CHASSIS DESIGN FOR ELECTRIC SWEEPER CAR PROTOTYPE UNIT

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Abstract - Organic and inorganic residual waste and litter have become one of the never-ending problems in rural and urban areas and therefore a special care is required to deal with this particular problem. Sweeper cars have been part of this special care in addition to efforts utilizing human power. However, this attempt has its limitation considering their high price after factoring in the import cost. Taking this condition into account, a research on sweeper car that incorporates latest technology and is affordable, yet eco-friendly needs to be conducted. It is because sweepers cars in the market generally use fossil fuel which is not eco-friendly. An electric sweeper car prototype is a newest breakthrough in technology because this sweeper car is electrically powered. This research aims to design a chassis of an electric sweeper car prototype that is safe to be used as a supporting frame of the weight that will be borne by the electric sweeper car prototype. The process of designing chassis was started from observing the design of the unit to get the exact and proportional dimensions to fixing the sweeper car components to the chassis. The entire process was done on SolidWorks 2017 software and later in order to determine the static weight of the chassis and safety factor value, a von Misses stress analysis test was carried out. Creating the design of the chassis yielded a result which contained information about material data of the chassis—it uses AISI 1045 mild steel which consists of 0.43% – 0.50% carbon. This material is chosen because this type of material is easy to be molded and also it has good engine capability and high ultimate and yield strength with maximum yield stress of 530 MPa. von Mises stress analysis test result showed that it has maximum stress value of 86.2 MPa and safety factor value of 6.14. Based on the data above, this design of chassis is considered safe and to meet the criteria for an electric sweeper car prototype.

Keywords - Design, Chassis, Stress Analysis, Safety Factor

I. INTRODUCTION

Waste is either solid or semi-solid residue that remains as a result of urban activities or a life cycle of living thing [1]. Organic and inorganic residual waste and litter have become one of the never-ending problems in rural and urban areas and therefore a special care is required to deal with this particular problem. Waste problem in urban areas is directly connected to the large population that the regions have. It is common knowledge that Indonesia is the biggest archipelagic state in the world but two thousand meters below its sea level, it has huge amounts of plastic waste after China [2]. As time goes by, as each region in Indonesia experiences growth with high enthusiasm for infrastructural development, there is also a huge need for waste management. Indonesia still relies on human power to manage waste in the streets while other countries have been using sweeper cars (vehicles for sweeping up the waste) which can increase effectiveness of cleaning the waste in the streets. It is time for Indonesia to own or to try producing its own eco-friendly sweeper car units at a lower cost, considering that in general sweeper cars in the market are still running on fossil fuel which is not eco-friendly. Two factors above support the idea of developing technology for electric sweeper cars to reduce air pollution.



Figure 1: A sweeper car, Tennant 636 [3]

This prototype of electric sweeper car is a unit that works by sweeping up the waste in the streets. This unit is also equipped with a vessel that will be able to hold a large capacity of waste in addition to a trash crushing system that functions as a waste crusher before the waste goes to the vessel. This unit later will hold the weight of the waste and sweeper car's heavy components. For this reason, a strong chassis design needs to be created in order to give the unit an impression of being strong. To produce a chassis design that is strong, a test or simulation in the form of stress analysis is required to determine the safety factor of the chassis.

II. THEORETICAL FRAMEWORK

2.1 Electric Vehicle

Electric vehicle (EV) is a vehicle that is mainly powered by electricity [4]. This electric sweeper car prototype is driven by brushless direct current (BLDC) electric motor that takes its electrical energy from a battery. This unit is powered by ten batteries that are located under the vessel. A controller is being used to control the drive system of the EV by adjusting current and voltage that flow out of the battery to the motor.

