DC Servo Motor PID Controller: A Demonstration on Position and Speed

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1 Summary

In the following report we will discuss how we set up the experiment shown in Figure 1 [1]. In the experiment a cart is placed on a conveyor belt, which is controlled by a DC servo motor. There is also another DC servo motor that controls a slotted wheel. The goal is for the cart, which has a plastic rod attached to the top, to move quickly and accurately through the spinning wheel such that the plastic rod slips through the slot without being hit.

There are two parts for this lab that will be performed. The first experiment is for the cart to move back and forth from the wheel so that every time the wheel completes a full rotation, the cart will go through the slot. The second part of the experiment will have a wheel spinning at full speed. The goal is to have the cart to also move really quickly and accurately enough such that it can go through the slot in the spinning wheel.

The following report will take both experiments into account, considering everything from the experiment setup, motor selection, design, and simulations using Simulink.

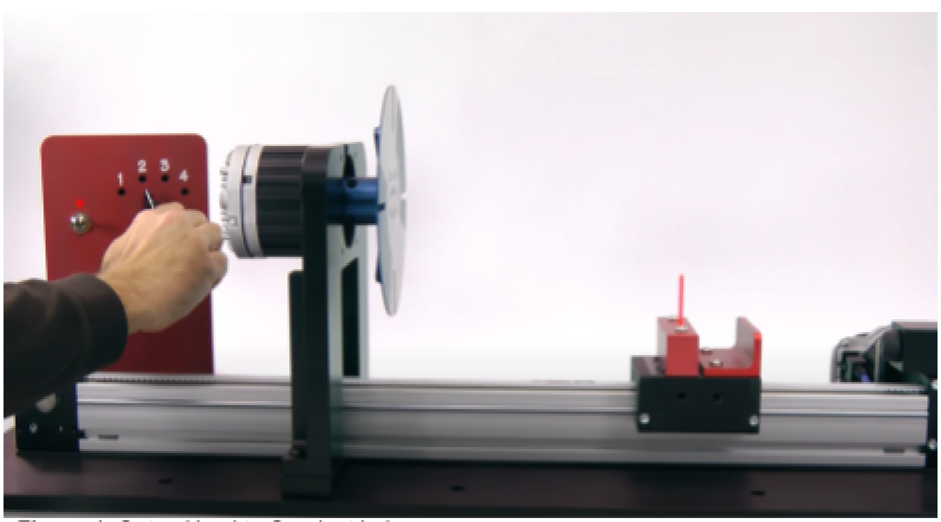

Figure 1: *Setup Used to Conduct Lab*

2 Introduction

In order for this set up to be used in a lab, it is integral to understand how to work with a DC servo motor. The DC servo motor's transfer function, which is the ratio of the angular velocity of the motor's shaft and input voltage, can be seen in Equation 1:

$$\frac{\omega_m(s)}{V_a(s)} = \frac{Km}{L_a J_T s^2 + (L_a B + R_a J_T)s + R_a B + K_m K_b} \quad (1)$$

Note that all the coefficients are dependent on the properties of the DC servo motor used, and they can be found on the respective motor's datasheet. The transfer function is derived by solving the block diagram in Figure 2:

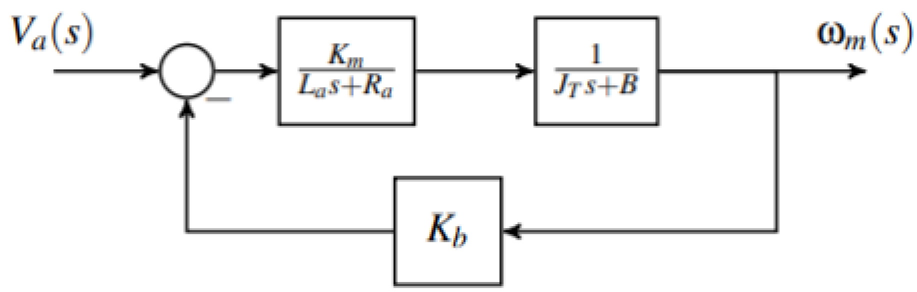

Figure 2: *The Block Diagram Used to Represent the DC Servo Motor*

These DC motors are critical to the experiment as they are what cause the slotted wheel and the conveyor belt to turn. The conveyor belt that is recommended in Figure 3 is recommended as it is relatively portable, light, the same size track as the one used in the video setup, which is approximately 0.7 [m] long [2].

