ANALYSIS OF VON MISES STRESS OF SWEEPER COMPONENT IN ELECTRIC SWEEPER CAR PROTOTYPE

[1]PUJI PRASETYO, [2]ELVAN ARYDONI BUDI SUSILO, [3]WIKAN SAKARINTO, [4]ISWORO DJATI

[1,2,3,4]Mechanical Engineering, Vocational College/Gadjah Mada University, Jl. Yacaranda Sekip Unit IV, Caturtunggal, Depok, Sleman, Daerah Istimewa Yogyakarta

Abstract - Indonesia is in the second place of the world's countries that produces the most plastic waste after China. As a solution, large cities in Indonesia such as Jakarta, Bandung, and Yogyakarta have started to take special care of their waste management by taking advantage of sweeper cars. The purpose of this special care is to increase effectiveness and rate at which waste removal is performed. High price has been one of the factors that hinders the possession of sweeper cars by other cities, considering the need to import one. Therefore, a research that aims to produce a design of more affordable and eco-friendlier sweeper car needs to be carried out, given that a sweeper car generally uses fossil fuel which produces air pollution as a result of its exhaust gas. A prototype of electric sweeper car is a new technology of sweeper car that is eco-friendly since it is powered mainly by electricity so that it does not produce exhaust gas. This research aims to produce a design of sweeper component with safe and efficient mechanical system. The design process was done on SolidWorks 2017 software and proceeded by Finite Element Analysis which seeks to analyze the characteristics of static load on sweeper component and to determine its von Misses stress and safety factor. The design of the component produced a result which shows that material used for the sweeper is AISI 1045 mild steel with yield stress of 530 MPa and housing motor's safety factor of 23.5, letter C's safety factor of 29,12, triangle plate's safety factor of 10,33, and letter U's safety factor of 8,52, and arm top/bottom's safety factor of 76,92. Overall safety factor of the component is more than one, which is then considered safe.

Keywords - Sweeper, Safety Factor, Von Mises Stress, Electric Sweeper Car.

I. INTRODUCTION

Waste in urban areas is a never-ending problem. This is due to high population density in big cities in Indonesia which is supported by the consumerism behavior of the population itself. High population density will have implications of piling up leftover of consumed products in the form of waste, organic and inorganic, and has been a real challenge faced by almost every big city in Indonesia. Now, Indonesia is in the second place of being a country that produces the most plastic waste after China [1]. Taking these phenomena into account, there is a need to give special care to the problem in management, government policy, quality of human resources, and technology aspects that can address the problem [2].

As technology advances, the mechanism for waste removal becomes easier with sweeper cars that are useful to sweeping up litter in the streets effectively. It is suggested that sweeper car units which are mainly support tools do not contribute to the damage of environment, that is air pollution. This has provided the foundation for producing prototype of electric sweeper car units with electricity as the power source (electric car) considering the functionality aspect of an electric car that do not produce exhaust gas [3].

The prototype of electric sweeper car uses sweeping mechanism in the form a sweeper with a sweeping arm that connects the sweeper to the chassis. The difference in the chassis of existing sweeper cars becomes the background of the research on safety factor of sweeper component. Therefore, this research aims to calculate stress distribution experienced by sweeper component as a result of static loading as well as identifying safety factor that the material of sweeper component has so that the material of sweeper component is categorized as safe or feasible to be operated in the electric sweeper car prototype.



Figure 1: Design of Electric Sweeper Car

II. THEORETICAL FRAMEWORK

Electric vehicle (EV) is a vehicle that makes use of electricity as its main power source. Electric vehicle becomes an alternative in deciding power source for vehicle because of several reasons that are considered to be beneficial, from reducing cost of maintenance as it has only a few spare parts to eliminating gasoline usage including exhaust gas emission [3].

This unit uses brushless direct current (BLDC) electric motor as the main drive, using a controller that operates by changing current and voltage from the battery to the motor. The main drive system consists of inverter and controller that are used to convert direct current (DC) power to alternating current (AC) power. In general, two parts make up the BLDC electric motor: a rotor made of permanent magnet and stator made of three-phase coil [4].