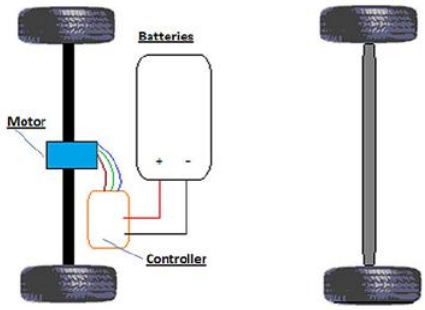

Figure 2: EV's power flow scheme [5]

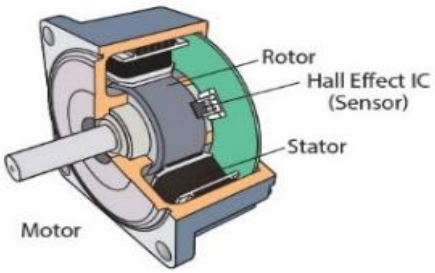

Figure 3: Brushless Direct Current (BLDC) [5]

2.2 Chassis

Chassis is a frame that bears the weight of the vehicle, engine, and passengers. This prototype uses ladder frame type of chassis. The special feature of a ladder frame is it is ladder-shaped and positioned at the bottom part of the body. Ladder chassis is solid and strong, separated from the body. Connecting both chassis and body is a mounting that absorbs the shock from the road, preventing it from reaching the body or cabin. The advantages of ladder frame are its flexibility to design, suitability for heavy vehicles, and durability. On the other hand, the disadvantage of having ladder frame is the weight that is heavier than other chassis models [6].



Figure 4: Ladder frame chassis structure

2.3 Loading on Chassis

The loads carried by the chassis of an electric vehicle are the weight of batteries, passengers, and the overall weight of electric vehicle's body and therefore the chassis will exert forces on itself causing deflection and tension.

1. Maximum Stress

Tensile strength, sometimes called ultimate strength, is a maximum stress a material can hold before it snaps (a state called breaking). Tensile strength value of a material or a bar is often used to determine its maximum stress value which eventually can determine maximum load a surface can hold.

2. von Mises Stress

According to von Mises [7], a failure is predicted to happen under multiaxial stress condition if distortion energy per unit volume is equal to or greater than distortion energy per unit volume when a failure encountered in simple uniaxial stress test against specimen from the same material.

A stress produced in the component after static loading of a weight that is carried slowly, without shock, and held at constant value is called static stress. An example is a load on a structure because of dead load of a frame component [8].

3. Weight Force

Weight is the Earth's gravitational force exerted on an object. Weight is one of some forms of force, hence weight force. Mass is the quantity of materials contained in an object. Mass is always constant wherever the object is.

4. Inertia Momentum

Inertia momentum is the measurement of inertia of an object to rotate around its axis. Inertia momentum plays a role in rotational dynamics such as mass in basic dynamics, and it defines the relationships between angular momentum and angular velocity, between force momentum and angular velocity, and other several units of measurement. As in the Earth that keeps spinning around its axis, there is inertia in rotational motion [9].

5. Centered Weight and Maximum Momentum

Centered weight is a weight concentrated at a certain point.

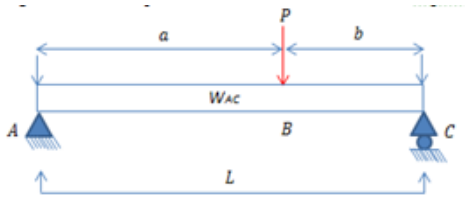

Figure 5: Centered weight [10]

2.4 Safety Factor

Safety factor is a factor value which is used to evaluate calculation process in a design by dividing maximum yield point stress by allowed working stress. The mathematical calculation of safety factor of pliant light steel, and having yield stress with static loading model is as follows [11]:

$$Safety\ factor = \frac{yield\ \ point\ \ stress}{working\ \ or\ \ design\ \ stress}$$

Before deciding on the right safety factor, several aspects need to be considered ahead of the design process:

1. Material strength and form change when weight is loaded.
2. Accuracy of the material strength test result and its application on the components that will be made.
3. Material toughness while carrying loads.
4. Endurance during loading failure.
5. Simplification of model assumption.
6. Width of area that is affected by the loading.
7. Safety level while holding weight during production.
8. Endurance against damage during loading failure.
9. Endurance against form change during loading failure.

