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Design of a Ladder Frame Chassis Made from Aluminum Alloy Hollow Material Used by the GARNESA Energy-Efficient Car Team with Static Testing

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Abstract

This study focuses on designing a ladder frame chassis for energy-efficient cars made of Hollow Aluminum Alloy. The chassis functions as the main supporting structure that must be able to withstand vehicle loads effectively, including static loads from the steering, driver, engine, and battery, as well as dynamic loads that arise while driving. The design process involves an in-depth analysis of the dimensions and strength of the material to achieve a stable, minimalist, and aerodynamic design. Testing is carried out to evaluate the strength of the chassis through static test methods. The method used is an experimental method where the work on the tool starts from the design which includes: observation, tool design and function testing. The results of the chassis design have final dimensions of 1740.40 mm (length) x 780 mm (width) x 876.20 mm (height), while the results of static testing obtained the highest deflection results of 0.2 cm with a safety factor of 7.29 ul, for the moment of inertia obtained a value of 996730.62 mm4, and for von mises stress 37.77 Mpa. These findings indicate that the designed chassis meets the safety and performance criteria required for energy-efficient cars, so it can be implemented in KMHE and SEM competitions.

Keyword:*Chassis Ladder Frame, Energy Efficient Car, Urban Concept, Static Test*.

I. INTRODUCTION

The Garuda Negeri Surabaya University (GARNESA) Racing Team is a student team that actively participates in the Energy-Efficient Car Contest (KMHE) and Shell Eco-Marathon (SEM) in the Urban Concept category with a Diesel Internal Combustion Engine (ICE). From 2018 to 2022, the GARNESA team consistently achieved podium finishes in the Diesel ICE category at KMHE. At SEM 2022, the team secured 6th place in the ICE category.GARNESA's achievements include a fuel efficiency of 165.25 km/l at KMHE 2022, which decreased to 136 km/l at SEM 2022 and further declined to 112 km/l at SEM 2023. These accomplishments are the result of hard work, smart strategies, and thorough execution by the entire team, supported by advisors and Negeri Surabaya University (UNESA).The Energy-Efficient Vehicle (EEV) by GARNESA is designed, simulated, and manufactured by students from various departments and faculties at UNESA. The EEV production process involves critical aspects such as engine performance, aerodynamics, drivetrain, bodywork, vehicle stability, chassis, and weight optimization, all working together to achieve optimal performance and stability.One potential factor contributing to the decline in fuel efficiency could be the chassis condition, both in terms of design and manufacturing. The chassis is a fundamental component of the vehicle, requiring a strong structure to support all loads, including passengers, batteries, the engine, and comfort equipment. Therefore, every chassis design must be capable of withstanding the vehicle's load, with the chassis itself weighing approximately 6 kg.

There are several types of chassis used in vehicles today, including the Ladder Frame, Monocoque Chassis, Backbone Chassis, Tubular Space Frame, and Aluminium Space Frame. The GARNESA team currently employs a Ladder Frame design. However, the chassis design implemented so far has not undergone academic analysis or material strength simulations, leading to chassis deformation. This raises the hypothesis that the decline in fuel efficiency may be caused by chassis-related issues.

In chassis design, it is crucial to account for static and dynamic loads. The selection of appropriate materials must comply with KMHE and SEM competition regulations to ensure the chassis can withstand static loads from components such as the steering system, driver, engine, battery, and body, as well as dynamic loads like engine vibrations and braking forces. The vehicles competing in KMHE and SEM Asia must be designed with ergonomic and minimalist principles to achieve maximum efficiency.

According to research (Hadi, 2021), urban concept vehicles are best suited for chassis made from 1 x 3 x 1/8 inch hollow structural sections. Research by (Khoiriah, 2020) demonstrates that ladder frame designs utilizing AISI 1018 118 QT steel offer superior safety with higher safety factors. Furthermore, research by (Arbintarso et al., 2019) proved that reducing vehicle weight without compromising physical or mechanical capabilities can significantly improve fuel efficiency.

Consequently, chassis design optimization necessitates precise structural calculations, comprehensive stress analysis, appropriate material selection, and optimal geometric configuration. Extensive research must be performed throughout the manufacturing process to guarantee the chassis maintains safety and stability during vehicle operation.

II. THEORY

A. GARNESA Racing Team Car

The Garuda Energy Efficient Car (MHE) of Surabaya State University (GARNESA) Diesel is designed for one passenger and is used in the KMHE (Energy Efficient Car Contest) and SEM (Shell Eco-Marathon) Asia events. This car is designed to be able to brake effectively on a 20° slope, stopping the vehicle from a speed of 50 km/h in a distance of 15 meters. The main focus on chassis design is very important to ensure that the car is easy to control and provides comfort when driving. Aspects that are considered include the selection of the steering system, chassis structure, type of material used, and smooth manufacturing processes.