Figure 3: *Conveyor Belt Recommended for Experiment*

The conveyor belt will require a DC servo motor to make it turn, and the DC servo motor that this report will analyze and recommend would be the Mclennan M642RE DC servo motor, shown in Figure 4, as it is comparable to the one used in the video and it has a mostly complete datasheet that was easy to understand [3].

Figure 4: *Mclennan M642E DC Servo Motor*

3 Background

In order to solve how to make the cart seamlessly go through the slotted wheel at the right time for both experiments, we need to consider the following problems: how do we track the position of the wheel using the DC servo motors, when can we move the cart so that the plastic rod goes through unharmed, and how far from the wheel should we keep the cart so that we can pass the cart when the wheel spins at its maximum speed, and how to stop the cart once it goes through the spinning wheel. This experiment will use a wheel with one slot for the sake of simplicity.

We will now consider the first part of the lab- moving the plastic rod back and forth from the spinning wheel. To first solve the problem regarding how to track the angular position of the wheel, we need to recall Equation 1, which is the ratio of the angular velocity and the voltage. When we recall basic rotational kinematics, we can see that we can find the angular position by integrating the angular velocity, as seen in Equation 2. As a result, we can simply track the position of the wheel by inserting a PID controller after the output of the DC servo block diagram as a PID can integrate the output angular velocity into angular position.

$$\theta = \int \omega \, dt \quad (2)$$

In order to move the plastic rod safely through the wheel, we need the wheel to pause for a moment so that the rod can pass, and make sure it repeats that periodically. We can simply do this by inputting a pulse generator so that it can provide power to the motor to spin for one full rotation, and then pause for the cart to go through.

In order to move the rod back and forth, we have to also move it back and forth periodically, just like the wheel. However, unlike the wheel, which returns to its initial angular position by rotating, we need to push the cart back using another external force. We can simply two pulse generators together, with one having the negative amplitude and a delay, so that we can make the cart move when the wheel is not spinning.

Now we will consider the second part of the experiment- having the rod move through the full-speed wheel. In order to make the wheel move in its full speed, we can simply add the maximum voltage of the DC servo motor. In our case the maximum voltage will be 60 [V] for the Mclennan M642R motor. Adding a PID with its integrator functionality, we can track its angular position.

Now to have the cart move through the wheel, we can also turn the conveyor belt at its maximum speed. Once we know the period of the angular position of the wheel, we can assume the same for the conveyor belt motor as they both are running in identical manner. Recall that we can calculate the position of the wheel by using Equation 3, where r is the radius of the sprocket turning the conveyor belt, which is 8.15 [cm].

$$d = \theta \cdot r \quad (3)$$

The distance the wheel turns will be the same as the distance the cart moves on the conveyor belt. Hence, by using the length of the conveyor belt, we can calculate how many wheel rotations we need so that the rod can slip into the slot while not going out of the conveyor belt. The calculations for this can be seen in fuller detail in the solutions.

4 Solution

When considering how to solve both parts of the experiment, it is important to recognize that in both cases the DC servo motors attached to the conveyor belt and to the slotted wheel need to work in conjunction. For the motor that is attached to the wheel, we must track the angular position of the wheel so that we know when the slot is available for the cart to go through. For the cart to go through, the DC servo motor will turn the conveyor belt, which will cause the resting cart to move through the slot.

4.1 Derivation

For the first part of the experiment, we first need to figure out the period of the wheel so that we can design the conveyor belt's action. First we make our block diagram of our motor. In order to first do that, we need to take the block diagram of the DC servo motor and fill the unknown coefficients with the ones specified by the Mclennan datasheet for the M642E DC servo motor, which can be seen in Table 1:

Table 1: Mclennan M642E DC Servo Motor Specifications [4]

