Wheel-hub and Upright Development on GE 19 Racing Cars for International Student Car Competition

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Abstract. This study aims to produce proper designs of the wheel hub and upright components of a GE 19 racing car. The design results were analyzed using analysis software to ensure the strength of the steering system components is safe in every driving condition. The upright and wheel hub which are designed are the developments of the EVO 14 racing car. The development was carried out because there was a change in the drive system from which the car initially used front drive to rear drive. In addition, the development also aims to minimize the occurrence of cracks in the upright and wheel hub components. The method used in this development is the Engineering Design Process model. The object of this development is the wheel hub and upright design which will then be applied to the GE 19 car to participate in the 2019 International Student Car Competition. The data analysis technique used is a power simulation using the Finite Element Analysis (FEA) feature on Solid works. FEA simulation data is in the form of stress contour images and safety factor values for the wheel hub and upright components of the steering system at each driving condition. The results of this development indicate that the design of the upright components and wheel hub of the GE 19 car has good strength and safety factors in every driving condition.

1. Introduction

Automotive is the study of land transportation using machines. The development of the automotive world from year to year has increased significantly. Indonesia is a developing country and seeks to actively support the development of world automotive. The International Student Car Competition (ISCC) is a competition that challenges all students around the world to design and build hybrid and electric racing vehicles. In this competition, the Garuda Team from Yogyakarta State University became a participant and designed an electric car called Garuda Electric 19 (GE-19). Besides, in this competition, dynamic tests are consisting of acceleration tests, gymkhana/meruver, and endurance, in which the safety and driver comfort factors are very important. One of the crucial factors that affect vehicle safety and comfort lies in the steering system.

To design a vehicle to take dynamic tests in the ISCC competition, it is necessary to prepare a steering system that is resistant to all driving conditions. Based on previous competition experience, the EVO 14 car belonging to the Garuda UNY Team uses a front-drive system which is too draining of the driver's energy due to the large driving force. The GE 19 car design will use a rear-drive system. With the front-drive system to the rear-drive system, the steering system will change automatically, especially for the upright and wheel components. For this reason, the GE 19 car uses the upright and front wheel hub design of the Garuda 16 (FG16) Formula car. However, during practice, there were cracks in the wheel hub components after the car was used for 10 races. In particular, the cracks occurred in the wheel bolt...
mounts on the wheel hub. Cracks are detected when checking the vehicle. If the wheel hub and upright are still used there will be more serious damage and danger to the driver. The crack is thought to have occurred due to the inaccurate analysis process so that it is upright, and the wheel hub is not able to fully accept the driving force.

The strength analysis was carried out on the wheel hub components and the upright GE-19 race car. The analysis was carried out using the help of the Finite Element Analysis (FEA) feature in the Solidworks software. The results of the analysis are in the form of a contour image that displays data on maximum intelligence and safety factors. With this development, it is expected that the steering component, to be precise the wheel hub, will have better strength and safety than before. So that the achievement of the Garuda UNY Team at the international level can increase.

2. Method
The method used in this study refers to the Engineering Design Process model proposed by Norton (1999). In this development process, the stages of development carried out are (1) conducting needs analysis and analysis of existing objects, (2) developing designs, (3) conducting design tests, (4) analyzing and discussing. For more details, the stages of development can be seen in Figure 1.

The needs analysis was carried out to determine the special needs of the wheel hub and upright components according to the GE-19 car design. The analysis was also carried out on the upright and wheel hub components, to determine the factors that cause cracks, which will be used as the basis for development assumptions. The safety factor that is already in the number 9 on the wheel hub is still experiencing cracks, making the basis for increasing the value of the safety factor, because driving a racing car sometimes finds or experiences extreme conditions. The assumptions related to static and dynamic forces, vehicle gravity, and design safety numbers are based on the analysis of the upright and wheel hub components of the FG16 car.

The next development process is to create a shape design. After the shape design is obtained, then the size adjustment is carried out based on the car design and its supporting components/systems, namely the chassis, body, engine position, and the position of the drive axle. The development process is based on 2 things, namely meeting the needs, and considering the results of the previous product analysis. The next step is to make 3D digital modeling of the wheel hub components and upright according to the shape and size that has been designed.

![Figure 1. Development Stages.](image)

The design testing process is carried out on a digital model (3D image) with the help of Solidworks software in the Finite Element Analysis (FEA) feature. This feature is used to test and determine the contour image of stress, maximum tension, and safety factor of the wheel hub and upright components. The amount of force used to simulate the GE 19 car steering system is the result of the calculation
of the force in the driving conditions. The driving conditions include bump conditions, braking conditions, acceleration conditions, and turning conditions. The following will describe the explanations and approaches/assumptions of each style, with an approach referring to the theory proposed by Milliken (1995).

The G-force of a GE 19 car when the bump conditions are assumed to be a maximum of only 2 G. This assumption is applied because the GE 19 car does not have a large aerodynamic force so that the downward force is not as big as a car that uses an aerodynamic package. The magnitude of the bump force of the front and rear wheels is the same, namely 1412.64 N.

![Figure 2. Wheel Hub Design.](image_url)

![Figure 3. Upright Design.](image_url)
The longitudinal g-force of a GE 19 car under braking conditions is assumed to be a maximum of only 1.15 G. The results of the calculation of braking force are obtained based on the braking test data of the EVO 14 car. The braking test performed is simulated the same as during the ISCC competition.