B. Energy Efficient Car Contest and Shell Eco Marathon

The Energy Efficient Car Contest (KMHE) is an annual competition organized by the National Achievement Center (PUSPRESNAS) of the Ministry of Education and Culture (KEMDIKBUD), while the Shell Eco-Marathon (SEM) Asia-Pacific is held by PT. Shell. The purpose of this competition is to find innovative solutions in mobility, as well as to design future vehicles that are safe and able to travel the furthest distance with very efficient energy consumption. There are two categories of vehicles being competed, namely Urban Concept and Prototype. The dimensions of vehicles participating in the competition must comply with the established Technical Regulations.

C. *Chassis*

The chassis or frame of a vehicle functions to support the load and weight of the vehicle, including the engine and passengers. The strength of the chassis material is crucial to ensure that the vehicle can bear the load safely. In addition, the chassis also plays an important role in keeping the car sturdy, rigid, and does not bend or deform during use (NURSABDIN et al., 2019). According to experts (N. Nazaruddin et al., 2020), car chassis are generally made of metal or composite materials that have the strength to support the load of the vehicle. The chassis is also responsible for maintaining structural rigidity, supporting the suspension system, integrating the brake system, distributing the load evenly, and protecting the vehicle from impact. Therefore, the chassis is not only a basic structure, but also a foundation for the safety, stability, and comfort of the driver and passengers.

There are various types of chassis used in the automotive industry, depending on the design and intended use of the vehicle, including:

1. *Ladder Frame*

   Ladder frame is a type of chassis consisting of two main bars that support the vehicle and has the capacity to withstand large loads (Ary Fadila, 2013). This chassis is usually used in transportation vehicles. Known as the most basic and oldest form of chassis, the ladder frame is so named because of its shape that resembles a ladder. Its construction structure consists of two symmetrical rails or beams connected by a cross member.
2. *Monocoque*

   Monocoque is a type of chassis structure that is integrated with the shape of the vehicle, so that its design can vary following the shape of the car (Shantika et al., 2018). Although it looks like a single unit between the frame and body, the manufacture of this chassis actually involves an automatic welding process, which produces neat and invisible welding.
3. *Aluminium Space Frmae*

   Aluminum Space Frame was developed as an alternative to monocoque steel chassis with the aim of creating a lighter vehicle frame (Shantika et al., 2018). Aluminum Space Frame is claimed to be 40% lighter than monocoque steel chassis, while maintaining 40% higher stiffness.

4. *Backbone*

The Backbone Chassis is a practical application of the pipe frame concept, where the main idea is to connect the front and rear of the vehicle using a pipe frame that stretches the length of the car. Unlike the tunnel transmission, the backbone chassis consists mostly of a rigid structure and is able to withstand the entire load. This structure has a number of continuous holes, with walls that are generally thick due to the small diameter of the pipe. The stiffness of the Backbone chassis depends on the area of the "backbone" section itself (Salafuddin, 2016).

5. *Tubular Space Frame*

Tubular Space Frame uses various types of round pipes (sometimes square pipes are used to make it easier to connect, although round pipes have very high strength). Tubular space frames are often used in racing cars because their tubular design makes them lighter. This frame is mainly used to support aerodynamics to increase vehicle speed (Khoiriah, 2020). The placement of the pipes in various directions creates mechanical strength to withstand forces from all directions. The pipes are joined together through a welding process, forming a complex structure.

D. Aluminium Alloy

Aluminum alloy 6061 is one of the most commonly used alloys in the 6000 series. This standard structural alloy, which is one of the easiest to process with heat treatment, has good qualities in terms of heat conduction, as well as high corrosion resistance. This material is widely used for applications that require medium to high strength, and has good toughness properties (Efendi, 2020).

E. Moment of Inersia

According to (Fadila1 & Syam, 2013: 73) the cross-sectional area of the main chassis which is a square hollow aluminum can be seen in the figure 1.

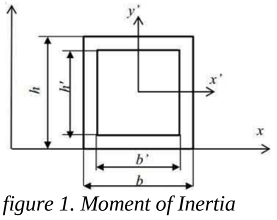


figure 1. Moment of Inertia

For the cross-sectional area of a rectangle, the formula for inertia of the area and length are :

$$I = \frac{1}{12} \times b \times h^3 \quad (1)$$

Information:

I = Inertia of Cross-Section Area (mm^2)
b = Cross-sectional width (mm)
h = Cross-sectional height (mm)

F. Von Mises Stress

Von Mises stress is an equivalent stress parameter used in solid mechanics to estimate the strain of a material under various types of loads. The concept was introduced by Hubertus von Mises and is often used in strength analysis of materials and structural design.