Specification	Units	Servo M642E 0860
Maximum Voltage	Vdc	60
Typical Voltage	Vdc	24
Maximum Continuous Output Power	Watts	150
Maximum No-load speed	rpm	4000
Typical speed @ rated torque	rpm	2250
Rated Torque	Nm	0.66
Maximum Peak Torque	Nm	3.3
Typical . No load current	Amps	0.5
Rotor Inertia	$Kgcm^2$	1.2
Mechanical time constant	milli secs	8.1
Torque Constant	Nm / A	0.0816
Voltage Constant	V / 1000 rpm	8.6
Terminal Resistance	Ohms	0.6
Rotor inductance	mH	0.42

For the coefficients in the DC motor block diagram, Kb is the EMF constant, La is the armature inductance, Ra is the armature resistance, and Jt is the total inertia- all which can be found on the data sheet. The coefficients which we do not have yet- Km (motor constant) and B (friction coefficient) we need to solve equations to find them [5]. Equation 4 lets us find Km by using Kt, the motor torque constant, and R, which is resistance. Equation 5 letus us find B by using T, the torque, and w is the angular velocity [6].

$$K_M = \frac{K_T}{\sqrt{R}} \quad [4]$$

$$b = \frac{T}{\omega} \quad [5]$$

Now, to simulate the motor wheel, we will used the previously discussed block diagram for the DC servo motor,and attach a PID and an integrator, which can be seen in Figure 5:

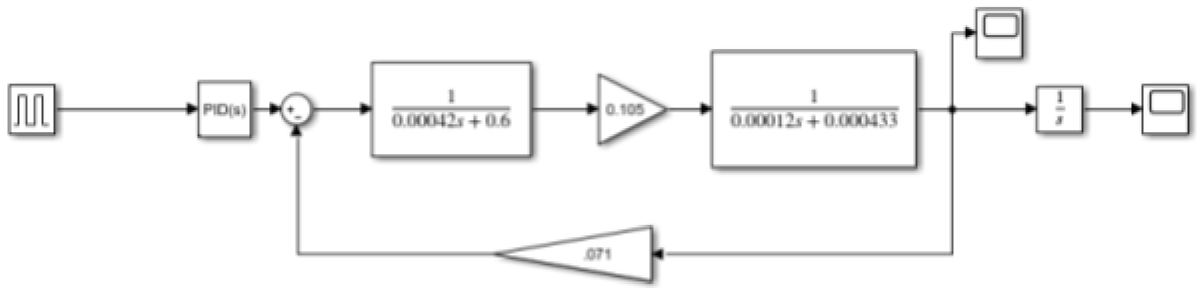

Figure 5: Block Diagram for Slotted Wheel Motor

For the PID in the initial part of, we made the proportional part 1, 0 for the integrator, and 0 for the derivative part. For the second part, we modeled the PID as an integrator so that we can find the angular position from the angular velocity.

When we select the pulse to have an amplitude of 2.5[V], a period of 1[Sec], and a pulse width of 18.465%, we can see the output in Figure 6. We chose the amplitude to 2.5 [V] so that the wheel does not spin fast enough to harm anyone in a lab setting. We selected the pulse width of 18.465% because with the input voltage of 2.5[V], this pulse width allowed for one complete rotation.

