trike chassis design. The following is a research flow chart:
Study of literature is carried out to learn about the design that will be carried out, look for good chassis design references, and find references for a sturdy chassis construction arrangement. From the literature study, this design will apply the type of ladder frame chassis construction, and this application is carried out because the ladder frame type is easy to make, and the ladder frame chassis type is considered efficient for designing FWD trike electric cars. Before starting the design on the software, the steps taken are to plan the total load received by the chassis and determine the type of material used in the chassis design. The complete data are as in Table 1.

Total load planning data that will work on the chassis

**Table 1. Chassis load planning**

| Load Type   | Weight (kg) |
|-------------|-------------|
| 2 Passengers| 150         |
| Battery     | 30          |
| Luggage     | 30          |
| Body        | 10          |
| Accessories | 10          |
The use of the material in a design is determined based on the needs, for the material used in the chassis construction uses carbon steel with the ASTM A53 code. ASTM A53 material is a type of material that is ductile or elastic where this property will stretch and deform before fracture. ASTM (American Society for Testing and Materials) is an international organization that develops technical standards for materials, products, systems, and services based in the United States. Specifications of ASTM A53 material can be seen in table 2.

| Mechanical Properties | Value   | Units  |
|-----------------------|---------|--------|
| Yield Strength        | 3.01 x 10^8 | N/m²   |
| Density               | 5.260   | Kg/m³  |
| Young Modulus         | 2.1 x 10^{11} | N/m²  |

Carbon steel material was chosen because it has greater strength and resistance. Denny et al explains that carbon materials are easily formed in complexes, have good material strength and have resistance to damage [10]. There are three types of carbon steel, namely low carbon steel, medium carbon steel, and high carbon steel. Low carbon steel has a carbon element content of 0 - 0.25%, medium carbon steel has a carbon element content of 0.25% - 0.55% and high carbon steel has a carbon element content above 0.55%[11]. The data sampling point on the chassis is taken from the point that is assumed to receive a high-stress value from each variation. What took the data sampling points four points from each type of chassis variation. These points were named points A, B, C, and D for convenience. Point A is the point in front of the chassis support stand; point B is the side connection point with the chassis neck, the point is the connection point for the chassis neck, point D is the connection point for the rear chassis construction with the center chassis construction. More details for the data sampling point will be shown in an image. The software used to design and perform static tests is Solidworks 2016. Software Solidworks is a design and simulation software that is easy to operate. The design image will be a 3D image created using Solidworks software. In this study, there are three independent variables, variables, and control variables; independent variables affect or cause changes. Figure 5 and Figure 6 describe the location of the data sampling point on the chassis.

In the figures above, purple arrows indicate the load acting on the chassis. The load planning is divided into 40% at the front of the chassis and 60% at the rear of the chassis. The working load is 920
N for the show, 1,380 N for the end; then for the back, it is divided into two, namely the right side and the left side of each side of 690 N. The load is increased twice to anticipate the occurrence of bumping, so the force acting on the chassis during the static test simulation was 1,840 N for the front of the chassis and 1,380 N for the rear of the chassis.

The load given to the pack is the passenger’s weight, the weight of the battery, the weight of the luggage, the weight of the body, and the weight of the accessories. The importance of the chassis in the design when testing is already listed. Therefore, it does not need to be included during the static simulation. The static simulation illustration of a rectangular tube below with ASTM A53 material with the following length, width, and height: 20,000 mm 40 mm 80 mm and thickness variations of 1.6 mm; 2 mm and 2.4 mm are proof that the program has included its weight. Therefore, there is no need to give the object weight (own weight) during static simulation. Figure 7 and Figure 8 are illustrations that the program has directly entered its weight.

![Figure 7. Illustration own weight of thickness 1.6 mm](image)

![Figure 8. Illustration own weight of thickness 2 mm](image)

![Figure 9. Illustration own weight of thickness 2.4 mm](image)

3. Results and Discussion
The chassis design and electric car concept are made in 3 dimensions. It is done so that the invention can be tested statically using Solidworks software. The results of the measurement of the dimensions of the chassis in the image below obtained the following data:
1. Chassis length = 1,238.03 mm
2. Chassis height = 591.18 mm
3. Chassis width = 1,004 mm
The chassis design produces different weights for each variation, along with the chassis of each variation as given in Figure 10.