(Trimulya et al., 2015) states that in designing structural parts, the allowable stress must be lower than the ultimate strength obtained through "static" testing for various considerations. Therefore, when designing, the von Mises stress value must be below the yield strength value so that the design is safe to use. The formula for calculating von Mises stress can be seen below (Mott et al., 2018).

$$\sigma t = \frac{M.y}{I} \quad (2)$$

Information:

σt = *Von Misses* Stress (Mpa)
M = Bending moment (N.mm)
y = Vertical distance (mm)
I = Moment of inertia (mm^4)

G. Safety Factor

Safety Factor measures the ability of a material to withstand external loads, either compression or tension. The load that causes the material to fail is called the ultimate load, which when divided by the cross-sectional area gives the ultimate strength. In elastic materials, the safety factor is usually calculated based on the yield stress. The safety factor is the ratio of the maximum allowable stress to the working stress. (Kriswanto et al, 2015).

$$Sf = \frac{\sigma y}{\sigma \text{ actual}} \quad (3)$$

Keterangan:

Sf = *Safety Factor* (n)
σy = Yield stress value of material (MPa)
σ actual = Maximum stress value on test specimen (MPa)

H. Uji Fungsi Statis

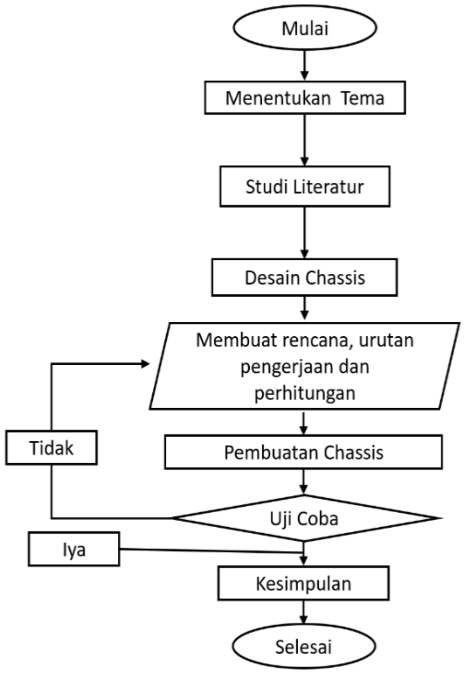
According to experts (Wahyudi & Fahrudi, 2017) to determine the ability of the frame strength to withstand loads effectively, a functional test is carried out.

Static testing is performed when the Chassis is stationary (Widjanarka, 2017). This testing is the process of evaluating vehicle components or systems without involving dynamic movement or operation, with the aim of ensuring that the components or systems meet design and quality specifications before being used in real conditions.

III. METHODE

The method used in this study is an experimental research method where the work on the tool starts from the design which includes: observation, tool design and function testing. Starting with a literature study from various sources such as articles, journals and theses. Problem identification Based on observations and field observations in the manufacture of the Garnesa car chassis. Determining the formulation of the problem along with the research objectives to be achieved. Based on references from several previous studies have discussed important aspects related to the chassis. One of them is a study entitled "Analysis of the Design and Construction of the Urban Garuda Type Car Chassis, Surabaya State University (GARNESA) Diesel" conducted by (Hadi, 2021) conducted an analysis of the chassis on an urban diesel car using hollow aluminum alloy material measuring 1x3x3.18 inches resulting in dimensions with a length of 1900 mm, a width of 720 mm, and a height of 859 mm.

The chassis design process begins with designing the chassis with hollow aluminum alloy material. After the design is complete, calculations are carried out on the design. After the calculation data is obtained, the next step is the design process that is in accordance with the design results that have been made.



IV. RESULT AND DISCUSSION

A. Result

The data obtained from the results of the ladder frame chassis test with Hollow Aluminum Alloy material using a fixed loading test (static) with a driver load of 50 kg and 70 kg obtained a deflection result that is still considered safe because the maximum deflection result is 0.4 cm, while the safety factor obtained from the calculation results is 7.29 ul. The results of the fixed loading (static) with a driver load of 50 kg obtained a deflection value of 0.1 cm, for a driver load of 70 kg obtained a deflection value of 0.2 cm.

Figure 2. Test result graph

This function test aims to determine the strength of the obtained deflection results. The function test is carried out by the chassis being ridden by a driver with a predetermined weight, then measurements are taken to obtain data from the deflection results.

B. Discussion

This section presents the design of a ladder frame chassis made of hollow aluminum alloy and chassis testing.

1. Chassis Design

   Before the design process is carried out, the chassis design process is carried out first to determine the final result that will be designed.