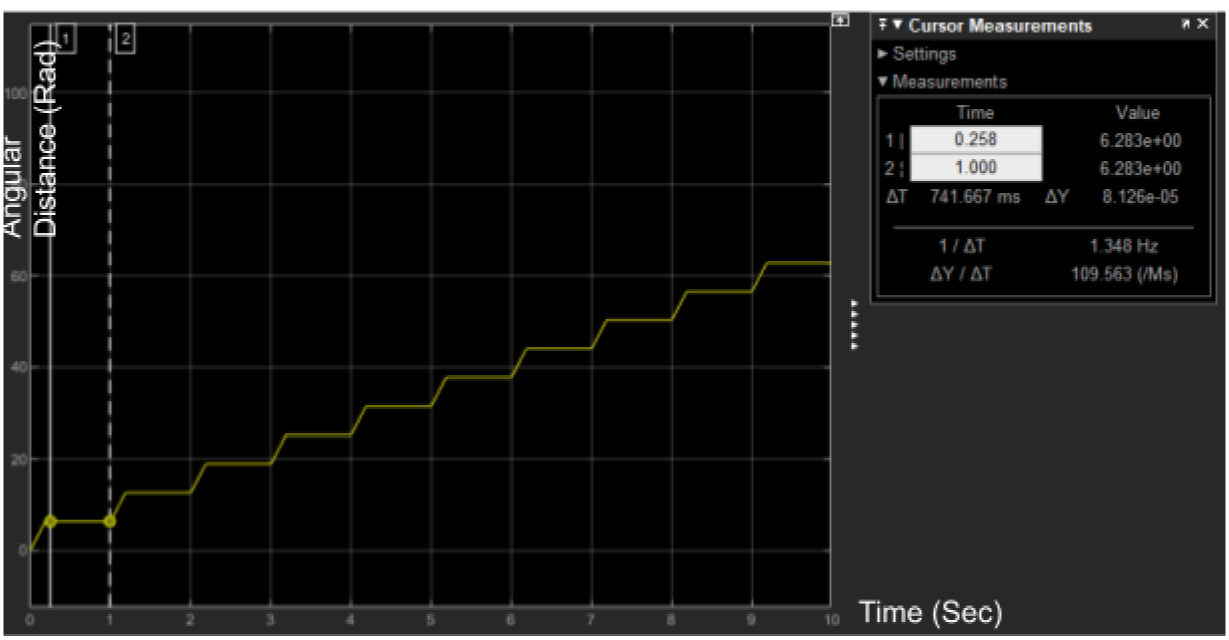

Figure 6: Output of the Wheel Motor in Radians

If you look at the data, you see the wheel spins really fast, but then for a period from 0.258 seconds to 1 second the wheel will not move, and this will repeat every period of 1 second. Hence we need to make the cart move through the wheel in between this moment.

For the second part of the experiment, we will analyze the wheel motor. Here the motor will be running at its maximum voltage of 60[V]. Also, since we do not need any modulation for the wheel to pause, we can just let the input source be a constant 60[V]. It will take the wheel 0.394 seconds to turn 5 times. We will figure out the design for the conveyor belt in the next section.