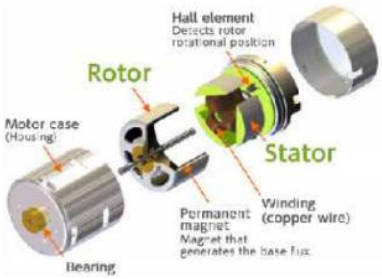

Figure 2: BLDC Motor Construction [5]

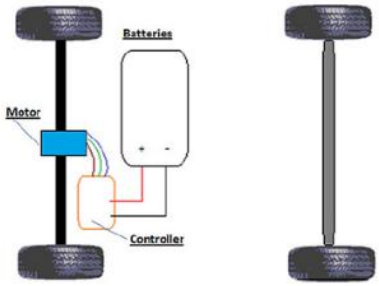

Figure 3: Power Flow Scheme of EV [6]

In the prototype, there are various pieces of working equipment each with different function. This working equipment is supporting component for the sweeper car to do its task. A sweeper is one of the pieces of working equipment that is attached at the very front part of the sweeper car. The purpose of the sweeper is to sweep up litter in the streets such as leaves, plastic waste, dust, etc. [7] The sweeper component with the help of a hydraulic motor works by moving the sweeper vertically and horizontally and a servo motor is used to rotate the sweeper broom.

The mechanism of translational motion performed by the sweeper unit are categorized into two types: vertical and horizontal motions. While not in use, the sweeper arm will get lifted, on the other hand, while in use it will reach the ground and move to the left and right. This mechanism takes advantage of power from the hydraulic motor while the retract and extend motion uses power from hydraulic cylinder with varied extend motion ability based on the type of the hydraulic cylinder.

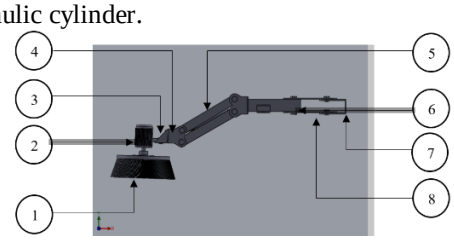

Figure 4: Sweeper Design

Keys:

1. Sweeper Broom	2. Servo Motor
3. Motor Housing	4. Letter C
5. Top/Bottom Arm	6. Rear Letter C
7. Letter U	8. Triangle Plate

The sweeper broom type commonly used in sweeper cars is Gutter Brooms Sweeper because the dimensions of which are not too large and it is suitable to be used to clean up waste in urban areas. Its compact size allows cleaning of hard to reach pieces of waste. Moreover, Gutter Brooms can be moved to the right or left and also clockwise (CW) and counterclockwise (CCW) while being moved by the servo motor.



Figure 5: Gutter Brooms Sweeper

Von Mises stress is a uniaxial tensile stress which can produce energy distortion equal to that produced by working combined stress. This stress is also a stress that causes failure in a material when it receives uniaxial stress that produces strain energy. It is determined that the material will start to yield when the von Mises stress reaches a critical point, usually known as yield strength [8].

von Mises stress is often used to predict the yield level of material when static or dynamic loading is applied from simple tensile test result by taking into account the yield stress of an object against maximum and minimum stress in an object.

In static loading experienced by a component when it carries a weight slowly, without shock, and held at constant value, the stress produced is called static stress. An example is a weight on a structure caused by the dead load of a structure component [9].

Safety factor is a factor value used to evaluate calculation process in a design so that the planning of machine reaches appropriate level of safety despite with as minimal dimensions as possible. Safety factor is a ratio of maximum stress to allowed working stress. A mathematical calculation of the safety factor with static loading model is as follows [10]:

Safety factor = (maximum stress)/(working or design stress)

Choosing the right safety factor in designing a product component depends on several factors such as material type, production method, loading model, field condition, and shape of the component. There are several aspects need to be considered beforehand:

1. Material strength and its shape change during loading,

2. Accuracy of material strength test result and its application to component that will be produced,
3. Material toughness while carrying loads,
4. Endurance during loading failure,
5. Simplification of model assumption,
6. Extent of area affected by loading,
7. Safety level of carrying loads during production,
8. Endurance against material damage during loading failure, and
9. Endurance against shape change during loading failure.

