HYDRAULIC SYSTEM DESIGN FOR ELECTRIC SWEEPER CAR PROTOTYPE

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Abstract - Waste problem in Indonesia, especially in the urban areas, has been left unresolved. This phenomenon is caused by the significant increase in the development of urban areas in Indonesia, that contributes to the rise in the remnants of the development in the form of waste. One of the measures taken by the governments to deal with the problem, in addition to using human power to clean up the litter in the streets, is by using sweeper cars. However, the sweeper cars' high price as a result of the import fees has been regarded as an obstacle. Taking this recent condition into account, a research that intends to invent a new technology for more affordable and eco-friendlier sweeper cars needs to be performed, considering sweeper cars in Indonesian market are still using fossil fuel. A prototype of electric sweeper car is a new breakthrough in sweeper car technology as it is mainly powered by electricity. This research aims to design a hydraulic system for the electric sweeper car prototype using SolidWorks software and also to design a hydraulic component layout and a hydraulic circuit (using FluidSIM software), and to calculate the specifications of the cylinder, hydraulic pump, and electric motor. The design yielded a result in the form of specification data of hydraulic system, which consists of several parts: external gear pump with displacement of 1,16 cc/rev and power of 110 watt, electric motor with power of 550 watt and speed of 1200 rpm, cylinder sweeper & arm with inside diameter of 12 mm, rod of 8 mm, stroke of 200 mm, cylinder vessel with inside diameter of 40 mm, rod of 22 mm, stroke of 500 mm. Moreover, cylinder vessel door has inside diameter of 16 mm, rod of 10 mm, stroke of 500 mm, tank with 16 liters capacity, 4/3-way control valve, and solenoid. In addition, sweeper control system uses lever and dump vessel uses button.

Keywords - Hydraulic System, Electric Sweeper Car, Sweeper Car

I. INTRODUCTION

Indonesia, especially in its urban areas, has a never-ending problem called waste. This phenomenon is caused by the significant increase in the development of urban areas in Indonesia, that contributes to the rise in the remnants of the development in the form of waste, organic and inorganic. Therefore, governments in urban areas needs to give special handling to deal with the waste management system. This waste management system consists of waste removal, collection, and transporting [1]. This special handling aims to increase the effectiveness of and rate at which the waste management is handled. Using sweeper cars is one of the actions that the governments take for waste cleaning in addition to making use of human power. However, the sweeper cars' high price as a result of the import fees has been regarded as an obstacle. Considering this condition, a research that intends to invent a new technology for more affordable and eco-friendlier sweeper cars needs to be carried out as sweeper cars in Indonesian market are still using fossil fuel and they will cause air pollution in return as a result of their exhaust gas. A prototype of electric sweeper car is a new breakthrough in sweeper car technology as it is mainly powered by electricity which will not produce any exhaust gas [2]. This research aims to produce a hydraulic system design in the electric sweeper car prototype that has hydraulic system mechanism to drive components such as cylinder of sweeper's driving motor, driving cylinder of sweeper arm, and driving cylinder of dumb or vessel. The main source of the hydraulic system in this prototype is an electric motor used to supply and to transfer motion energy which will move a hydraulic pump to convert mechanical energy to hydraulic energy. This hydraulic energy through the pump's pressure will then distribute itself to the hydraulic cylinder to produce certain movements.



Figure 1: A Sweeper Car, Dulevo 850 [3]

II. THEORETICAL FRAMEWORK

2.1 Electric Vehicle (EV)

Electric vehicle (EV) is a vehicle that uses electricity as its main driving power. This prototype uses ten batteries located underneath the vessel. This prototype also uses brushless direct current (BLDC) as the main drive, using a controller that performs a task of controlling current and voltage that goes 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, BLDC electric motor comprises two parts: a rotor made of permanent magnet and stator made of three-phase coil [4].

