Static Simulation of Electric Tilting Tricycle Frame Structure Using The Finite Element Analysis

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Abstract. Electric Tilting Tricycle is a three-wheeled vehicle that has tadpole configuration driven by two sources of motion, that motion by a manual pedal and power from an electric motor. The three-wheeled vehicle has better stability and the tilting system improves ergonomics at curves. This research aims to design and analyze the strengths frame with three different materials using the Autodesk inventor software. By using the Stress Analysis feature that comes with the method of finite element analysis (FEA), we can know the result of von misses stress, displacement, strain, and safety factor. The main consideration of structural strength was seen from the distribution of static loads using three types of materials (Aluminium 6061, Steel Mild and CFRP). The minimum factor of safety resulting from the design simulation was estimated to be 1.83 using steel mild material.

Keywords: Electric Tilting Tricycle, frames, Finite Element Analysis

1. Introduction

A three-wheeled vehicle can be alternative transportation that provides a higher level of safety because of its stability is equivalent to a four-wheeled vehicle with smaller dimensions. Three-wheeled vehicles with two-wheel configuration in front and one behind are also called tadpoles. The technology in this type of vehicle that can be implemented is tilting system. The tilting system on the tadpole increases the stability and comfort of driving, especially when around corners. When cornering using a tadpole that has a tilting system the driver does not feel the force caused by the force of gravity, centripetal acceleration, and torque from the tilting. When the tilting system works, the resultant direction of the force is perpendicular to the axis of the driver's body, that the lateral acceleration is less pronounced by the driver when turning.[1-2,7] Engineers are currently developing energy sources that are friendly to the environment with renewable sources, one of the sources is electrical energy. The application of electrical energy to a bicycle can reduce the energy needed to pedal a bicycle and cut the time taken. [2-3]

The finite element method is a numerical approach using digital computing. With the advent of high-speed and large-capacity digital computers, FEA is increasingly being used throughout the industry as a practical analysis solution for designs with high complexity.[3-6] This means the design with an unusual shape, can be solved with this method. Also, FEA can resolve the conditions of heterogeneous materials. (Syehan, 2019)

2. Methods
2.1. Component Design and Assembly
The first step of this study was to make a design using Autodesk Inventor 2018 software to make the frame shape of the electric tilting tricycle. One of the things to consider in the design of the elements was the contacts of each tube of the frame. In the present study, the parameters considered were the design of the frame and the materials used without the effect of welding. Because of that reason, all of the tubes were assumed as single element without using weld as a joint.

![Figure 1. Electric tilting tricycle components.](image1)

The assembly process was a process of assembling the elements of the electric tilting frame that contain mainframe, suspension mounting, swingarm bushing, and swingarm. The important thing in the assembly process is the type of joint between the elements. Six types of joint provided by Autodesk Inventor namely rigid, rotational, slider, cylindrical, planar, and ball. In the present study, only two types of joints used to make the design represented the actual electric tilting tricycle frame. The elements to be assembled with the rigid joint was suspension mounting to mainframe and the rotational joint was swingarm to mainframe. Since it was a static simulation and to simplify the simulation, the suspension assumed as a rigid element.

2.2. Constraints and Load in Assembly
In present studies, the types of constraints used in the simulation of electric tilting tricycle design were fixed and pin. The use of fixed constraint is located at the rear of the swingarm which is used as the rear wheel shaft and also on the head tube that will be connected to the tilting system of the bicycle. These constraints were used to represent components not included in frame design. In the simulation, the fixed constraint of the rear axle shaft will give a reaction force from the load given by the wheels, as well as the head tube section which gives the reaction of the front wheel. Whereas the pin constraint is used at the joint between the swingarm and mainframe, this makes one degree of freedom at that point which limiting motion when the joint is given by reaction force of the rear wheel and the load of the driver on the seat tube.

![Figure 2. Constraints used on the electric tilting tricycle frame.](image2)

![Figure 3. Load on the electric tilting tricycle frame.](image3)
In the electric tilting tricycle stress analysis study there were three loads (the rider’s, electric motor, and battery). The electric tilting tricycle design can withstand rider’s and luggage with a total mass of 90 kg (rider’s load 82 kg and the 8 kg load luggage) located on the seat tube, pedal and also the handlebar. For the rider’s, based on the present study, the rider’s loads would be distributed to several points on the elements of the electric tilting tricycle, i.e. 50% on the seat tube, 100% on the pedals, and 44% on the handlebar.[1] The features used in the simulation of the tricycle frame were force, remote force, and gravity. The force feature was used to represent the driver's load on the seat tube and pedal. Besides, the force feature is also used to define the motor and battery located on the mainframe. Remote force was represented the load of the rider’s on the handlebar. Since the handlebar was not included in the assembly frame components, so it defined using the remote force feature. The gravity force was used to define the direction of gravity on the tricycle with a magnitude of gravity was 9.81 m / s².