III. RESEARCH METHODOLOGY

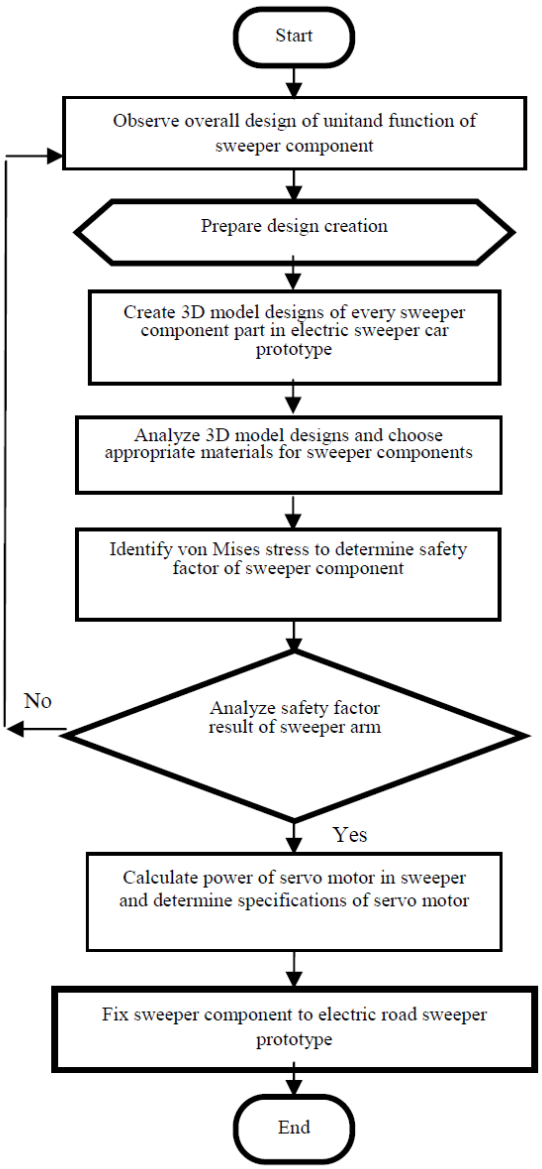

Figure 6: Flowchart

IV. RESULT AND DISCUSSION

The design concept of the sweeper component in electric sweeper car prototype was made based on the actual condition of the location where this unit will be operated. The long sweeper arm design was made to accommodate the design of prototype's cabin which will provide the driver with maximum control over the sweeper component as figured in Figure 7. The design puts the steering wheel in the middle of the cabin, causing the two sweeper arms to be positioned to the left and right side of the driver in parallel which allows direct view of the sweeper component during operation. With adequate field of view, the driver can move the sweeper to the left and right in order to reach for the waste.

The movement of the sweeper itself was designed with hydraulic system which is controlled by a control valve and a hydraulic cylinder as the actuator. The hydraulic cylinder in each sweeper arm uses double acting cylinder, that is cylinder with two active motions: extend and retract motion so it has two ports. The stroke capacity of this type of cylinder is 200 mm in each hydraulic cylinder.

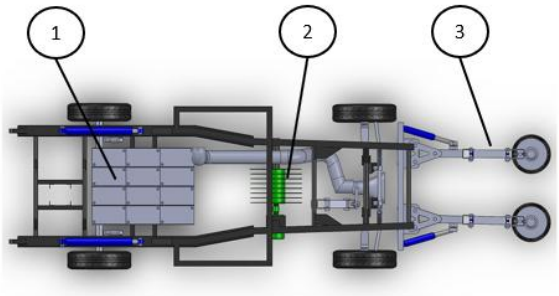

Figure 7: Structural Design of the Prototype

Keys:
1. Batteries Box
2. Roller (Trash Crushing System)
3. Sweeper

4.1 Sweeper Design Result Analysis

The sweeper component which is divided into two parts uses AISI 1045 mild steel as its material with plate thickness of 5 mm for all components in each part. The components of the sweeper are letter U, triangle plate, rear letter C, letter C, top/bottom arm, and motor housing. Those components are shown in Figure 4.2 to Figure 8.

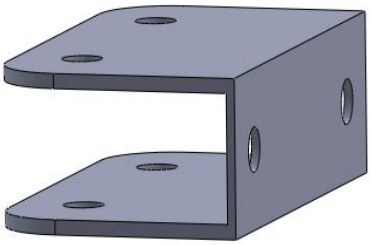

Figure 8: Letter U Component

This component is attached directly to the front chassis of the prototype. Letter U is also a part that holds all parts of the sweeper arm and is static (immovable).

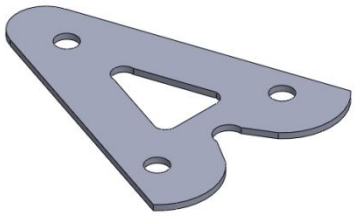

Figure 9: Triangle Plate

Triangle plate is a component located in the rear arm which moves to the left and right. Triangle plate is connected directly to the letter U by a pin to ensure smooth movement of sweeper arm.