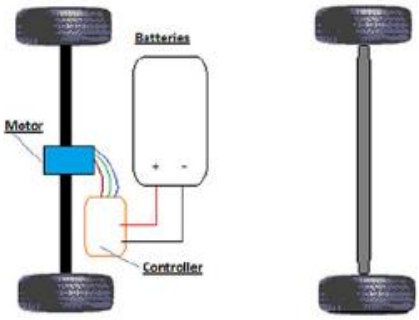

Figure 2: Power Flow Scheme of EV [5]

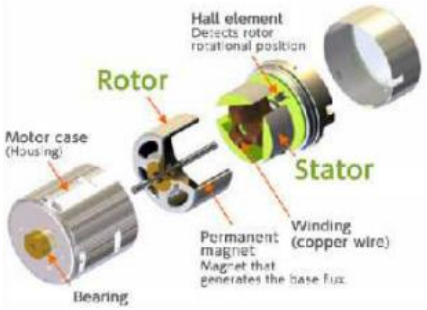

Figure 3: BLDC Motor Construction [4]

2.2 Hydraulic System

Hydraulic system is a system used for transferring power with liquid as a medium to produce movement (work). The basic principle of hydraulic system is a power convert or a power transfer that takes advantage of basic properties of liquid or fluid such as easily adjusting its shape, almost incompressible, distributing its pressure evenly, and flowing from higher to lower level and from higher to lower pressure [6].

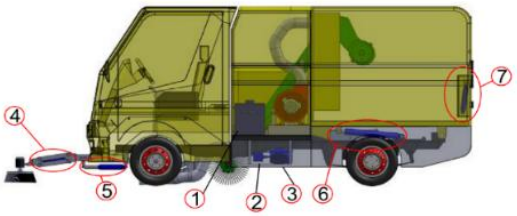

Figure 4a: Parts of Hydraulic System of the Prototype

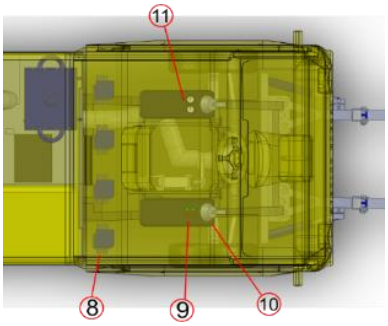

Figure 4b: Parts of Hydraulic System of the Prototype

Keys:

1. Hydraulic tank with 16 liters capacity
2. Hydraulic pump, fixed displacement gear pump type
3. 550-Watt electric motor
4. Sweeper cylinder with inside diameter of Ø7,20 mm and 8 mm cylinder rod.
5. Arm cylinder with inside diameter of Ø7,20 mm and 8 mm cylinder rod.
6. Vessel cylinder with inside diameter of Ø21,36 mm and 22 mm rod cylinder.
7. Vessel door cylinder with inside diameter of Ø8,41 mm and 10 mm cylinder rod.
8. Directional control valve with 4/3 valve.
9. Button to open and close vessel door.
10. PPC lever
11. Manometer

2.3 Hydraulic System Circuit

A hydraulic system circuit is used to simulate the components of a hydraulic system and the flow of the fluid in the system [7]. This design of the circuit was created using FluidSIM software.