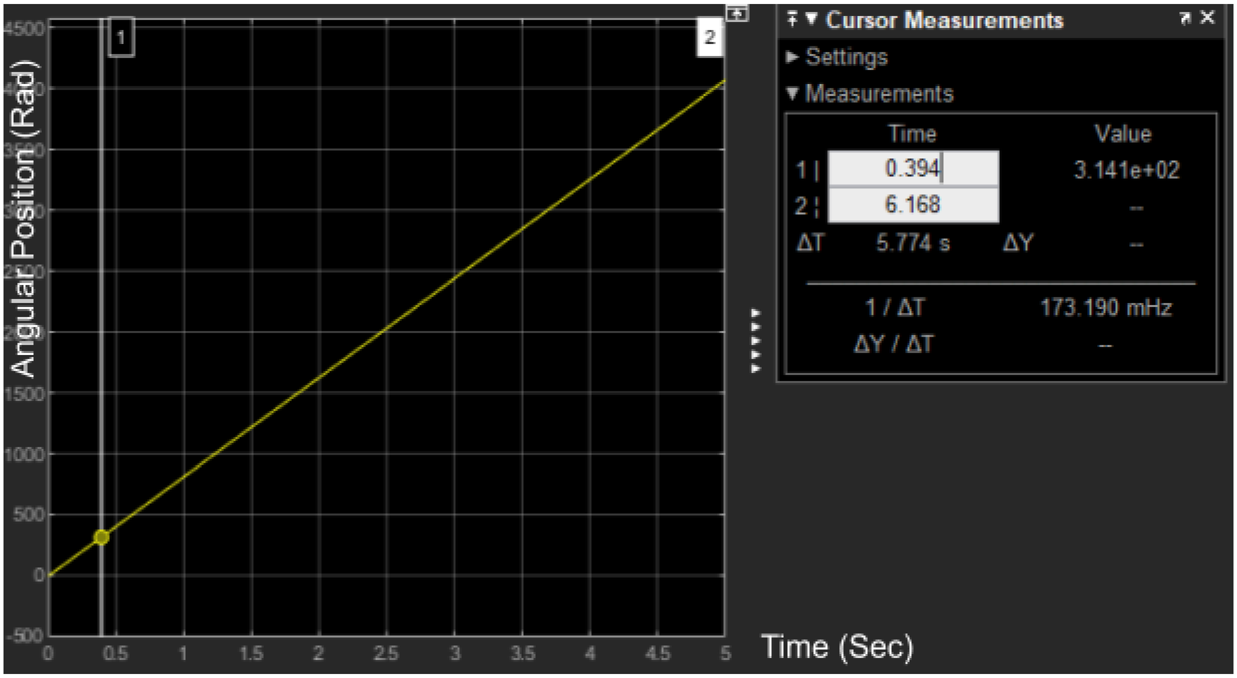

Figure 7: Max Voltage Wheel Angular Position Graph

4.2 Verification

For the cart to move back and forth easily, we need to modify our initial block diagram for the DC servo motor. In order to move the cart safely through the slot, we will make the pulse generator for the cart operate at its highest voltage and add a 0.5 second delay to it since the wheel stopped spinning at .258 seconds. The amplitude of the pulse generator should be high since it will make the motor turn rapidly so that once it makes one full rotation the cart will have ample time to go though.

In order to move the cart to move back and forth, we would need to attach another pulse generator so that we can have two seperate pulse generators. The second pulse generator will be used to give a negative voltage to the DC servo motor so that it can bring the cart back to its original position. The setup can be seen in Figure 8:

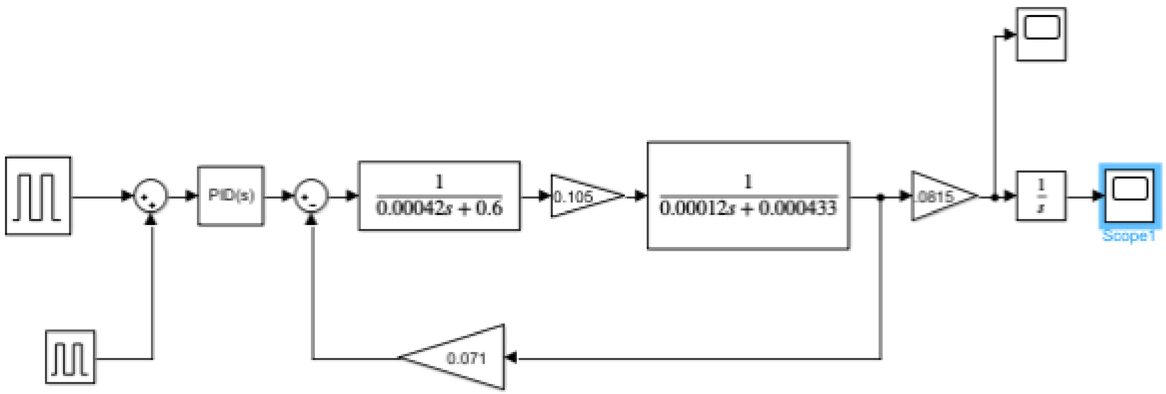

Figure 8: Block Diagram of the Motor Controlling the Conveyor Belt

In order for the back and forth motion to occur, we already discussed how the maximum voltage will be applied to the conveyor belt to push the cart quickly and then how a negative voltage of the same maximum magnitude will be applied to bring the cart back to its original position. However, we also need to carefully analyze when to use which type of voltage. In order to do this, we need to pay attention to the delay and period of the two pulse generators.

For the pulse generator pushing the cart foard, it will have the previously discussed 0.5 seconds delay so that it can move immediately after the wheel stops. Finally, after a 1.5 second delay, the second pulse generator will turn on and bring the cart back to its original position. Also, this second pulse generator will have a period of 2 seconds as it needs to skip every other wheel turn so that it can allow the first pulse generator to push the cart forward.

Now for the second part of the experiment, we need to consider how to move the cart through the wheel in one go. The solution is very similar to that of the first part of the experiment. We will need a second signal generator which will have the same magnitude of the maximum voltage but negative, but it's delay will be at around .4 seconds. The reason for this delay is so that when the cart goes through the wheel, at 0.394 seconds, it will not keep on going. The second signal generator will effectively cancel the initial signal, and hence stop the cart. The block diagram for the conveyor belt can be seen in Figure 9.

