

CHAPTER 4 – RESULT AND DISCUSSION

4.1 Finished AMR

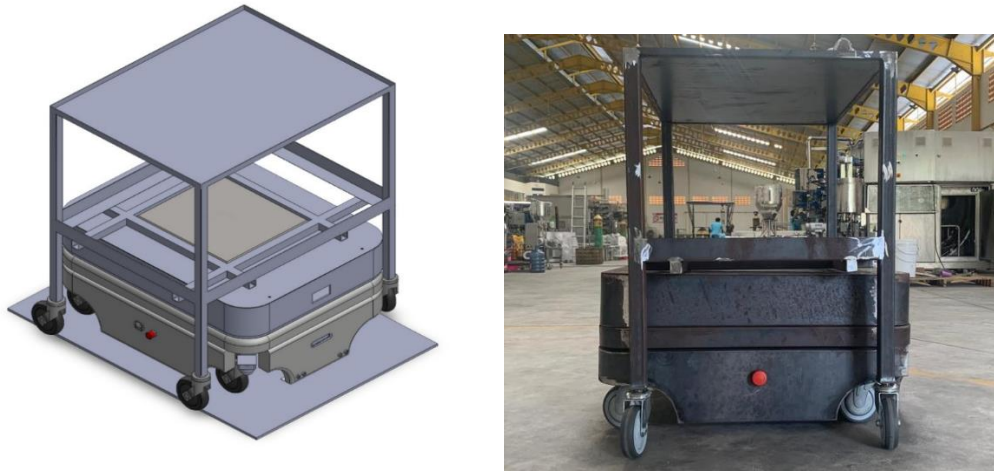


Figure 4. 1 Result AMR Robot

What is shown in the picture is the final design of the mechanical assembly (the AMR Robot, the locking Pin, and The Cart Carrier) made using Solidworks (on the left) and the final robot that has been finalized (on the right picture). This Design completely different from the previous works. In this thesis, three parts of the robot (Robot, locking pin and cart carrier.) was designed properly and minimalist, thus it can be used for industrial needs nor indoor environment. Furthermore, the size and the shape of the robot is important because it will define the length and the width of the whole robot.

4.1.1 The Frame

This is the result and comparison between frame from the design and result after being manufactured. It shows no differences in appearance and the body of the frame successfully developed in this thesis work.

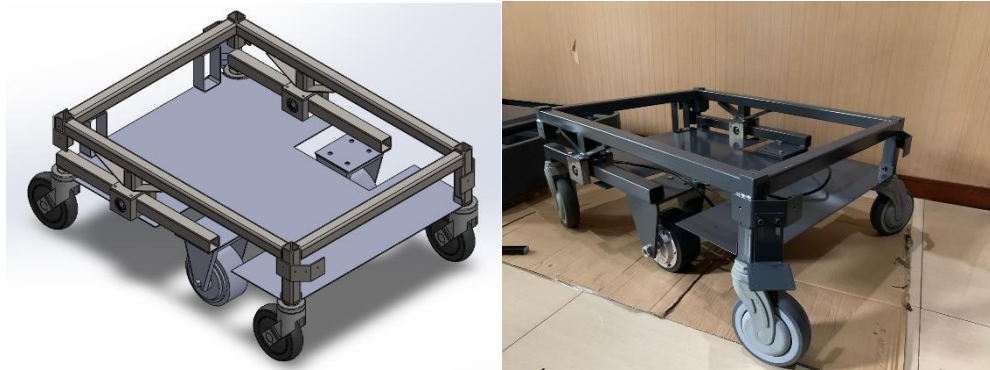


Figure 4. 2 Frame Result

4.1.2 Seesaw Drive Mechanism

The result is developed exactly the same with the design. However, there were some adjustments on the process of manufacturing shaft connector between seesaw shaft and ball bearing. The drive will balance the robot when there is uneven surface.

