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Topology Optimization of Rear Sprocket of Electric Prototype Vehicle

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Abstract

Kompetisi Mobil Hemat Energi (KMHE) competes for energy efficient vehicles, which are composed of integrated energy-saving systems. One of the systems that is required to be energy efficient is transmission. The transmission discussed in this study is the sprocket chain transmission system. The rear sprocket is an object that needs to be optimized to obtain a lighter mass, thus efficient in terms of overall weight. Using topology optimization via CAD software, rear sprocket mass can be reduced. The results of topology optimization are used as a reference for changing the shape of the sprocket face, to make it easier in terms of fabrication. These results were then re-tested with static simulations to ensure its strength. The conclusion is that the latest sprocket design has a mass reduction of 66% of its original version and the von Misses stress was only 55% of the yield strength at most.

Keywords: KMHE, sprocket, topology optimization

1 Introduction

The increasing number of motorized vehicles in urban areas has become a major contributor to exhaust emissions that have a negative impact on air quality and public health. Emissions from fossil fuels used by vehicles produce pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), and particulates (PM), which contribute to global warming and respiratory diseases. Although vehicle technology is increasingly developing, the rate of vehicle growth still exceeds the capabilities of emission control systems. Therefore, there needs to be stricter policies and the development of environmentally friendly fuels and technologies to reduce these emissions.

The impact analysis of electric vehicle use in the road transportation sector is used to evaluate energy demand and CO_2 emissions in Indonesia [1]. Using the Modified Mobility Model (MoMo) and PUCE method, this study projects that by 2040, a moderate electric vehicle adoption scenario can reduce energy consumption by 6% and CO_2 emissions by 4.8%. Meanwhile, a high adoption scenario shows a potential reduction in energy consumption by 14% and CO_2 emissions by 8.8%. These findings emphasize that increasing the adoption of electric vehicles can contribute significantly to reducing greenhouse gas emissions in the Indonesian transportation sector.

Kompetisi Mobil Hemat Energi (KMHE) is a vehicle competition focusing on energy saving in Indonesia. This competition is a response to issues related to the decreasing availability of energy [2]. KMHE tests the ability of a group of students to design a vehicle that uses as little energy as possible. Students are asked to design and build energy-efficient vehicles that comply with KMHE regulations. Vehicles must be designed as light as possible to achieve the most efficient energy consumption. The use of carbon fiber and aluminum is widespread in this competition vehicle.

The use of static simulation with CAD software provides significant benefits in the engineering design and analysis process. With this simulation, designers can evaluate the strength and resistance of a component to static loads before a physical prototype is made. This not only saves time and production costs but also minimizes the risk of design errors. In addition, CAD simulation allows visualization of stress distribution and deformation, so that design improvements can be made more precisely. As in the study related to the design of a prototype vehicle chassis with CAD software, it was found that the maximum deformation was 2.5 mm [3]. The chassis was then fabricated and tested with the same load, but no deformation was visually found. The topology optimization feature in CAD software also supports material efficiency by producing a lightweight but strong structural shape based on the results of the load analysis. Therefore, the integration of static simulation in the design process is very important to produce safe, efficient and reliable products.

Apart from materials which are the main factor in reducing vehicle weight, the application of topology optimization can be used to reduce the weight of vehicle components further. Topology optimization is a method that distributes initial mass in each 3D space to create the best possible shape for mechanical construction. It gives efficient geometry by concentrating on material volume. Topology optimization has been proven to reduce the weight of electric motor high-speed stator to 20.2% [4], motorcycle engine cover to 16% [5], 125 cc sport bike rear sprocket to 27% [6], Formula Student car front upright to 60.43% [7], steering shaft support bracket to 34,25% [8], and motorcycle swingarm to 30% [9].

One of the crucial parts of this vehicle is the transmission system. The use of chain and sprocket transmission systems is intended to achieve high power transfer efficiency. Under correct lubrication and installation conditions, the chain drive's mechanical efficiency was 98,4 – 98,9 % [10].