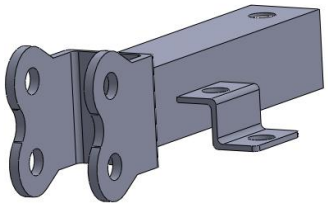

Figure 10: Rear Letter C

Rear letter C functions as a holder for all movement mechanisms performed by the sweeper arm, upward and downward, as well as to the left and to the right. On the outer side of each rear letter C component, there is a mounting whose purpose is to act as a support for hydraulic cylinder which is the main drive of sweeper arm component that drives it to the left and right.

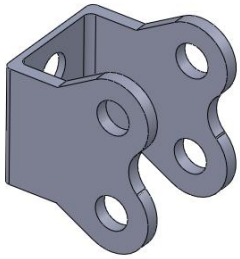

Figure 11: Letter C

The purpose of a letter C is to support sweeper arm movement which is connected to hydraulic cylinder by a shaft. The shaft can make the upward and downward movements easier and smoother caused by the extend and retract activities in hydraulic cylinder which are controlled from the control valve.

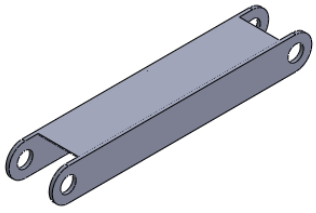

Figure 12: Top/bottom Arm

This component functions as a hydraulic cylinder cover located above and below the hydraulic cylinder. It also serves as the part that connects hydraulic cylinder to each of letter C component allowing sweeper arm movement.

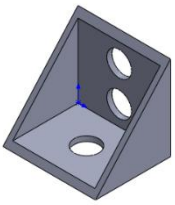

Figure 13: Motor Housing

The purpose of a motor housing is to act as a holder for the servo motor that is connected by a pin with the servo motor and letter C component.

4.2 Analysis of Sweeper Chassis' Safety Factor

The safety factor analysis of each component of the sweeper was performed using von Mises stress analysis, a simulation feature in SolidWorks 2017 software. This analysis aims to determine the safety level of each component when static load is applied to ensure safety during operation. The weight value of the components was assumed to be 324.8 N. Material used is AISI 1045 mild steel with yield stress of 530 MPa.

The test results are shown below:

1. Letter U component

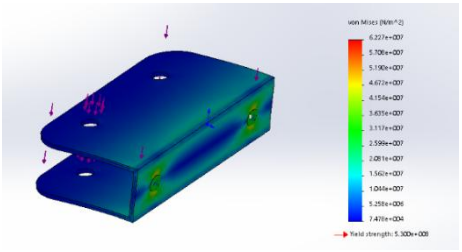

Figure 14: Letter U Component Analysis Result

From the data above, the maximum stress is identified as 62.2 MPa, thus:

Safety factor = "530" /"62,2" = 8,52

The safety factor of the letter U component is more than one and therefore is classified as safe.

2. Triangle plate component

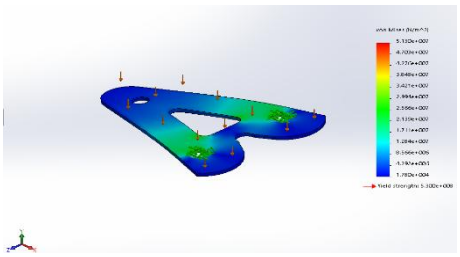

Figure 15: Triangle Plate Component Analysis Result

From the data above, the maximum stress is identified as 51.3 MPa, thus:

Safety factor = "530" /"51,3" = 10,33

The safety factor of the triangle plate component is more than one and therefore is classified as safe.

3. Rear letter C component

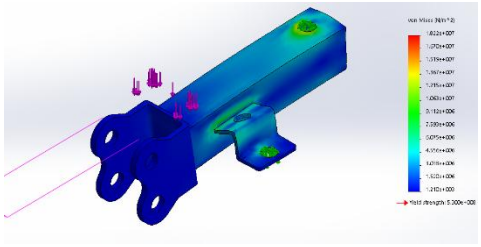

Figure 16: Rear Letter C Component Analysis Result

From the data above, the maximum stress is identified as 18.2 MPa, thus:
Safety factor = "530" /"18,2" = 29,12
The safety factor of the rear letter C component is more than one and therefore is classified as safe.