III. RESEARCH METHODOLOGY

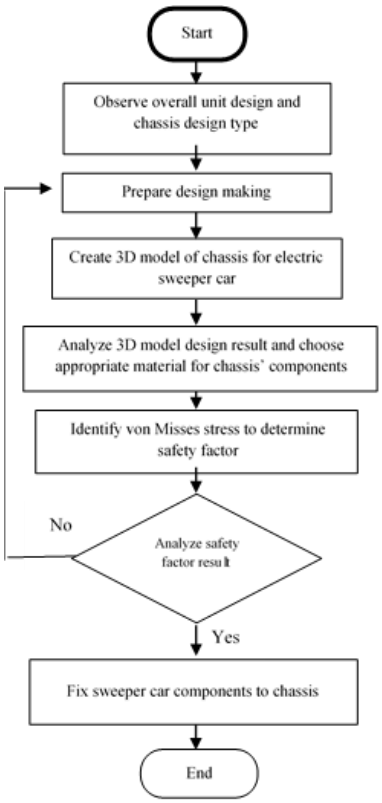

Figure 6: Flowchart

The workflow of an electric sweeper car is as follows: sweeper car sweeps up the waste, sand, gravel in the streets by collecting them using a sweeper driven by an electric motor located in the sweeper's arm. Collected waste is then sucked by a blower through suction hose and goes to the vessel. Meanwhile, the waste will be lifted by a conveyor to be crushed by the crusher inside the vessel. The components that make up the prototype of electric sweeper car can be seen in Figure 3.3 and Figure 3.4.



Figure 7: The prototype of electric sweeper car



Figure 8: The prototype of electric sweeper car

Keys:

1. Blower
2. Generator
3. Cylinder
4. Crusher
5. Conveyor
6. Hydraulic Tank
7. Roller
8. Cabin
9. Sweeper
10. Vessel

IV. RESULT AND DISCUSSION

In designing electric sweeper car prototype, some details about dimensions of several pickups were used as reference:

	Daihatsu Grand Max	Mitsubishi L-300	Suzuki Carry
Total Length (mm)	4.045	4.170	4.155
Total Width (mm)	1.670	1.700	1.680
Height (mm)	2.070	1.845	1.865
Wheelbase (mm)	2.650	2.200	1.970
Ride Height (mm)	175	200	180
Total Weight (kg)	2100	2.540	2.085
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Ride Height (mm)	175	200	180
Total Weight (kg)	2100	2.540	2.085

Table .1 Dimensions of pickups

The prototype of electric sweeper car was designed with Suzuki Carry as a reference since it has appropriate dimensions for an electric sweeper car prototype.
Electric sweeper car prototype is different from other sweeper cars because it is an eco-friendly sweeper car which is driven by electric motor drawing electricity from battery.

4.1 Components of Electric Sweeper Car Prototype

The prototype has ten different components (cabin, sweeper, cylinder, vessel, generator, crusher, conveyor, roller, blower, and hydraulic tank) with total mass being borne by the chassis of 1457 kg. When the unit of electric sweeper car prototype is in operation, lifting the waste, the weight which is borne increases, for example 700 kg of waste will result in 2157 kg of total mass being borne by the chassis.
W = 2,157 kg × 9.81 m/s2
W = 21,160.17 N
Moreover, obtained is a value of weight force of all components that is being borne by the chassis as many as 21,160.17 N. This weight force later will be used as a loading value when stress analysis, displacement, and strain tests are conducted using SolidWorks Simulation 2017 software.

4.2 Loads Distribution and Maximum Momentum Calculation

An analysis of electric sweeper car prototype dynamics is defined by assuming that the center of gravity which is borne by the vehicle is distributed centrally. For this reason, it is required to calculate even loads distribution and maximum momentum borne.

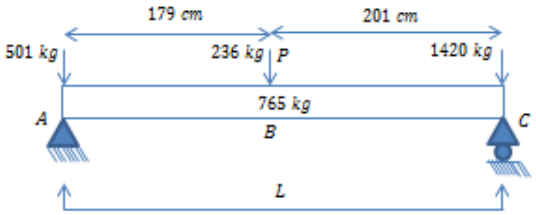

Figure 9: Loads Distribution and momentum

Based on figure above, it is identified that point A is the front wheel and point C is the rear wheel. Thus, a calculation process can be performed to determine centered weight by finding weight at point A and C. Distance is identified as 380 cm in length.