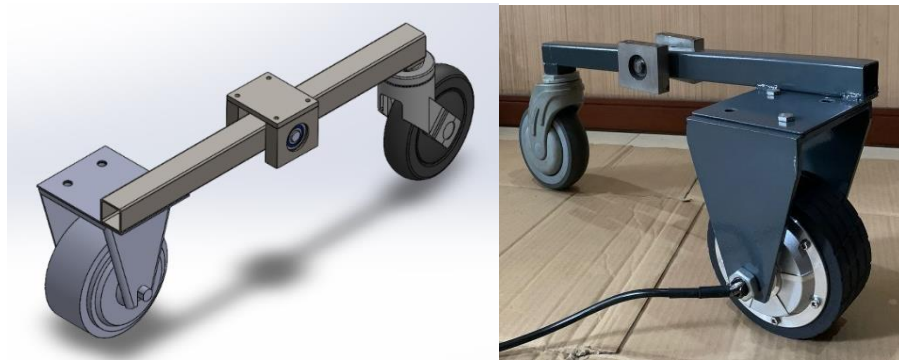


Figure 4. 3 Result Seesaw Drive Mechanism

4.1.3 Covers

The robot that has been design in chapter 3 is finally manufactured in this chapter and shown in picture below. For the result, there is no big differences from robot design and

final result. The appearance practically the same as the design. However, some dissimilarity of the size design and final result occurred. There were some flaws between the design and the final result where the size was not matched to each other parts in every side of the cover when they been assembly in to the robot frame due to some factors.



Figure 4. 4 Result Covers

This flaw is happened because the robot manually manufactured of man-made where human error occurred such as cutting parts of the robot affecting the cutting size result. The welding and grinding were not presentable as the 3D design from Solidworks.

Other reasons some flaws occurred were after all the part had been finished manufacture, it was sent to the paint vendor by manufacture company without further communication. This made some part got more misalignments because the paint vendor did not understand how the parts were being assembly and which side of every part need to be considered for the thickness of the paint. Therefore, some part had thicker surface because the paint used was fairly thick powder coat. Meanwhile, in this condition those part should be places for installing bolts by doing tapping step. Due to thicker surface, some problem occurred such as unfit size part that supposed to fit perfectly and some holes that already have the right size became unequal. So, with the condition of the result of painting with the powder coat, adjustments were made re-tapping some holes and sanding some parts.

4.1.4 Locking System

In this thesis work, Arduino worked well for this robot. It reached the purpose of the locking system where the locking system went upper and lower position by 3 indicator buttons. This indicator button gave function to the signal transmitter informing the stepper motor to go to the normal position, locking position, and stop.

4.1.5 The Cart Carrier

From the picture below (), it can be seen the cart carrier result has no difference appearance from the design. The cart carrier successfully developed exactly the same as the design.



Figure 4. 5 Result Cart Carrier

4.2 AMR Movement Test

AMR movement test was done by using Zltech application to test the movement test. Four condition was given and each condition giving different values of current. This test was done by moving the robot 10 m and the average result was taken.

4.2.1 The Robot

First data was taken by testing and monitoring the condition of robot only. This result was taken by moving the robot and the current was shown in monitor (Zltech application). The result of the current shown in the graphic below;

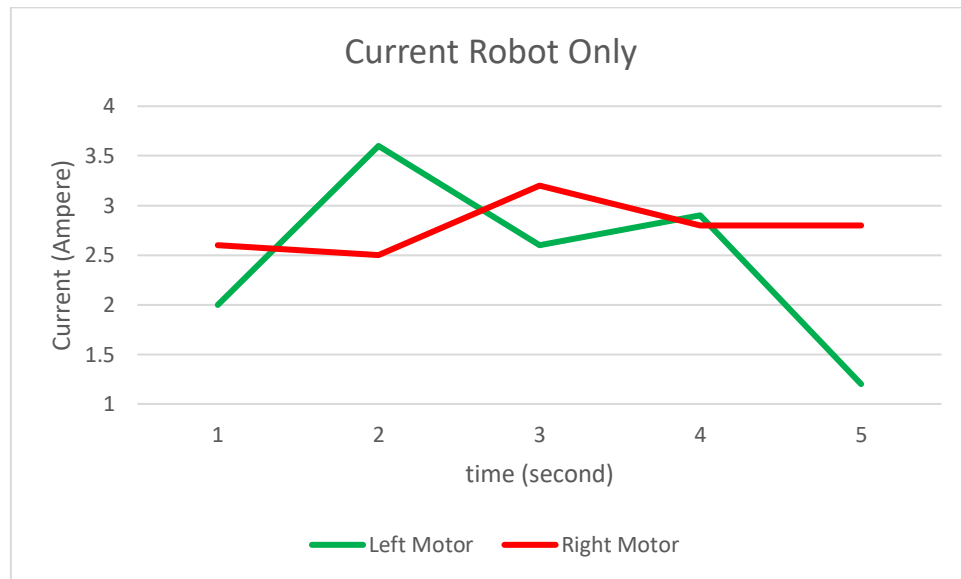


Figure 4. 6 Current Graph Test 1

Based on the graphic, it shown that all the current are below 4 ampere. Left motor and right motor had different result due to some reasons. From the data, the average result was determined. The average of the left motor was 2,46 ampere and right motor resulting 2,78 ampere. This data used to calculate torque and power.