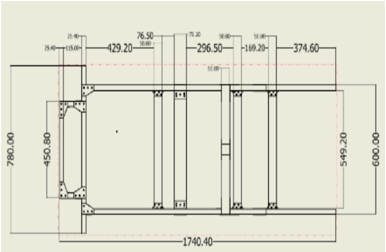


Figure 3. 2D chassis design

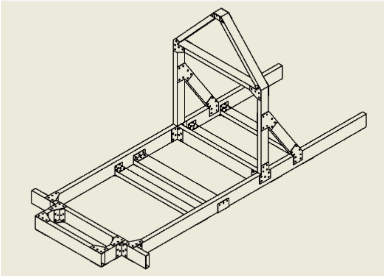


Figure 4. 3D chassis design

2. Design

The chassis design process is designed to be as concise as possible for data collection, but in the design process we still take into account all the aspects needed in the design, the following are the steps for designing a ladder frame chassis made from hollow aluminum alloy:

a. Measurement and marking

In this process, measurements and marking are carried out on the hollow aluminum alloy material measuring 1x3x0.047 inches and 1x2x0.047 inches. The cutting process is in accordance with the existing dimensions in the chassis design.

b. Cutting

In this process, the hollow aluminum alloy material that has been marked is cut, then cut using a hand grinder.

c. Penyambungan

At this stage, the hollow is connected using 2mm thick aluminum plate and 2mm thick angle plate, after which the riveting process is continued.

The results of the design process can be seen in the image below.

Figure 5. Chassis made from Hollow Aluminum Alloy

3. Testing

After the chassis is designed, a functional test phase is needed to determine the strength of the chassis. Before testing, it is necessary to know the center point (point for measuring the curvature) on the chassis so that in the chassis testing process the deflection value (chassis curvature at the center point) is obtained.

Figure 6. Chassis Center Point

After the midpoint is known, a test is carried out to determine the deflection strength of the chassis. At the chassis testing stage, a fixed loading function test (static) is carried out. The following are the results of the static loading test.

Figure 7. Static testing

At this stage, the chassis is raised on a jackstand so that the chassis does not move, after which the load (driver) is raised onto the chassis and continued with the process of taking data from the deflection results. The results of the fixed (static) loading test can be seen in the table below.

Table 1. Static Test Results

No	Berat Driver (Kg)	Waktu Pengujian	Uji Statis			
			Sebelum diberi beban (cm)	Saat diberi beban (cm)	Sesudah diberi beban (cm)	Lendutan
1	50Kg	5 Menit	22,6	22,5	22,6	0,1cm
2	70Kg	5 Menit	22,6	22,4	22,6	0,2cm

4. Calculation

Calculations on the chassis are carried out to obtain the maximum value of the results that occur on the chassis. Calculation of stress on the Hollow 1x3x0.047 inch frame.

To calculate the moment of inertia, you can use equation (1) as follows.

$$I = \frac{1}{12} \times b \times h^3$$

$$I = L_A - L_B$$

$$I = \frac{1}{12} \times b \times h^3 - \frac{1}{12} \times b \times h^3$$

$$I = \frac{1}{12} \times 25.40 \times 76.20^3 - \frac{1}{12} \times 23 \times 73.80^3$$

$$I = 936520.70\ mm^2 - 770398.93\ mm^2$$

$$I = 166121.77 mm^4$$

Since there are six rods in the main chassis, the moment of inertia must be multiplied by six.

$$I = 166121.77 mm^4 \times 6$$

$$I = 996730.62 mm^4$$

To find the von Mises stress value, use equation (2) as follows.

$$\sigma t = \frac{M \cdot y}{I}$$

$$\sigma t = \frac{987879{,}6 \text{N/mm} \cdot 38{,}1 \text{ mm}}{996730{,}62\ mm^4}$$

$$\sigma t = \frac{36091596{,}6\ N.mm^2}{498365{,}31\ mm^4}$$

$$\sigma t = 37{,}77 \text{ N/mm}^2$$

$$\sigma t = 37{,}77 \text{ Mpa}$$

Meanwhile, to find the safety factor, equation (3) is used as follows,

$$Sf = \frac{\sigma y}{\sigma \text{ actual}}$$

$$Sf = \frac{275}{37.77}$$

$$Sf = 7.29 \text{ ul}$$

V. CONCLUSION

Based on the results of the design that has been carried out, several conclusions can be drawn as follows:

1. The design of the ladder frame chassis using hollow aluminum alloy material produces dimensions with a length of 1740.40mm x width 780mm x height 876.20mm. The results of this design indicate that the designed chassis is in accordance with KMHE and SEM regulations.
2. The results of the static load function test show that the chassis is still considered safe because the highest deflection during testing is 0.4 cm, while the safety factor is 7.29 ul, the moment of inertia is 996730.62 mm4, and the von mises stress is 37.77 Mpa.

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