With optimization topology, reducing the mass of a component can reduce the total mass of the vehicle, with the aim of increasing fuel efficiency. In a study, increasing the battery capacity from 10.5 kWh to 21 kWh caused an increase in vehicle weight of 125 kg. This resulted in an increase in energy use of 5.8% [11]. Based on the results of this study, it is necessary to reduce weight through topology optimization of the rear sprocket of the electric prototype vehicle

2 Material and Methods

The rear sprocket, which is the subject of the research, is designed to accommodate the RS-35 chain. The steps in this research can be shown in Figure 1. The first step is to create a 3D model of the 92 teeth rear sprocket via CAD software, SolidWorks. Aluminum 7075-T6 mechanical properties (Table 1) were added to the model. Aluminum 7075-T6 was chosen because it is widely used as a sprocket for motorbikes, go-karts, and all-terrain vehicles. The sprocket model is then subjected to topology optimization inside SolidWorks. The results of the topology optimization are then exported into a separate file. At the re-design phase, the results of both the default and the topology optimization of the rear sprocket model are compared. The default rear sprocket model was then redesigned by tracing the hollow parts from the results of the topology optimization model. The redesigned default model is saved as a lightweight version. This lightweight version is then subjected to static simulation to ensure its safety. Both forces that act on each sprocket tooth for topology optimization and static simulation are generated from the torque of the 500-Watt DC motor that that drives this vehicle.

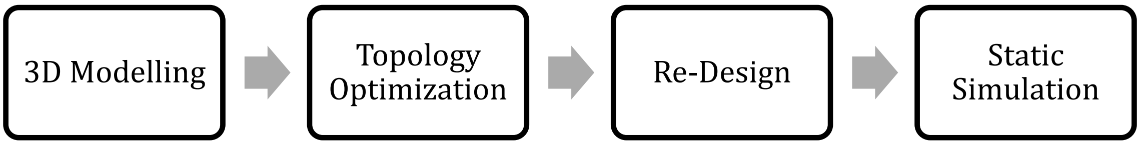


Figure 1. Lightweighting rear sprocket process

Table 1. Mechanical properties of aluminum 7075-T6

Mechanical properties	Value
Elastic Modulus (N/m^2)	7.19×10^{10}
Poisson's Ratio	0.33
Tensile Strength (N/m^2)	5.7×10^{8}
Yield Strength (N/m^2)	5.05×10^{8}

3 Results and Discussions

3.1. 3D Modelling

Through the SolidWorks Toolbox add-in, a model of the 92-tooth RS35 rear sprocket can be created, by entering the options as shown in **Figure 2**a. Next, the model can be edited to add features such as 6 – Ø6 mm holes equally spaced in Ø92 mm PCD, and a bore diameter of 88 mm to match the rear wheel hub, as shown in **Figure 2**b.

3.2. Topology Optimization

3.2.1. Force of each sprocket tooth

The force acting on each sprocket tooth is caused by the tension, F. The tension F is a combination of effective circumferential force, F_1; the centrifugal force tension, F_e; and the sag of the loose side tension, F_f.

A. Effective Circumferential Force, F_1

It is known that the torque of the 500-Watt DC motor is 0.5 N.m, and the diameter of the rear sprocket is 0.56 m, thus F_1 can be calculated using the following formula.

$$F_1 = \frac{M_2}{r_1} = \frac{M_1}{r_2} \quad (1)$$

where,

F_1 : effective circumferential force (N)

M_1 : motor sprocket torque (N.m)

M_2 : rear sprocket torque (N.m)