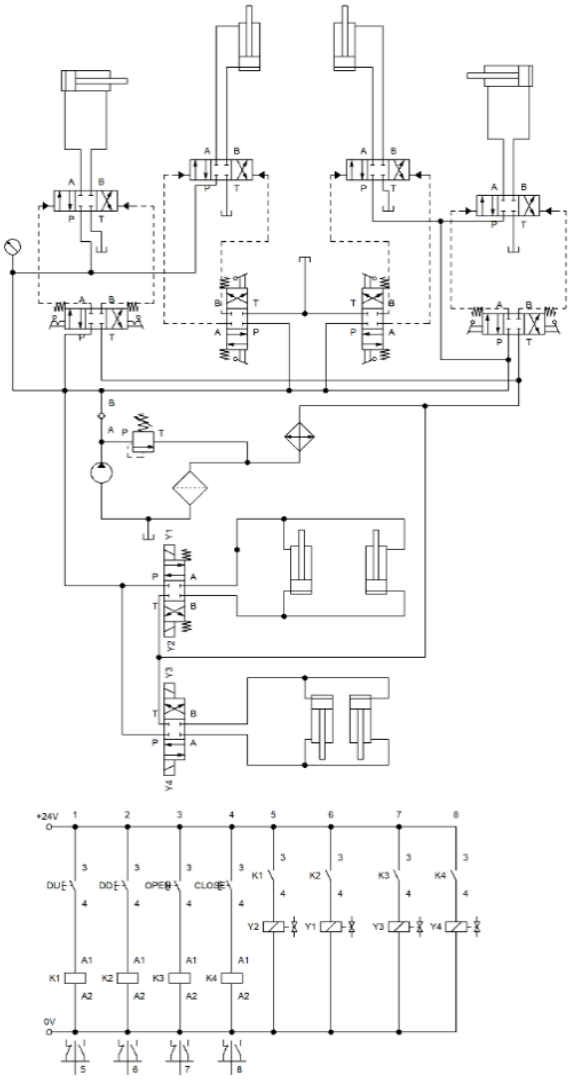

Figure 5: Hydraulic System Circuit of the Prototype

III. RESEARCH METHODOLOGY

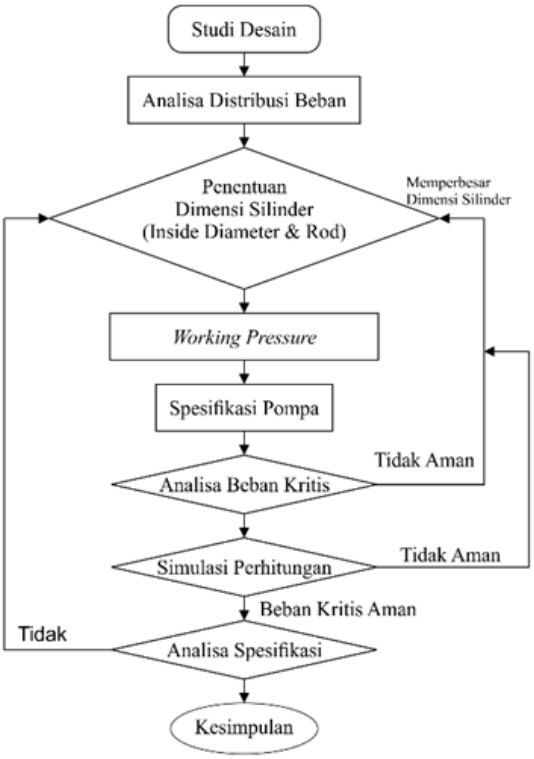

Figure 6: Flowchart

IV. RESULT AND DISCUSSION

4.1 Theoretical Calculation

1. Length and Diameterof Sweeper Cylinder

A sweeper cylinder is a cylinder that drives the electric motor of a sweeper upwards and downwards. There are two sweeper cylinders one on the left side and the other is on the right side. Before determining the diameter of a cylinder, maximum length, minimum length, and stroke of which need to be identified first.

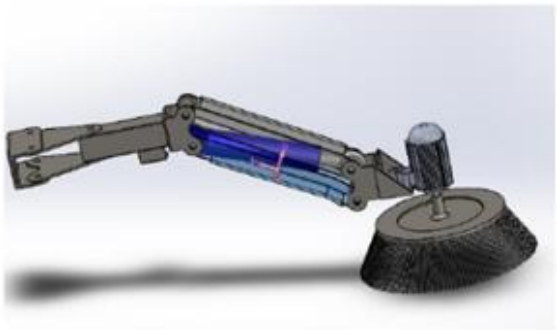

Figure 7: Design of Sweeper Cylinder Showing Its Position

Given: Total mass (m): 35 kg, Modulus elastic modulus (E) of AISI 1045: 190 Gpa = 190000 N/mm², L = 600 mm. The next step is calculating weight force of the cylinder: w = 35 kg x 9,81 (m/s²) = 343.35N, then calculating rod (Pcr) with safety factor Pcr = 2 x 274,68 N = 686,70 N.