	Left Motor	Right Motor	Voltage
	2	2,6	42,29
	3,6	2,5	42,49
	2,6	3,2	42,32
	2,9	2,8	42,46
	1,2	2,8	42,36
Rate	2,46	2,78	42,384

Table 4. 1 Result Test 1

The robot voltage data was also taken from Zltech application and shown in the graphic below;

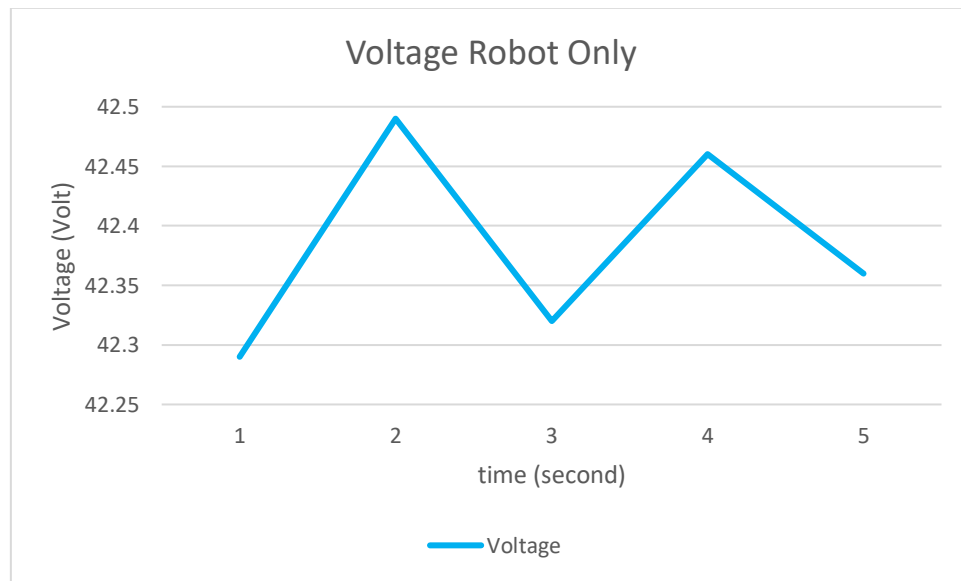


Figure 4. 7 Voltage Graph Test 1

As can be seen from the graphic it shown that the voltage that the motor drains in staible for around 42 Volt.

4.2.2 The robot and Locking System

The second condition data was taken by monitoring the current and voltage when the robot and locking System was attached. The result is shown on the graphic below;