2.3. Mesh Process
In the present study, the size of elements was adjusted to the capabilities of inventor stress analysis for the best results of the simulation with an average size of 0.05 and the smallest size of the element 0.10. Next thing to arranged was the grading factor, with the amount set to the smallest size of 1.5. In addition, the maximum turning angle of the element is adjusted to the design of the bicycle which has curved tubes with the largest turning angle of 45° to maximize stress analysis on the tricycle frame.[6]

2.4. Material Selection
In the present study, there were 3 different materials selected as a comparison of the results of each stress analysis of the object. the material used is a material commonly used on bicycle frames. Following are the mechanical properties of the material used:

| Table 1. Material properties. |
|-----------------------------|
| Al 6061 | Steel mild | CFRP |
| **Elastic Modulus** | 68.9 GPa | 220 GPa | 133 GPa |
| **Poisson’s Ratio** | 0.33 | 0.28 | 0.39 |
| **Shear Modulus** | 26 GPa | 82 GPa | 53 GPa |
| **Mass Density** | 2.7 g/cm³ | 7.85 g/cm³ | 1.75 g/cm³ |
| **Tensile Strength** | 310 MPa | 367 MPa | 577 MPa |
| **Yield Strength** | 276 MPa | 306 MPa | 550 MPa |

3. Results and discussion

3.1. Results of Frame Design Simulation Using the Steel Mild Material
The results of the static simulation were Von misses stress, deformation, safety factor, and strain. Based on the simulation results, the maximum value of Von misses stress is 113 MPa located in the middle of the seat tube. The maximum stress value that occurs due to the load given by the rider’s on the seat tube with 0.814 mm deformation at the maximum Von misses stress value.
The maximum deformation occurred on the frame with a mild steel material was 4.865 mm on the back of the seat tube that holds the load from the rider’s with a load of 90 kg. The smallest safety factor value is 1.83 at the same point as the largest von misses stress value. The load generated from the prototype II prototype bicycle using mild steel material was 6.92 kg.

### 3.2. Results of Frame Design Simulation Using the Al 6061 Material

The results of static simulation with Aluminium 6061 material, the maximum Von misses stress value was 156.7 MPa which was located in the center of the seat tube which contact with the suspension mounting. As well as the other material, the maximum stress value that occurs due to the load given by the rider’s with 0.532 mm deformation at the maximum Von misses value. The yield strength of the Aluminum 6061 material was 277 MPa, this means by using this material there was no plastic deformation on the object.

The maximum deformation that occurred in the frame with aluminum 6061 material was 6 mm on the end of the seat tube that holds the load of the driver by 90 kg. While the smallest safety factor value of 2.41 lies at the same point as the maximum von misses stress value. The load generated from the prototype II prototype bicycle using Aluminum 6061 material is 4.19 kg. The tricycle with this material was safer than steel mild material, but it has bigger deformation on the end of the seat tube because of the young’s modulus of the material.

### 3.3. Results of Frame Design Simulation Using the CFRP Material

Static simulation of the frame using CFRP material the maximum value of Von misses stress is 113.5 MPa which is located in the middle of the seat tube. The maximum stress value that occurs due to the
load given by the rider’s on the seat tube with 0.922 mm deformation at the maximum Von misses stress value.

\[ \text{Figure 8. Von Mises stress simulation results of the tricycle frame using CFRP material.} \]

\[ \text{Figure 9. Strain simulation results of the tricycle frame using CFRP material.} \]

The maximum deformation that occurs on the frame with CFRP material was 7.57 mm on the end of the seat tube that holds the load from the rider’s with a load of 90 kg. While the smallest safety factor value of 2.64 is located at the same point as the largest von misses stress value. The load generated from the tricycle using CFRP material is 3.14 kg.

4. Conclusions
Based on the static simulation of the tricycle design, it can be concluded :

- CFRP material is the highest level of safety with a minimum safety factor value of 2.64, followed by Aluminum 6061 material with a safety factor value of 2.41, and Steel mild material with a safety factor value of 1.83.
- CFRP material is the lightest frame mass by 3.14 kg, followed by the aluminium 6061 mass by 4.19, and the steel mild mass by 6.92 kg.
- In the Static simulation results using several materials, since the maximum Von misses stress value below the yield point of the material, the design can be able to withstand the simulated load.

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