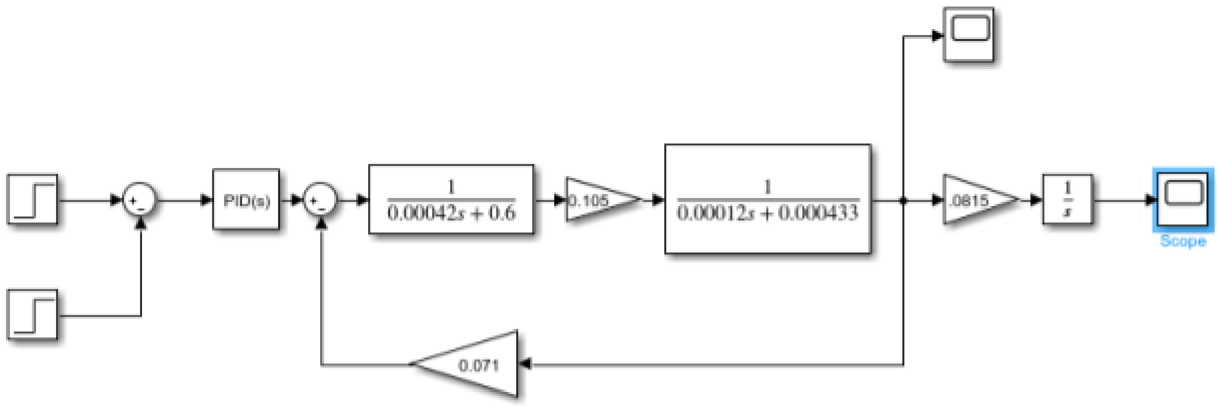

Figure 9: Block Diagram for the Conveyor Belt for Second Experiment

4.3 Application

When we run our simulation, we see that the cart movement is moving as intended. Recall that the wheel stops turning from a period of 0.258 seconds to 1 second. Also recall that the conveyor belt block diagram has a gain of 0.0815 as this is the radius in meters for the sprocket inside the conveyor belt, so what we see in Figure 10 is the actual lateral distance moved by the wheel, and hence the cart, rather than the angular position. Figure 10 shows that the cart moves forward 2 [cm] every even half second (so 0.5, 2.5, 4.5… seconds) while it moves back 2[cm] every odd half second (so 1.5, 3.5, 3.5… seconds). Most importantly the cart is not moving when the wheel is turning, so that means the cart will move back and forth without ever hitting the wheel.

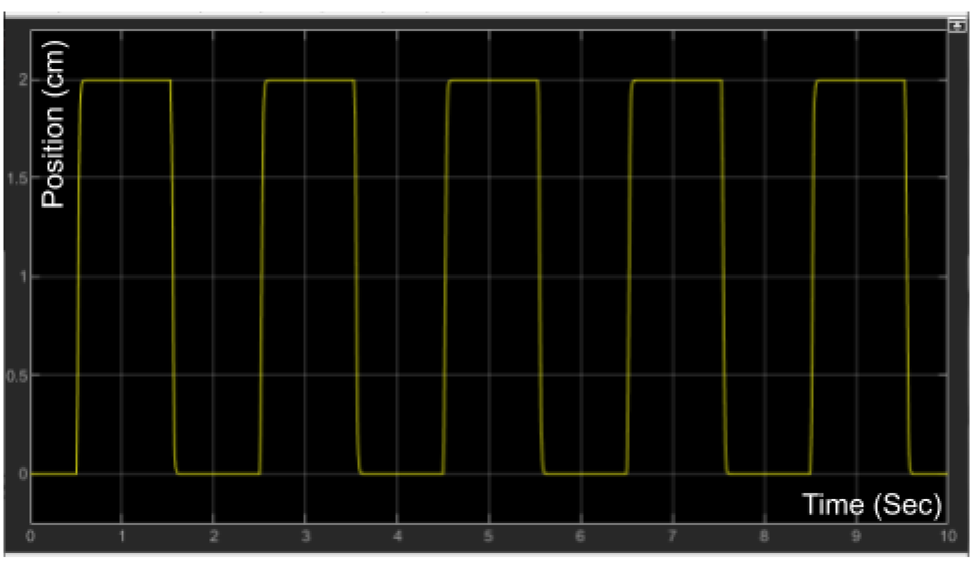

Figure 10: The Conveyor Belt Operation times and the Distance it Moves

Now for the second part of the experiment, we will use a similar analysis to the first experiment. In Figure 11 we can see that at 0.4 seconds the cart stops moving once it reaches the 32.28 [cm} mark. This shows that the second pulse generator effectively stopped the cart from going past the maximum 0.7[m] length the conveyor belt has, meaning the cart stays on the conveyor belt and does not fall. Since the conveyor belt and the wheel are moving at the same speed, we know that the rod will move past the wheel without being hit if the cart is placed 32.38[cm] from the wheel.