Furthermore, weight carried at point A is:

$$\Sigma T_C = 0$$

$$W_C.(L_{CC}) + W_B.(L_{BC}) + W_{AC}.\left(\frac{1}{2}L_{AC}\right) + W_A.(L_{AC}) - N_A.(L_{AC}) = 0$$

1420 (0) + 236 (201) + 765 (190) + 501 (380) - N_A(380) = 0
0 + 47436 + 145350 + 190380 + N_A(380) = 0
383166 - N_A(380) = 0
N_A (380) = 383166
$N_A = 1008\ kg$

In addition, weight carried at point C is:

$$\Sigma T_A = 0$$

$$N_C.(L_{AC}) - W_B.(L_{AB}) - W_{AC}.\left(\frac{1}{2}L_{AC}\right) - W_C.(L_{AC}) - W_A.(L_{AA}) = 0$$

N_C(380) –236 (179) –765 (190) –1420 (380) - 501(0) = 0
N_C(380) – 42244 – 145350 – 539600 – 0 = 0
N_C(380) = 727194
$N_C = 1913\ kg$
Identified in the calculation above that weight value at point A is $1008\ kg$ while weight value at point C is $1913\ kg$. Therefore, the value of maximum momentum is:

$$P = \frac{F}{A} = \frac{236\ kg\ .9{,}81\ {}^{m}/_{s^2}}{3{,}8\ m\ .0{,}06\ m}$$

$$= \frac{2315{,}16}{0{,}228}$$

$$= 10154\ {}^{N}/_{m^2}$$

$$Mmax = \frac{10154\ {}^{N}/_{m^2}\ .\ 1{,}7\ m\ .\ 2\ \text{m}}{3{,}8\ m}$$

$$= 9085{,}15\ {}^{N}/_{m}$$

Based on the calculation, the obtained maximum momentum value is 9085,15 ${}^{N}/_{m}$.

4.3 Inertia Momentum and Maximum Stress Calculation

Weight values of 1008 kg and 1913 kg for point A and C respectively have been obtained from previous loads distribution calculation. On the other hand, maximum momentum that the chassis can hold is 9085,15 ${}^{N}/_{m}$.

Afterwards, a calculation of chassis inertia momentum is performed.

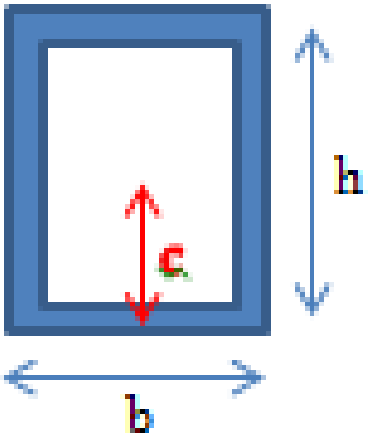

Figure 10: An example of inertia momentum calculation

Given:
b = 6 cm

h = 10 cm

c = 5cm = $5x10^{-2}$ m

Then, a solution to inertia momentum formula is:

$$I = \frac{0{,}06\,m \times (0.1\,m)^3}{12} = 5 \times 10^{-6} m^4$$

It is identified in designing chassis that the material is hollow block in shape. After inertia momentum is identified, the next step is to find out the value of maximum stress on the chassis using maximum stress formula.

$$\sigma \max = \frac{9085{,}15\ {}^{N}/_{m} \times 5x10^{-2}}{5x10^{-6} m^4}$$

$$\sigma \max = 9085{,}15x10^{4}$$

$$\sigma \max = 9{,}08x10^{7}\ {}^{N}/_{m^2}$$

From calculation above, maximum stress the chassis can bear is able to be identified, which is $9{,}08x10^{7}\ {}^{N}/_{m^2}$.

4.4 Sweeper Car Chassis Design

In production process, the length of the chassis is 381 cm and its ride height is 26 cm. Th following is the result of the design using SolidWorks 2017 software:

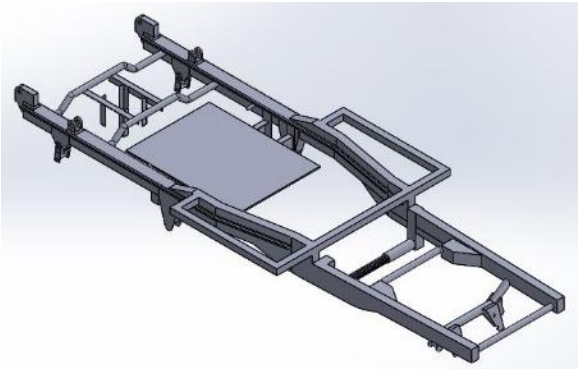

Figure 11: The chassis design with the battery located underneath the vessel

The prototype is using ten batteries as its main power source so an easy access to the batteries is needed while performing battery removal and installation process. As seen in Figure 11. batteries are located underneath the vessel. This position allows a technician an uninterrupted access in order to perform removal and installation process because the vessel can still carry out dumping operation.