From **Table .1** the inside diameter of Ø16 mm can be obtained with the diameter of cylinder rod of Ø8 mm. Afterwards, an analysis of cylinder rod is performed in order to determine whether its condition is safe from buckling. Obtained from data above are work pressure of 34,17 bar and cylinder velocity of 0,003 m/s with flow of 0,04 lpm.

Theoretical Output

OUT ← → IN

The dual rod ensures an output twice that of existing cylinders. (N)

Bore size (mm)	Rod size (mm)	Operating direction	Piston area (mm²)	Operating pressure (MPa) 0.2	0.3	0.4	0.5	0.6	0.7
6	3	OUT	57	11	17	23	29	34	40
		IN	42	8	13	17	21	25	29
8	4	OUT	101	20	30	40	51	61	71
		IN	75	15	23	30	38	45	53
12	6	OUT	226	45	68	90	113	136	158
		IN	170	34	51	68	85	102	119
16	8	OUT	402	80	121	161	201	241	281
		IN	302	60	91	121	151	181	211
20	10	OUT	628	126	188	251	314	377	440
		IN	471	94	141	188	236	283	330
25	12	OUT	982	196	295	393	491	589	687
		IN	756	151	227	302	378	454	529

Note) Theoretical output (N) = Pressure (MPa) x Piston area (mm²)

Table .1 Theoretical Output Cylinder

2. Length and Diameter of Arm Cylinder

An arm cylinder is a cylinder that moves in swinging mechanism, to the left and right. There are two arm cylinders on the left and right sides.Before determining the diameter of the cylinder, maximum length, minimum length, and stroke of which need to be identified first.



Figure 8: Design of Arm Cylinder Showing Its Position.

The analysis result of the arm sweeper is as follows; total mass (m): 35 kg, elastic modulus (E) of AISI 1045: 190 Gpa = 190000 N/mm², L = 600 mm. After finding analysis result, weight force is determined: w = 35 kg x 9,81 (m/s²) = 343.35N, then determining rod (Pcr) with safety factor Pcr = 2 x 274,68 N = 686,70 N.

From **Table .1** the inside diameter of Ø16 mm can be obtained with the diameter of cylinder rod of Ø8 mm. Afterwards, an analysis of cylinder rod is performed in order to determine whether its condition is safe from buckling. Obtained from data above are work pressure of 34,17 bar and cylinder velocity of 0,003 m/s with flow of 0,04 lpm.

3. Length and Diameter of Vessel Cylinder

Vessel cylinder is a cylinder used to move a tank for waste or a vessel for a mechanism. In addition to the

weight of the cylinder, it also bears the weight of a crusher inside the vessel.

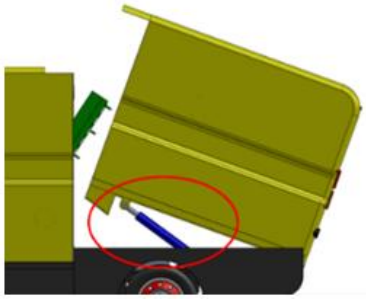

Figure 9: Design of Vessel Cylinder Showing Its Position.

The result of the analysis: total mass (m): 650 kg, elastic modulus (E) of AISI 1045: 190 Gpa = 190000 N/mm², L = 1225 mm. After analysis result is found, weight force of the cylinder is calculated: w = 650 kg x 9,81 (m/s²) = 63.765N, rod (Pcr) is then determined with safety factor Pcr = 2 x 63.765 N = 127.530 N.
Based on **Table .2** inside diameter used is Ø40 mm with the diameter of cylinder rod of Ø22 mm. An analysis of cylinder rod is then performed to determine whether its condition is safe from buckling. Based on the data above, the work pressure is 50,77 bar, cylinder velocity is 0,008 m/s with flow of 1,26 lpm.