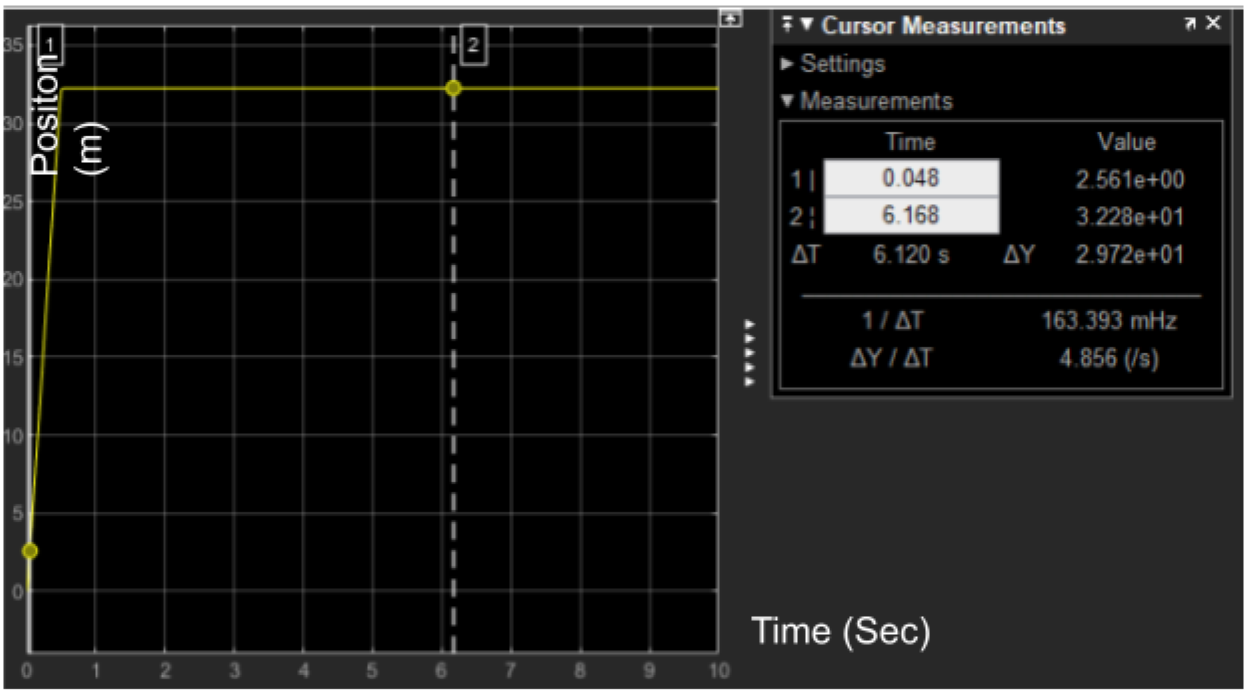

Figure 11: Second Experiment Conveyor Belt Data Regarding Distance

5 Conclusion

By using the Mclennan datasheet for the M642E DC servo motor, we were able to substitute the unknown coefficients in the DC servo motor block diagram so that we can actually replicate the M642E motor. By using Simulink, we were able to make a model that we were able to perform analysis on.

For the first experiment, it was crucial for us to input a pulse generator so that the wheel and the cart paused and moved only when the other was doing the opposite motion. When we made the model for the wheel, we realized we want the wheel to quickly rotate one and then pause long enough for the cart to pass. For the cart to pass, we added a second pulse generator so that a negative pulse can be given. This allows for the cart to move back and forth 2[cm] from the wheel. When completing the analysis for the experiment, we realized that the cart would comfortably go in and out of the wheel smoothly without any collisions.