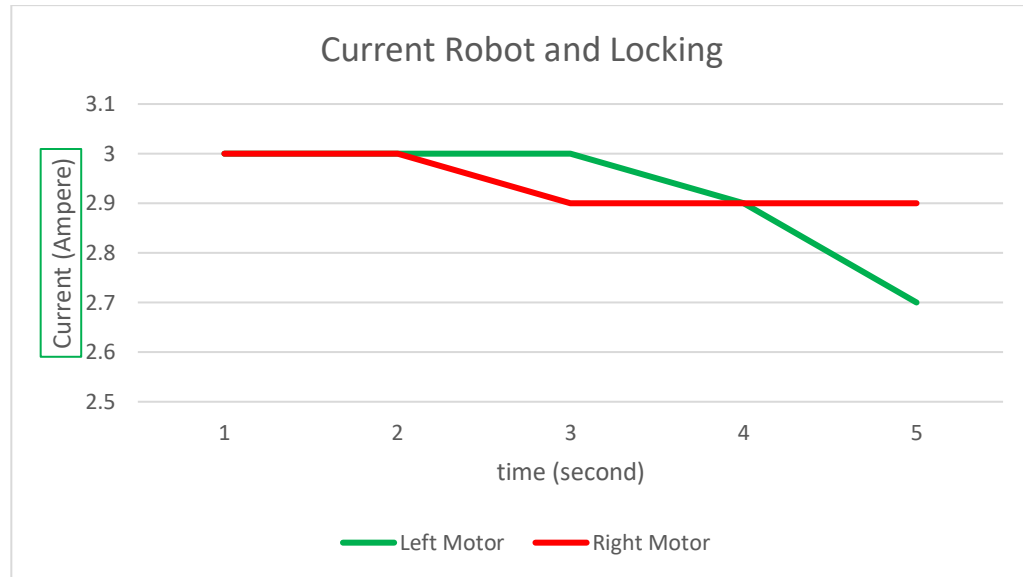


Figure 4. 8 Current Graph Test 2

Based on the graphic, it shown that all the current are still below 4 ampere. Left motor and right motor also had different result.

	Left Motor	Right Motor	Voltage
	3	3	42,25
	3	3	42,23
	3	2,9	42,32
	2,9	2,9	42,21
	2,7	2,9	42,31
Rate	2,92	2,94	42,264

Table 4. 2 Result Test 2

From the data, the average result was determined. The average of the left motor was 2,92 ampere and right motor resulting 2,94 ampere. This data used to calculate torque and power.

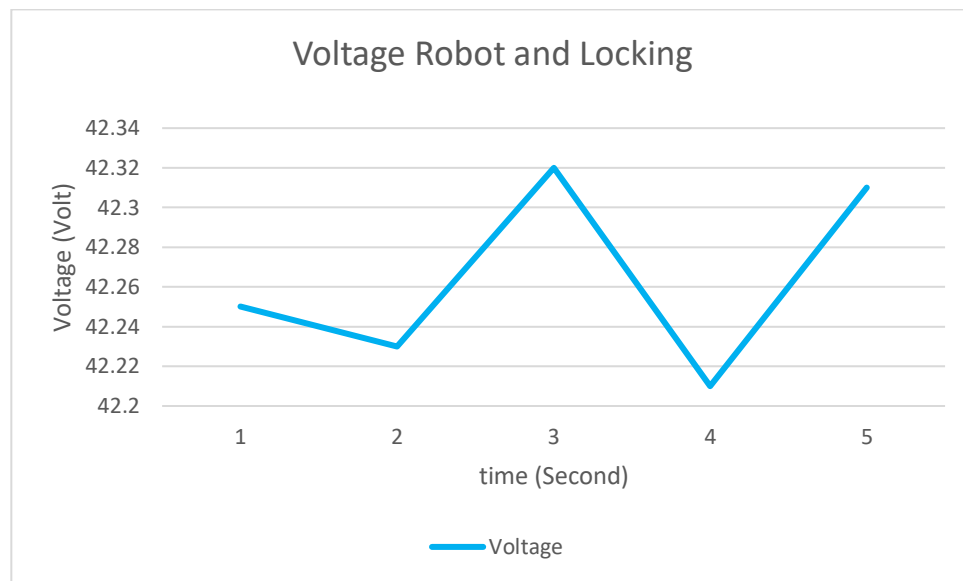


Figure 4. 9 Voltage Graph Test 2

The graphic above is shown the result of the voltage of second condition. The voltage drained is still the same from the first condition, it is resulting 42V.

4.2.3 The Robot, Locking System, and Cart Carrier

Third condition was the robot, locking system, and cart carrier attached at the same time. The data was taken by monitoring the current and voltage. The result shown in graphic below;