4. Letter C component

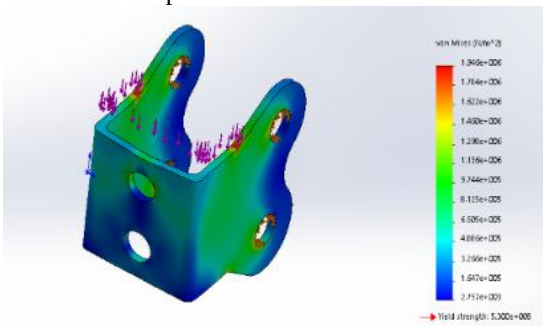

Figure 17: Letter C Component Analysis Result

From the data above, the maximum stress is identified as 1.94 MPa, thus:
Safety factor = "530" /"1,94" = 273,19
The safety factor of the letter C component is more than one and therefore is classified as safe.

5. Top/bottom arm component

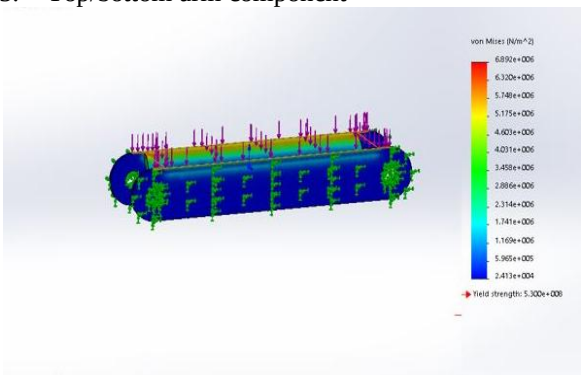

Figure 18: Top/bottom Arm Component Analysis Result

From the data above, the maximum stress is identified as 6.89 MPa, thus:
Safety factor = "530" /"6,89" = 76,92
The safety factor of the top/bottom arm component is more than one and therefore is classified as safe.

6. Motor housing component

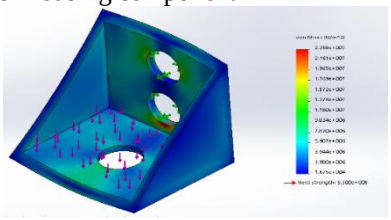

Figure 19: Housing Motor Component Analysis Result

From the data above, the maximum stress is identified as 23.5 MPa, thus:
Safety factor = "530" /"23,5" = 22,55
The safety factor of the motor housing component is more than one and therefore is classified as safe.

V. CONCLUSION

Based on the safety factor analysis using von Mises stress analysis, a feature in SolidWorks simulation software, all components are classified as safe to be used since their safety factor values are more than one. Component with the lowest safety factor value is letter U as it is attached to the front chassis and carries all the loads of sweeper components. On the other hand, letter C has the highest safety factor value.

REFERENCES

[1] J. R. Jambeck, "Plastic Waste Inputs from Land into The Ocean", 769, 2015.
[2] M. A. Budihardjo and B. Zaman, "Optimasi Pengumpulan dan Pengangkutan Sampah Kota dengan Menggunakan Model PowerSim", Vol. 28, No. 2, 2007.
[3] S. A. Adderly, "Electric vehicles and natural disaster policy implications", Energy Policy, 437-448, 2017.
[4] A. Purwadi et al, "Testing Performance of 10 kW BLDC Motor and LiFePO4 Battery", 1075, 2013.
[5] NXP, "BLDC motor control with LPC1700", Rev. 01, NXP Semiconductors, Hongkong, Philips, 2010.
[6] Linden, David, and B. Thomas, "Handbook of Batteries 3 Ed", Amerika Serikat, The McGraw-Hills Companies, Inc, 2002.
[7] A. Pratama, "Analisa Sifat Fisik dan Sifat Mekanik Sweeper Pada Kendaraan Penyapu Sampah", Yogyakarta, Universitas Gadjah Mada, 2018.
[8] V. Bhandari, "Design of Machine Elements", New Delhi, Tata McGraw-Hill, 1994.
[9] R. L. Mott, "Machine Element in Mechanical Design", London, Pearson, 2017.
[10] R. Khurmi and J. A. Gupta, "Textbook of Machine Design", New Delhi, Eurasia Publishing House (PVT), 2005.

★★★