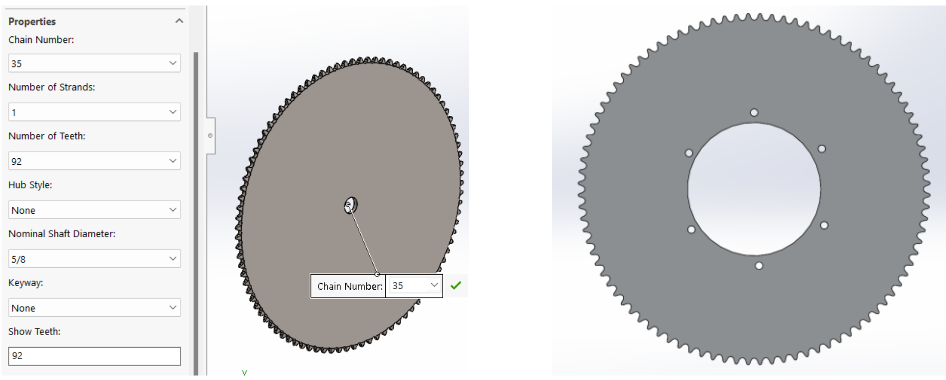
r_1 : motor sprocket radius (m)

r_2 : rear sprocket radius (m)

Thus,

$$F_1 = \frac{M_1}{r_2}$$

$$= \frac{0.55}{0.28} = 1.96\ N$$



(a) (b)

Figure 2. Rear sprocket modeling

B. Centrifugal Force Tension, F_e

Using RS35 chain pitch, 9.525 mm; 10 teeth motor sprocket, weight per meter, 0.33 kg; and the 500-Watt DC motor could reach 10000 RPM, centrifugal force tension F_e can be calculated as follows:

$$v = \frac{p \times N \times n}{60 \times 1000} \quad \textbf{(2)}$$

$$F_e = q \times v^2 \quad \textbf{(3)}$$

where,

v : chain speed (m/s)

p : chain pitch (mm)

N : number of teeth of motor sprocket

n : rotational speed of motor (RPM)

F_e : centrifugal force tension (N)

q : chain weight per meter (kg)

Thus,

$$v = \frac{9.525 \times 10 \times 10000}{60 \times 1000} = 15.87\, m/s$$

$$F_e = 0.33 \times (19.05)^2 = 83.11\ N$$

C. Sag of The Loose Side Tension, F_f

The design of the chain sprocket is required to be slightly loose. The lower part is made a little loose when the chain transmits power. This looseness also creates a force, which can be calculated by

$$F_f = g \times K_f \times q \times a \quad (4)$$

where,

F_f : sag of the loose side tension (N)

g : gravitational force (m/s^2)

K_f : coefficient (6-7 for horizontal chain arrangement)

q : chain weight per meter (kg/m)

a : center distance of chain (m)

Thus,

$$F_f = 9.8 \times 6 \times 0.33 \times 0.34 = 6.59\ N$$

3.2.2. Topology optimization parameter

The first step in the topology optimization stage is to determine the location of the fixture, in this case 6 bolt holes. The next step is to place the force on each sprocket tooth, which is $F = F_1 + F_e + F_f \approx 92\ N$. Then determine the goals and constraints, in this case, the mass constraint is 90% reduction. The next step is to determine the preserved region in the manufacturing control section. The preserved region is the area where the part must not be lost due to the overall topology optimization stage. The last step is to mesh and run the topology.

3.2.3. Topology optimization result

After going through the process above, the results of the optimization topology are obtained as shown in **Figure 3**. On the right side of the image there is a description showing the parts of the component that are OK to remove (blue color region) and must be kept (yellow color region). The results of this topology optimization are then exported into a separate file to be compared with the original file.

3.3. Re-Design

The re-design begins by combining the topology optimization result files with the original files in an assembly. The next step is to create a hole pattern on the original file by tracing the hole pattern on the topology optimization result file, as shown in Figure 4a. A 5 mm radius fillet was added to the hole pattern to reduce stress concentration. The hole pattern is then extruded cut, and the file is saved as a re-design edition, as shown in Figure 4b. The re-design version has a mass of 194.56 grams compared to the original version, 578.71 grams.