1. The chassis variation of 2.4 mm produces a weight of 29.6 kg.
2. The chassis variation of 2 mm results in a weight of 25 kg.
3. The variation of the 1.6 mm chassis produces a weight of 20.3 kg.

The chassis design of the electric trike front-wheel-drive car produces a centre of gravity, revealed in Figure 11.

The results of measuring the dimensions of the FWD trike electric vehicle concept in the image below obtained the following data:

1. Distance between two wheelbases = 1,792.83 mm
2. Ground clearance = 167.98 mm
3. Car length = 2,234.69 mm
4. Car width = 1,070.98 mm

The chassis designed and statistically simulated with optimal results will be used for FWD electric trike cars. There are three variations of the material used for the simulation. Next, the third variation will be compared with a good thickness variation to use. Stress values take from several points on the chassis; more details will be presented in table 3. Data retrieval was carried out on the three variations of the chassis thickness, namely the thickness of 2.4 mm, 2 mm, and 1.6 mm. The data collection results will display a graph of the comparison of the stress values of each variation in the thickness of the chassis. The following is a table of stress values from sampling data at points A, B, C, and D.
Table 3. Stress values from data sampling at points A, B, C, and D.

| Sampling Point | Stress Value (N/m²) | Thickness Variation |
|----------------|---------------------|---------------------|
| 2.4 mm         | 6.503 x 10⁷         | 8.833 x 10⁷         | 1.157 x 10⁸         |
| 2 mm           | 1.034 x 10⁷         | 4.276 x 10⁷         | 7.366 x 10⁷         |
| 1.6 mm         | 5.845 x 10⁷         | 7.473 x 10⁷         | 1.318 x 10⁸         |

3.1 Simulation Test Result Data
The data from the Chassis static simulation are shown in Table 4 to Table 7.

Table 4. Stress Value Result from Static Simulation Test

| Thickness Variation | Stress Value (N/m²) |
|---------------------|---------------------|
| 2.4 mm              | 7.582 x 10⁷         |
| 2 mm                | 1.079 x 10⁸         |
| 1.6 mm              | 1.809 x 10⁸         |

Table 5. Displacement Value Results from Static Simulation Test

| Thickness Variation | Displacement Value (mm) |
|---------------------|--------------------------|
| 2.4 mm              | 2.567                    |
| 2 mm                | 3.160                    |
| 1.6 mm              | 4.190                    |

Table 6. Strain Values from Static Simulation Tests

| Thickness Variation | Strain Value |
|---------------------|-------------|
| 2.4 mm              | 3.368 x 10⁻⁴ |
| 2 mm                | 3.981 x 10⁻⁴ |
| 1.6 mm              | 9.388 x 10⁻⁴ |

Table 7. Value of Factor of safety Results from Static Simulation Test

| Thickness Variation | Factor of safety Value |
|---------------------|------------------------|
| 2.4 mm              | 3.5                    |
| 2 mm                | 2.5                    |
| 1.6 mm              | 1.3                    |
The data obtained is the result of static simulation testing on the Chassis using variations in the thickness of the Chassis constituent materials. The load is acting on the Chassis is a $2x$ normal load with a load sharing of 40% for the front and 60% for the rear. The stand is taken at the point between the two wheelbases. The distance between the two wheelbases is 1792.83 mm. Earth's gravitational acceleration is $10 \text{ m/s}^2$. The chassis composition materials are 40 mm, 80 mm, and 40 mm, 60 mm, with variations in the thickness of 2.4 mm, 2 mm, and 1.6 mm. The material used is carbon steel ASTM A53.

3.2 Discussion of Simulation Results
The discussion of the simulation results explains the data that has been obtained.

1. Comparison of the allowable stress value with the maximum stress on the chassis pad. From equation (2.1) in the previous discussion, get the allowable stress value with the following calculation:

$$\frac{301.000.000}{2} = 150.000.000 \text{ N/m}^2$$

$$= 150 \times 10^6 \text{ N/m}^2$$

The allowable stress value with ASTM A53 material type from the above calculation is $150 \times 10^6 \text{ N/m}^2$. When compared, the maximum stress values for each chassis variation from a thickness of 2.4 mm, 2 mm and 1.6 mm are: $150 \times 10^6 \text{ N/m}^2 > 7.582 \times 10^7 \text{ N/m}^2$, $150 \times 10^6 \text{ N/m}^2 > 1.079 \times 10^8 \text{ N/m}^2$, dan $150 \times 10^6 \text{ N/m}^2 < 1.809 \times 10^8 \text{ N/m}^2$. Comparing the allowable stress value with the maximum stress value for each variation shows that the variation of 1.6 mm exceeds the allowable stress value, so the variation of 1.6 mm does not qualify as an optimal chassis.