4.5 Safety Factor Analysis of Chassis

SolidWorks 2017 allows a simulation of the weight's center of gravity applied on the object. The following is the center of gravity as defined by SolidWorks 2017:

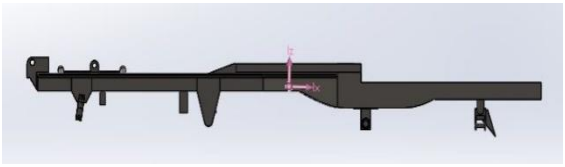

Figure 12: The center of gravity of chassis

It is identified that the chassis of the prototype is made of AISI 1045 material with 60 mm wide, 100 mm high, and 1 mm thick. The analysis process of the chassis design includes calculating both chassis' weight and von Mises stress on the chassis when weight force is applied.

This analysis aims to determine the safety factor value of the chassis design against static load while being operated. The value of component weight based on the prior calculation is 21,160.17 N. Material used is AISI 1045 mild steel with yield stress as much as 530 MPa.

The result of the test is as follows:

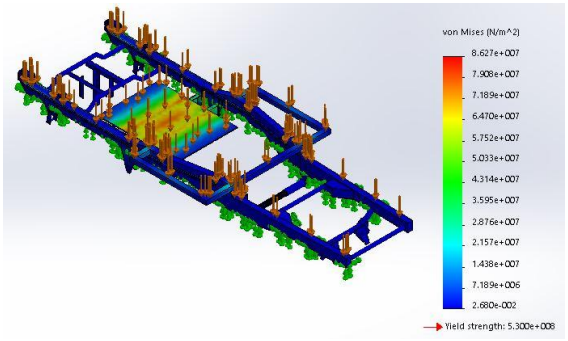

Figure 13: Stress analysis test result

Based on the von Mises analysis result performed, maximum stress applied on the chassis is 86,2 MPa while the minimum stress is 0,0002680 MPa and the yield stress is 530 MPa. Therefore, safety factor can be determined as shown below:

$$\textit{Safety Factor} = \frac{530\ MPa}{86{,}2\ MPa}$$

$$\textit{Safety Factor} = 6{,}14$$

Based on the calculation above, safety factor value is identified as 6.14 which is considered **SAFE** to hold a weight as much as 21,160.17 N. A construction of a model or a design is considered **FAILED** if its safety factor is less than one (≤1).

V. CONCLUSION

Based on the research result and the analysis of chassis construction structure for the prototype of electric sweeper car using SolidWorks 2017 software, the result shows that AISI 1045 mild steel is used as the material with carbon value of 0.43% – 0.50% and is hollow solid block-shaped with length of 60 mm, height of 100 mm, and thickness of 1 mm.This material is chosen because of its easy molding and good engine capability as well as its high ultimate and yield strength with maximum yield stress of 530 MPa.

Finally, safety factor analysis with von Mises stress analysis yielded data showing that maximum stress value is 86.2 MPa with safety factor of 6.14.

Based on all data above, then the chassis design for the electric sweeper car prototype is SAFE.

5.1 Hydraulic System Design

The hydraulic system of the electric sweeper car uses PPC valve control to drive the sweeper cylinder and the arm cylinder. The dump vessel part (which controls vessel cylinder and vessel door cylinder) can be controlled by a switch that is used to move the solenoid.

See attached FluidSIM Hydraulic Circuit.

5.2 Power Requirement for Motor

Based on the calculation above, it can be inferred that to pump 50.77 bar of working pressure, the power required is 106.28 Watts. The power from the shaft is 118.08 Watts and the minimum power from the electric motor is 131,02 Watts and therefore the electric motor selected has 0.55 kW power and 0.75 HP with full load speed of 1,425 rpm.

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