The longitudinal g-force of a GE 19 car in acceleration conditions is assumed to reach a maximum of only 0.87 G. The force is quite small because the maximum speed of a GE 19 car is not more than 100 km/hour. The results of this calculation are obtained based on data on the fastest team car at the acceleration event at the 2018 International Student Car Competition.

The lateral g-force of a GE 19 car in turning conditions is assumed to be a maximum of only 1.5 G. The results of this calculation are obtained based on data on the fastest team car at the gymkhana event at the 2018 International Student Car Competition. Turning car data is taken with the same curve as the gymkhana track.

Setting styles, moments, and support during testing using Finite Element Analysis (FEA) software, using references put forward by Dhakar (2016), with the following illustration:

3. Result and Discussion

3.1. Result

The wheel hub design was tested using Finite Element Analysis (FEA) software. The basic concept of FEA is to replace any complex shape by changing it into simple shapes such as small triangles that are combined exactly according to the original object (Akin, 2009). The results of the FEA test showed that the maximum tension component was 3.37e+08 N/m2 and the safety factor was 1.354e+00 when turning. The results of the analysis can be seen graphically in Figure 6 and 7.
The upright design is tested by involving integrated simulation conditions, which involve integrated and installed wheel hub and upright. The test is assumed to be under optimal load conditions, namely when turning and braking. Tests were carried out using Finite Element Analysis (FEA) software. The test results obtained the maximum tension component value of 228 N/m² and the safety factor of 2.21 when turning. The results of the analysis can be seen graphically in Figure 8 and 9.
Figure 9. Results of Upright Safety Factor Analysis When Turning.

The test results obtained the maximum tension component value of 146 N/m² and the safety factor of 3.45 when braking. The results of the analysis can be seen graphically in Figure 10 and 11.

Figure 10. Results of Strength Upright Analysis When Braking
Figure 11. Results of Upright Safety Factor Analysis When Braking

The results of the upright and wheel hub tests, if presented in the table, are shown in the following table.

| Part          | Maximum Tension | Safety factor |
|---------------|-----------------|---------------|
| Upright       | 228 N/m²        | 2.21          |
| Wheel hub     | 3.37e+08 N/m²   | 1.354e+00     |

3.2. Discussion

The development of upright and wheel hub is carried out to minimize the occurrence of component cracks when the vehicle is used for racing in all driving conditions. The following is an upright construction design and wheel hub testing before development.

Figure 12. Upright Construction Design Before Development.

Based on these results, there is a significant change in the upright construction that will be used on the GE 19 racing car. This is because the front upright is no longer used as a mount for the electric motor as a driving force. The upright design for the GE 19 race car required a wheel hub to connect to the front wheels.
The GE 19 car upright components and wheel hubs are designed using proven materials and small tolerances. Besides, the design process is aimed at components that work dynamically. Based on these provisions, the minimum safety factor for these components is 1.21. These results are obtained from calculations using theory (Ulman, 2010) as follows:

$$FS = FS_{\text{material}} \times FS_{\text{stress}} \times FS_{\text{geometry}} \times FS_{\text{failure}} \times FS_{\text{reliability}}$$

$$FS = 1.0 \times 1.0 \times 1.0 \times 1.1 \times 1.1 = 1.21$$

- **Material FS** = 1.0; because the material has been tested.
- **FS stress** = 1.0; because static and dynamic loads are analysed by accurate methods.
- **Geometry FS** = 1.0; because the process is manipulated with medium tolerance.
- **FS failure** = 1.1; because the analysis is carried out using a theory that has a high enough accuracy.
- **FS reliability** = 1.1; because the reliability is around 90%.

The higher the safety factor than the minimum limit, the stronger and safer the component will be. Conditions that affect the driving force include steering geometry and wheel alignment, which includes camber, caster, and toe. The determination of the values of these factors is very important for driving stability and the amount of force acting on the vehicle components. (Smith, 1978; Knowles, 2011; Shimada, 2007; Miliken, 1995; Reimpell, 2001). Besides, dynamic conditions during driving, such as bump steer, roll steer, chamber change rate, roll camber and tire forces will greatly affect the amount of force on the vehicle. (Rouelle, 2016; Scalabroni, 2013; Smith, 1978; Berkum, 2004; Lamers, 2008). Consideration and the right design approach as well as a large safety factor will result in a good and safe design.

### 4. Conclusion
The conclusions obtained from testing the results of the development that have been carried out are the resulting upright design has a significant change compared to before. This is indicated by the change in construction from the upright. Upright component analysis is simulated when the vehicle turns and brakes. When turning upright, it has a maximum tension of 228 N/m² with a safety factor of 2.21. Meanwhile, when doing upright braking, it has a maximum tension of 146 N/m² with a safety factor of 3.45.

Using the front wheel hub in electric cars is something new. This is because in previous electric cars that used a front drive system, a wheel hub was not required. Analysis of the wheel hub force is simulated when the car is braking. The maximum wheel hub tension when the vehicle is braking is $3.37 \times 10^8$ N/m². Meanwhile, the wheel hub safety factor when the car is braking is $1.354 \times 10^0$.

Based on the analysis results that have been obtained, the upright and wheel hub components can be said to be safe. This is because the safety factor of each component exceeds the minimum allowable limit, namely 1.21 (Ulman, 2010). The higher the safety factor and the further from the minimum limit, the stronger the component will be. The results of this development are expected to improve the ability/performance of the GE 19 racing car so that it can improve the performance of the racing team at the International Student Car Competition.

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