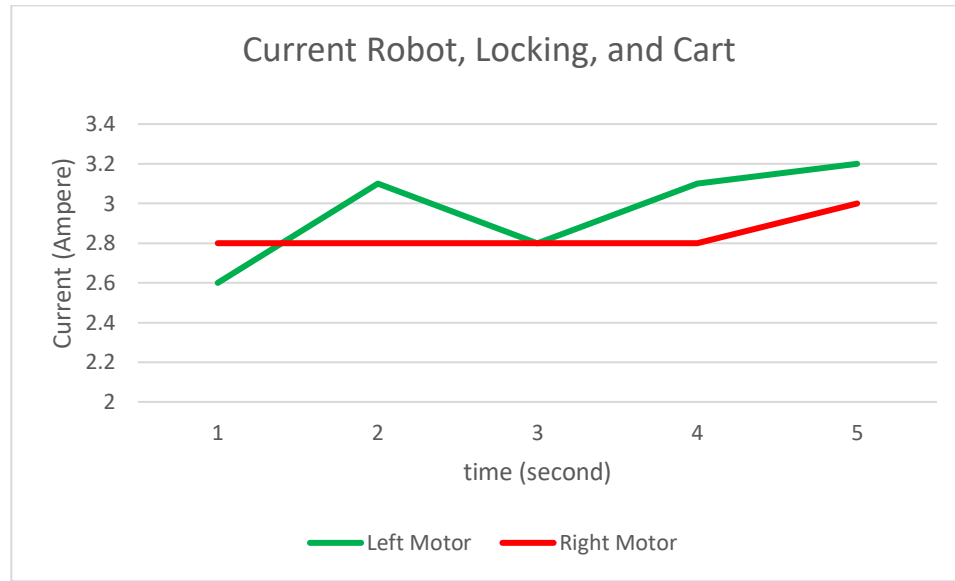


Figure 4.10 Current Graph Test 3

Based on the graphic, it shown that all the current are still below 4 ampere. However, the current is increasing from the first and second condition. Left motor and right motor still had different result.

	Left Motor	Right Motor	Voltage
	2,6	2,8	42,27
	3,1	2,8	42,32
	2,8	2,8	42,21
	3,1	2,8	42,21
	3,2	3	42,07
Rate	2,96	2,84	42,216

Table 4.3 Result Test 3

From the data, the average result was determined. The average of the left motor was 2,96 ampere and right motor resulting 2,84 ampere. This data used to calculate torque and power.

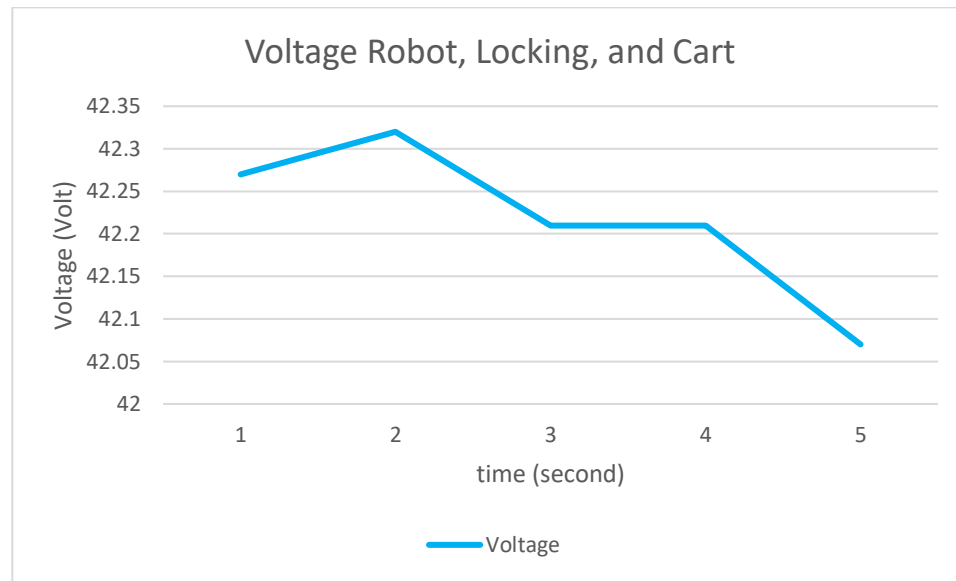


Figure 4. 11 Voltage Graph Test 3

The graphic above is shown the result of the voltage of third condition. The voltage drained is still the same from the first condition and second, it is resulting 42V.

4.2.4 The Robot, Locking System, Cart Carrier, and Extra Load 15kg

The fourth condition is when the Robot, locking System, cart Carrier, and gas cylinder 15kg attached at the same time. This data was done with the condition when the cart carrier given extra 15kg load to carry. The result of the current of the fourth condition is shown graphic down below;