2. Weight Comparison Graph of Each Chassis Variation
From the chassis design results, the weight of each variation is then visualized in the form of a graph to facilitate the comparison of each value generated. Figure 13 is a graph of the weight comparison of each chassis variation.

![Figure 13](image)

**Figure 13.** Chassis weight comparison chart for each variation.

3.3 Graph of Data Sampling Stress Value of Each Chassis Variation
The simulation results produce some data, and then it can be visualized in the form of a graph to facilitate the comparison of each value generated. Figure 14 is a graph of the comparison of the stress sampling data values for each chassis variation.
From the graph above, we can see that the highest stress value is shown in the thickness variation of 1.6 mm, and the lowest is shown in the 2.4 mm variation.

3.4 Comparison Graph of Maximum Stress Value of Each Chassis Variation
From the results of the simulation, several data are produced and then can be visualized in the form of a graph to facilitate the comparison of each value generated. Figure 15 is a graph of the comparison of stress values for each chassis variation:

**Figure 14.** Comparison graph of the stress value of the sampling point of each variation

**Figure 15.** Graph of the comparison of the maximum stress value of each variation
3.5 Comparison Graph of Maximum Displacement Value of Each Chassis Variation
The simulation results produce some data, and it is visualized in the form of a graph to facilitate the comparison of each value generated. Figure 16 is a comparison chart of the displacement values of each chassis variation.

![Graph of Maximum Displacement Value of Each Chassis Variation](image)

**Figure 16.** Graph of Maximum Displacement Value of Each Chassis Variation

From the comparison graph of the maximum displacement value, the highest value is 1.6 mm and the lowest is 2.4 mm.

3.6 Comparison Graph of Maximum Strain Value of Each Chassis Variation
From the simulation results, it produces some data and then it can be visualized in the form of a graph to facilitate the comparison of each value generated. Figure 17 is a graph of the comparison of the strain values of each chassis variation.

![Comparison graph of the maximum strain value of each variation](image)

**Figure 17.** Comparison graph of the maximum strain value of each variation

From the comparison graph of the maximum strain value above, it can be seen that the highest value is found in a variation of 1.6 mm and the lowest value is found in a variation of 2.4 mm.
3.7 Comparison Graph of Factor of Safety Value of Each Chassis Variation

From the simulation results, it produces some data and then it can be visualized in the form of a graph to facilitate the comparison of each value generated. Figure 18 is a graph of the comparison of the factor of safety values for each chassis variation.

![Comparison graph of factor of safety value for each variation](image)

**Figure 18.** Comparison graph of factor of safety value for each variation

The comparison graph of the Factor of safety value above can be seen that the highest value is found in the variation of 2.4 mm, and the lowest value is found in the interpretation of 1.6

4. Conclusion

The simulation results carried out on the front-wheel-drive trike electric car chassis using Solidworks software can be said: (1) The chassis with a thickness of 2.4 mm weighs 29.6 kg with a maximum value of stress, displacement, strain, and other factors. Safety as follows: 7,582 x 10^3 N/m², 2,567 mm, 3,368 10^4 and 3.5, 2 mm thick chassis weighs 25 kg with maximum stress, displacement, strain, and safety factor values as follows: 1,079x10^8 N/m², 3.160 mm, 3,981 10^{-4} and 2.5 then the chassis thickness of 1.6 mm weighs 20.3 kg with the maximum stress, displacement, strain, and safety factor values as follows: 1.809 x 10^8 N/m², 4.190 mm, 9,388 10^{-4} and 1.3. It can be said that the chassis with a thickness of 1.6 mm does not meet the requirements because the maximum stress exceeds the allowable stress value. Then for the chassis with a thickness of 2.4 mm seen from the simulation results that it is too strong or too rigid and the method used in the simulation (inverted mode with a centre fulcrum) is suitable for testing the chassis, (2) Chassis with a thickness of 2 mm using a rectangular tube and ASTM A53 material has a safety factor value that is by the requirements and the maximum stress value on the chassis does not exceed the allowable stress value and weight.

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