Theoretical Output — OUT / IN

Unit: N

Bore size (mm)	Rod size (mm)	Operating direction	Piston area (mm²)	Operating pressure (MPa) 3.5	7	10
40	22	OUT	1256	4396	8792	12560
		IN	876	3066	6132	8760
50	28	OUT	1963	6871	13741	19630
		IN	1347	4715	9429	13470
63	36	OUT	3117	10910	21819	31170
		IN	2099	7346	14693	20990
80	45	OUT	5026	17591	35182	50260
		IN	3436	12026	24052	34360
100	56	OUT	7853	27486	57971	78530
		IN	5390	18865	37730	53900

Theoretical output (N) = Pressure (MPa) x Piston area (mm²)

Table .2 Theoretical Output Cylinder

4. Length and Diameter of Vessel Door Cylinder

Vessel door cylinder is a cylinder that moves vessel door for a dump mechanism in this prototype. There is one vessel door cylinder on either side as shown in Figure 7.



Figure 10: Design of Vessel Door Cylinder Showing Its Position

The vessel door cylinder analysis: total mass (m): 65 kg, elastic modulus (E) of AISI 1045: 190 Gpa = 190000 N/mm², L = 600 mm. After analysis result is obtained, weight force of the cylinder is calculated: w = 65 kg x 9,81 (m/s²) = 6.376N, rod (Pcr) is determined with safety factor Pcr = 2 x 6.376 N = 12.753 N.
Based on **Table .1** inside diameter used is Ø40 mm with cylinder rod diameter of Ø22 mm. Afterwards, an analysis of cylinder rod is performed to check whether its condition is safe from buckling. Based on the data above, the work pressure is 50,77 bar, cylinder velocity is 0,008 m/s with flow of 1,26 lpm.

5. Pump Calculation

To find out the specification of the pump, the value of displacement needed to support the performance of the cylinder used needs to be determined. This protype unit uses gear pump type to support the electric motor. Based on the data analysis, the size of a flow cylinder in the prototype can be determined.
The amount of each component is as follows:
Flow of Sweeper Cylinder : 0,04 lpm
Flow of ArmCylinder : 0,04 lpm
Flow of Vessel Cylinder : 1,26 lpm
Flow of Vessel Door Cylinder : 0,13 lpm
Based on the data above, the largest amount of flow is 1,26 lpm and the rotation when idle is 750 rpm. Based on the calculation of the data, the largest working pressure is 50,77 bar in vessel cylinder. From the calculation, obtained are Displacement (D)=1,16 cc/rev, Torque=1,04 Nm, and Power (P)=0,106 kw. Based on displacement value = 1,16cc/rev, the appropriate pump model is H62.
Based on the calculation above, the power needed to pump 50.77 bar of working pressure is 106.28 Watts. The power from the shaft is 118.08 Watts and minimum power from electric motor is 131.02 Watts.

Performance Data

Flow in Gallons Per Minute — GPM (LPM) — Data Based on 100 SSU Viscosity Fluids at 120°F (49°C)