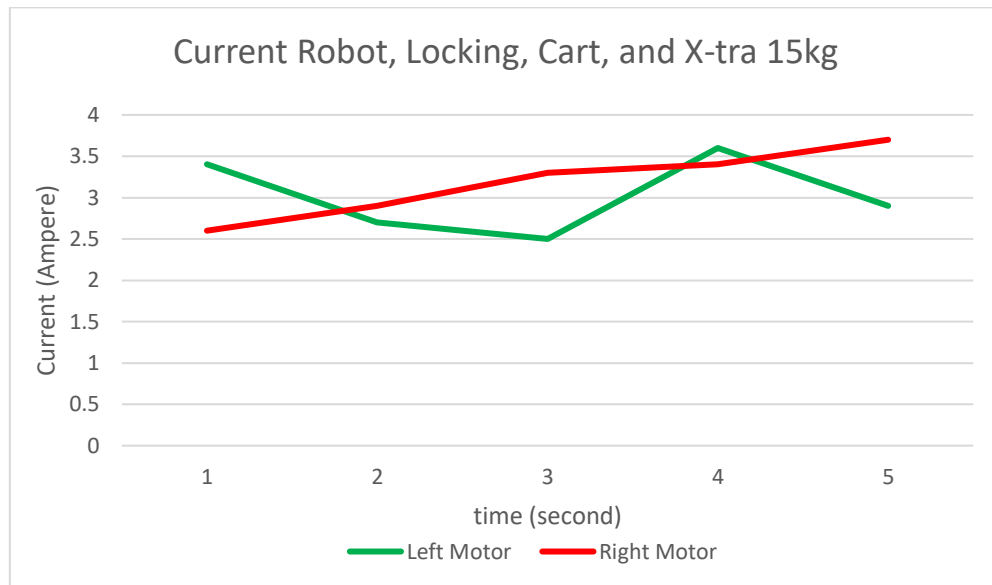


Figure 4.12 Current Graph Test 4

Based on the graphic, it shown that all the current are still below 4 ampere. However, the current is increasing from the first, second and third condition. Left motor and right motor still had different result.

	Left Motor	Right Motor	Voltage
	3,4	2,6	42,38
	2,7	2,9	42,15
	2,5	3,3	42,26
	3,6	3,4	42,17
	2,9	3,7	42,33
Rate	3,02	3,18	42,258

Table 4.4 Result Test 4

From the data above, the average result was determined. The average of the left motor was 3,02 ampere and right motor resulting 3,18 ampere. This data used to calculate torque and power.

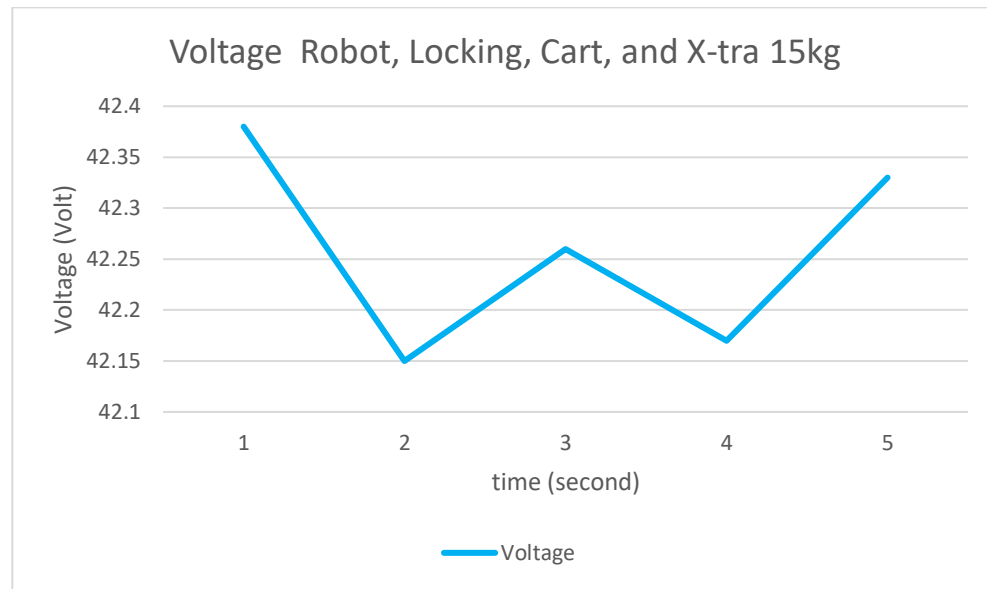


Figure 4. 13 Voltage Graph Test 4

For the voltage itself as can be seen from all the testing condition it is stable result which shown 42V.

As can be seen from all the data above, the current is increasing from first condition to forth condition. The more load received by BLDC Motor, the higher power is drawn by BLDC motor. This situation requires higher torque. Therefore, the BLDC motor will draw more power. Afterwards, the voltage and current result will be entered into the formula to calculate the torque produced by each condition.