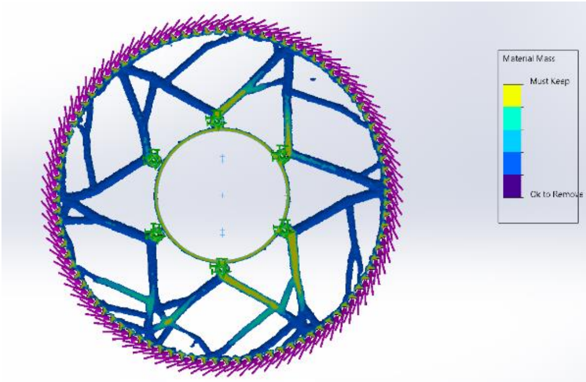
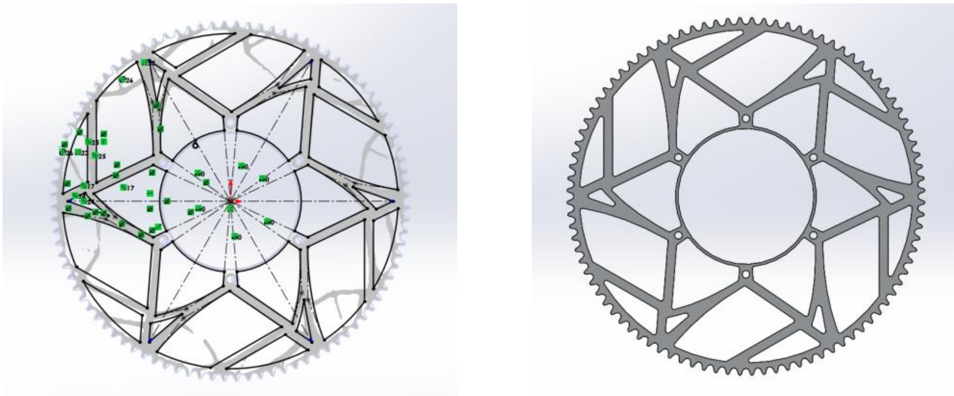


Figure 3. Topology optimization result

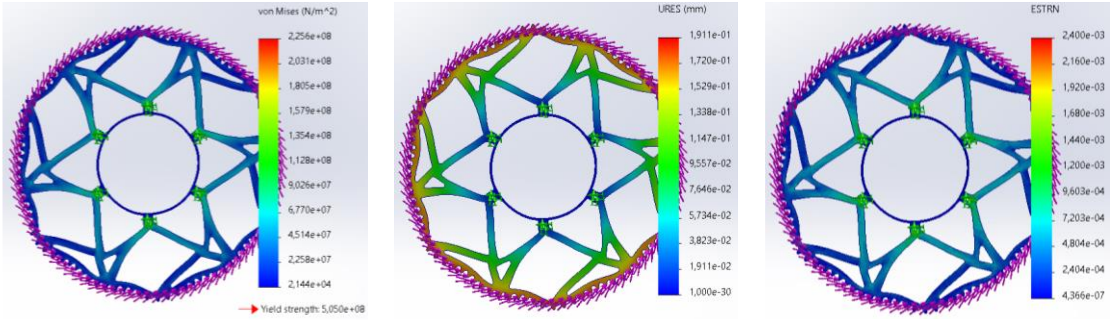


(a) **(b)**

Figure 4. Redesign process (a) hole pattern tracing, and (b) re-design result

Static Simulation

The static simulation stage is used to verify that the redesign results have the same strength. The simulation parameters are the same as those in the topology optimization stage. The static simulation results show that the maximum von Misses stress is valued at 2.256×10^8 N/m^2, about 55% below yield strength, 5.050×10^8 N/m^2, as shown at Figure 5. The results of this static simulation show that the redesigned version is considered strong enough to receive the appropriate forces.



(a) (b) (c)

Figure 5. Static simulation (a) von Mises, (b) displacement, and (c) strain result of re-design sprocket

4 Conclusions

The topology optimization process with manual tracing resulted in a sprocket design with a mass reduction of 66% of its original version. After being retested with static simulation, the von Misses stress was only 55% of the yield strength at most. This result is considered good for later production and use in electric prototype vehicles. Although it is rated as good in terms of software, the rear sprocket needs to be fabricated from the same material and tested under appropriate loads before being finally installed on the vehicle.

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