Pump Model	Displacement IN³ (CC/REV.)	RPM	100 PSI (6.9 Bar)	1000 PSI (69 Bar)	1500 PSI (103 Bar)	2000 PSI (138 Bar)	2500 PSI (172 Bar)
H25	.603 (9.88)	1200	3.02 (11.45)	2.84 (10.76)	2.75 (10.42)	2.66 (10.08)	2.57 (9.74)
		1800	4.54 (17.21)	4.35 (16.49)	4.26 (16.15)	4.17 (15.80)	4.09 (15.50)
		3600	9.07 (34.36)	8.93 (33.84)	8.85 (33.54)	8.78 (33.28)	8.70 (32.97)
H31	.754 (12.35)	1200	3.78 (14.33)	3.58 (13.57)	3.49 (13.23)	3.40 (12.89)	3.30 (12.50)
		1800	5.67 (21.49)	5.48 (20.77)	5.38 (20.39)	5.28 (20.01)	5.19 (19.67)
		3600	11.34 (42.96)	11.19 (42.41)	11.11 (42.11)	11.03 (41.80)	10.96 (41.54)
H39	.942 (15.44)	1200	4.72 (17.89)	4.51 (17.09)	4.41 (16.71)	4.30 (16.30)	4.20 (15.92)
		1800	7.08 (26.83)	6.87 (26.04)	6.77 (25.66)	6.66 (25.24)	6.56 (24.86)
		3600	14.20 (53.82)	14.00 (53.06)	13.90 (52.68)	13.80 (52.30)	13.70 (51.92)
H49	1.178 (19.30)	1200	5.90 (22.36)	5.67 (21.49)	5.56 (21.07)	5.44 (20.61)	5.33 (20.20)
		1800	8.85 (33.54)	8.62 (32.67)	8.51 (32.25)	8.39 (31.80)	8.28 (31.38)
		3600	17.70 (67.06)	17.50 (66.33)	17.40 (65.95)	17.30 (65.57)	17.20 (65.19)
H62	1.473 (24.14)	1200	7.39 (28.01)	7.13 (27.02)	7.00 (26.53)	6.88 (26.08)	6.75 (25.58)
		1800	11.10 (42.07)	10.81 (40.97)	10.70 (40.55)	10.60 (40.17)	10.40 (39.42)
		3600	22.20 (84.14)	22.00 (83.38)	21.90 (83.00)	21.80 (82.62)	21.70 (82.24)
H77	1.842 (30.18)	1200	9.23 (34.98)	8.95 (33.92)	8.81 (33.39)	8.67 (32.86)	—
		1800	13.90 (52.68)	13.60 (51.54)	13.46 (50.79)	13.30 (50.41)	—
		3600	27.70	27.50	27.40	27.20	—

Table .3 Gear Pump Specifications

4.2 Clutch Design Calculation

Connecting hydraulic pump and electric motor using flange clutch and cast iron material with outer diameter of 80 mm, hub diameter of 40mm, thickness of flange of 10mm, and M5 bolt size.

V. CONCLUSION

After designing a hydraulic system and performing analysis in previous chapter, it can be concluded that by doing design analysis as follows:

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.

5.3 Hydraulic System Specifications

The following are design data based on the calculation of sweeper, arm, vessel, and vessel door cylinders:

1. Calculation data obtained:

a. Sweeper Cylinder:
- Inside Diameter = 12 mm
- Rod = 8 mm
- Stroke = 200 mm
- Working pressure needed by each cylinder is 34.17 bars.

b. Arm Cylinder:
- Inside Diameter = 12 mm
- Rod = 8 mm
- Stroke = 200 mm
- Working pressure needed by each cylinder is 34.17 bars.

c. Vessel Cylinder:
- Inside Diameter = 40 mm
- Rod = 22 mm
- Stroke = 500 mm
- Working pressure needed by each cylinder is 50.77 bars.

d. Vessel Door Cylinder:
- Inside Diameter = 16 mm
- Rod = 10 mm
- Stroke = 200 mm
- Working pressure needed by each cylinder is 20.31 bars.

2. The hydraulic pump component that will be used is an external gear pump with displacement value of 1, 16 cc/rev. This type of pump has working pressure of up to 172 bars and rotational speed of 700 to 3600 rpm. Connecting hydraulic pump and electric motor using flange clutch and cast iron material with outer diameter of 80 mm, hub diameter of 40mm, thickness of flange of 10mm, and M5 bolt size.

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