4.3 Locking Pin Test Up and Down

The result of this test after several adjustment, Arduino program successfully work. And here the Arduino code result;

```
const int pinPUL = 7;
const int pinDIR = 6;
int buttUP = 21;
int buttDN = 20;
int exeButt = 19;

int buttStateCW;
int buttStateCCW;
int buttStateCCCW;
```

Firstly, there must be some adjustment that need to be defined. In this matter;

- Pin 7 Arduino chosen to be pin that later on will connect to pinPUL- on stepper driver.
- Pin 6 Arduino chosen to be pin that later on will connect to pinDIR- on stepper driver.
- The indicator button UP will be connected to pin 21 Arduino and to the GND
- The indicator button Down will be connected to pin 20 Arduino and to the GND
- The indicator button execute will be connected to pin 19 Arduino and to the GND
- And for buttStateCW, buttStateCCW, buttStateCCCW is will be the substitute name later on.

```
void setup() {
  pinMode(pinPUL, OUTPUT);
  pinMode(pinDIR, OUTPUT);
  pinMode(buttUP, INPUT_PULLUP);
  pinMode(buttDN, INPUT_PULLUP);
  pinMode(exeButt, INPUT_PULLUP);
}
```

Put all digital pin that has been determine to be defined as either “Input” or “Output”.

```
    }

    void loop() {
        buttStateCW = digitalRead(buttUP);
        buttStateCCW = digitalRead(buttDN);
        buttStateCCCW = digitalRead(exeButt);

        if(buttStateCW == LOW && buttStateCCCW == LOW){
            digitalWrite(pinDIR, HIGH);
            //for(int i = 0; i < 5000; i++){
            while(buttStateCCW == HIGH) {
                digitalWrite(pinPUL, HIGH);
                delayMicroseconds(500);
                digitalWrite(pinPUL, LOW);
                delayMicroseconds(500);
                buttStateCCW = digitalRead(buttDN);
            }
        }

        else if(buttStateCCW == LOW && buttStateCCCW == LOW){
            digitalWrite(pinDIR, LOW);
            //for(int i = 0; i < 5000; i++){
            while(buttStateCW == HIGH) {
                digitalWrite(pinPUL, HIGH);
                delayMicroseconds(500);
                digitalWrite(pinPUL, LOW);
                delayMicroseconds(500);
                buttStateCW = digitalRead(buttUP);
            }
        }
    }
}
```

In void loop, “if” and “else if” command been used to control the direction and start stop the stepper motor, by connect it whit 3 button as the trigger identification.

However, some problems occurred in this test. For instance, the rate current of stepper motor NEMA 23 was supposed to have 4.4 Ampere but in driver TB 6600 the maximum peak current is about 4 amperes. Therefore, the driver TB 6600 is changed to Driver 556 because the maximum peak current 5.6 ampere. After changing the driver, the program worked perfectly well.



Figure 4. 14 Driver Stepper DM556

4.4 BLDC Motor Torque Test

In this test, 1 revolution equals to 1 circumference. 1 revolution calculated by using the equation below,

$$C = \pi \times 0.128$$

Eq 1

$$C = 0.40192 \text{ m}$$

So, in this matter 1 revolution is 0.401m. Because of the parameters in truffle test in 1m, then 1m should be equal to 2.5 revolution and because speed is adjusted to 1 m/s so it can be assumed 2.5 revolutions can be achieve in 1 second. Then the result converted to RPM. Thus, the speed that need to set up is 150 RPM. This speed used for all testing condition. Lastly, these data used to obtain torque value.

4.4.1 The Robot Torque

At first condition, the power obtained when the robot attach by using formula below is;

Rate	2,46	2,78	2,62
------	------	------	-------------

$$\begin{aligned}
 P &= V \times I \\
 &= 42V \times 2,62 \\
 &= 110,04Watt
 \end{aligned}
 \tag{Eq 2}$$

The result of power with the robot attach has 2,62A current and 110,04Watt.

After knowing the power of the robot attached, the result is converted to HP resulting;

$$\frac{110,04 \text{ Watt}}{746} = 0.147HP
 \tag{Eq 3}$$

Then, the torque obtained by inputting HP to the formula below;

$$\begin{aligned}
 \tau &= \frac{5250 \times 0,147}{150} \\
 \tau &= 5,162 \text{ lb ft} : 0,73756 \\
 \tau &= 6,99 \text{ Nm}
 \end{aligned}
 \tag{Eq 4}$$

So, the torque that has been issued by the BLDC motor to move this robot is 6,99 Nm

4.4.2 The Robot and Locking System Torque

Second test condition, the power when the robot and locking system attach obtained from this formula;

Rate	2,92	2,94	2,93
------	------	------	-------------

$$P = V \times I
 \tag{Eq 5}$$

$$= 42V \times 2,93A$$

$$= 123,06Watt$$

The result of power with the robot and locking system attach has 2,93A current and 123,06 Watt.

Then, 123,06Watt power convert to HP by using the formula below;

$$\frac{123,06 \text{ watt}}{746} = 0.164HP \quad Eq 6$$

Then, the torque obtained by inputting HP to the formula below;

$$\tau = \frac{5250 \times 0,164HP}{150}$$

$$\tau = 5,773 \text{ lb ft} : 0.73756$$

$$\tau = 7,82 Nm \quad Eq 7$$

So, the torque that has been issued by the BLDC motor to move this robot and locking system is 7,82 Nm.

4.4.3 The Robot, Locking System, and Cart Carrier Torque

On the third test condition, power of the robot, locking system, and the cart carrier attach obtained from this formula;

Rate	2,96	2,84	2,9
------	------	------	------------

$$P = V \times I$$

$$= 42V \times 2,9A$$

$$= 121,8Watt \quad Eq 8$$

The result of power with the robot, locking system, and the cart carrier attach has 2,9A current and 121,8Watt.

121,8Watt power convert to HP by using the formula below;

$$\frac{121,8 \text{ Watt}}{746} = 0,163 \text{ HP} \quad \text{Eq 9}$$

Then, the torque obtained by inputting HP to the formula below;

$$\begin{aligned} \tau &= \frac{5250 \times 0,163}{150} \\ \tau &= 5,714 \text{ lb ft} : 0.73756 \\ \tau &= 7.74 \text{ Nm} \end{aligned} \quad \text{Eq 10}$$

So, the torque that has been issued by the BLDC motor to move this robot and locking system is 7.74 Nm.

4.4.4 The Robot, Locking System, Cart Carrier, and Extra Load 15kg

On the fourth test condition, the power when the robot, locking system, cart carrier with extra 15kg load attach obtained from this formula;

Rate	3,02	3,18	3,1
------	------	------	------------

$$\begin{aligned} P &= V \times I \\ &= 42\text{V} \times 3,1\text{A} \\ &= 130,2\text{Watt} \end{aligned} \quad \text{Eq 11}$$

The result of power with the robot, locking system, and the cart carrier attach has 3,1A current and 130,2Watt.

130,2Watt power convert to HP by using the formula below;

$$\frac{130,2 \text{ Watt}}{746} = 0,174 \text{ HP} \quad \text{Eq 12}$$

Then, the torque obtained by inputting HP to the formula below;

$$\tau = \frac{5250 \times 0,174}{150}$$
$$\tau = 6,108 \text{ lb ft} : 0.73756$$
$$\tau = 8,28 \text{ Nm}$$

Eq 13

So, the torque that has been issued by the BLDC motor to move this robot and locking system is 8,28 Nm.

To sum up, the weightier load is received by motor the higher power required to generate higher torque.

4.5 Battery Durability

After the power that the BLDC Motor drained is obtained.

The power that BLDC motor drained when the condition The Robot, Locking System, and Cart Carrier, and given Extra Load 15kg all attach together has 130,2Watt when it running. So, in this condition the running time can be obtained by this formula;

$$\text{Running time} = \frac{\text{Power Capacity of the Battery}}{\text{The Power Drained by The Motor}}$$
$$\text{Running time} = \frac{432 \text{ Watt hours}}{130,2 \text{ Watt}}$$
$$\text{Running time} = \mathbf{3,31 \text{ hours}}$$

If the battery still has 100% of battery capacity, this calculation should have the same result with the real time running nonstop test.

After running the Robot with the same condition as the calculation above. The result the robot running from the battery in 100% powers until the powers drained out, it takes 3 hours and 10 minutes. Its takes faster to rained out the battery that the calculation before. This difference in value occurs because the unstable current that been drown by the BLDC motor.