For the second part of the experiment, we realized that by making the cart and wheel move at the motors maximum speed, they both would move in an identical motion. This means that if the cart is moved to a position equivalent to the distance travelled by the wheel, the rod will go through the wheel without hitting it. However, to stop the cart from continuing forward and crashing out the setup, we included a second signal generator with an input of the negative of the maximum magnitude so that it stops the cart. As a result the cart will move through slot, without being hit by the wheel.

References

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[2] Dubot, “DOBOT Conveyor Belt Kits The Simplest Production Line,” *DOBOT Conveyor Belt Kits The Simplest Production Line*, 2018. [Online]. Available: www.amazon.com/DOBOT-Conveyor-Belt-Simplest-Production/dp/B073NXVW1H. [Accessed: 27-Apr-2020].

[4]Mclennan, “M600 Brushed DC Servo Motors,” *Mclennan*. [Online]. Available: https://www.mclennan.co.uk/product/m600-brushed-dc-servo-motors. [Accessed: 27-Apr-2020].

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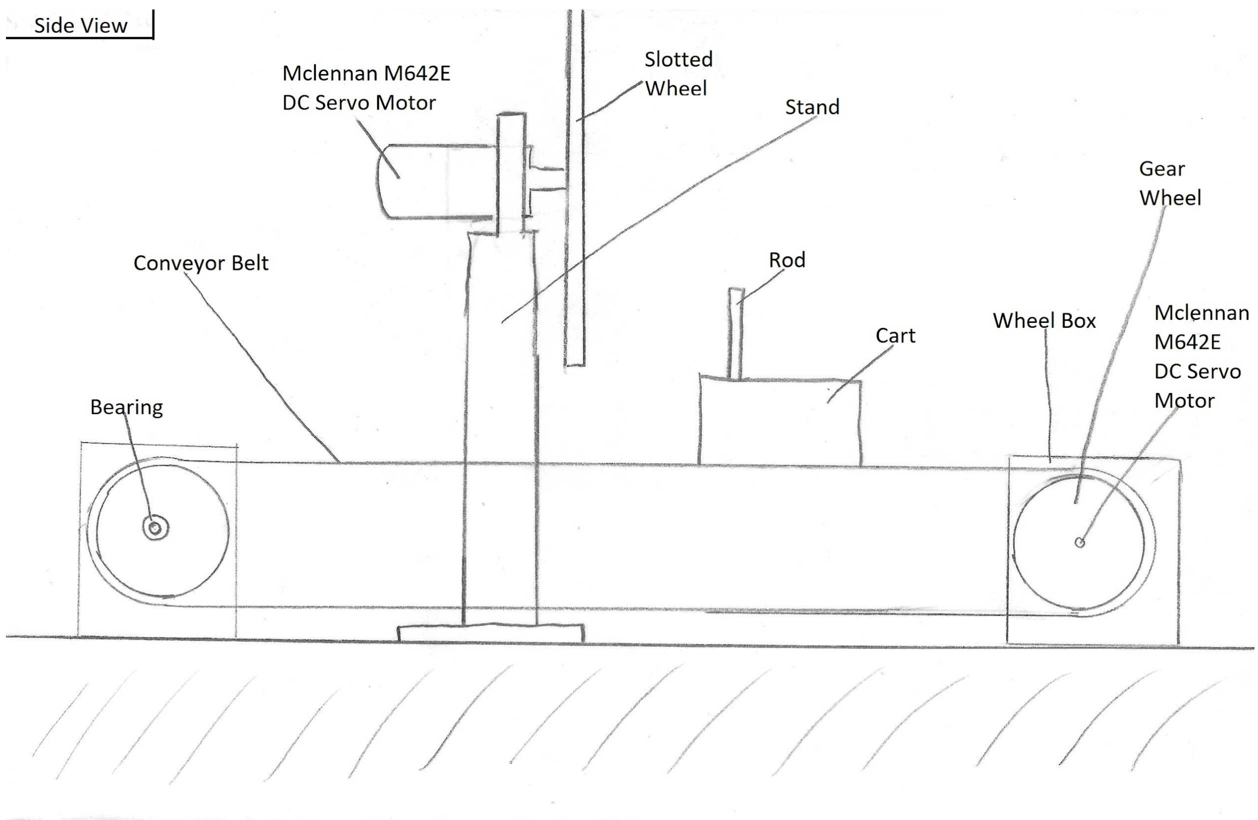
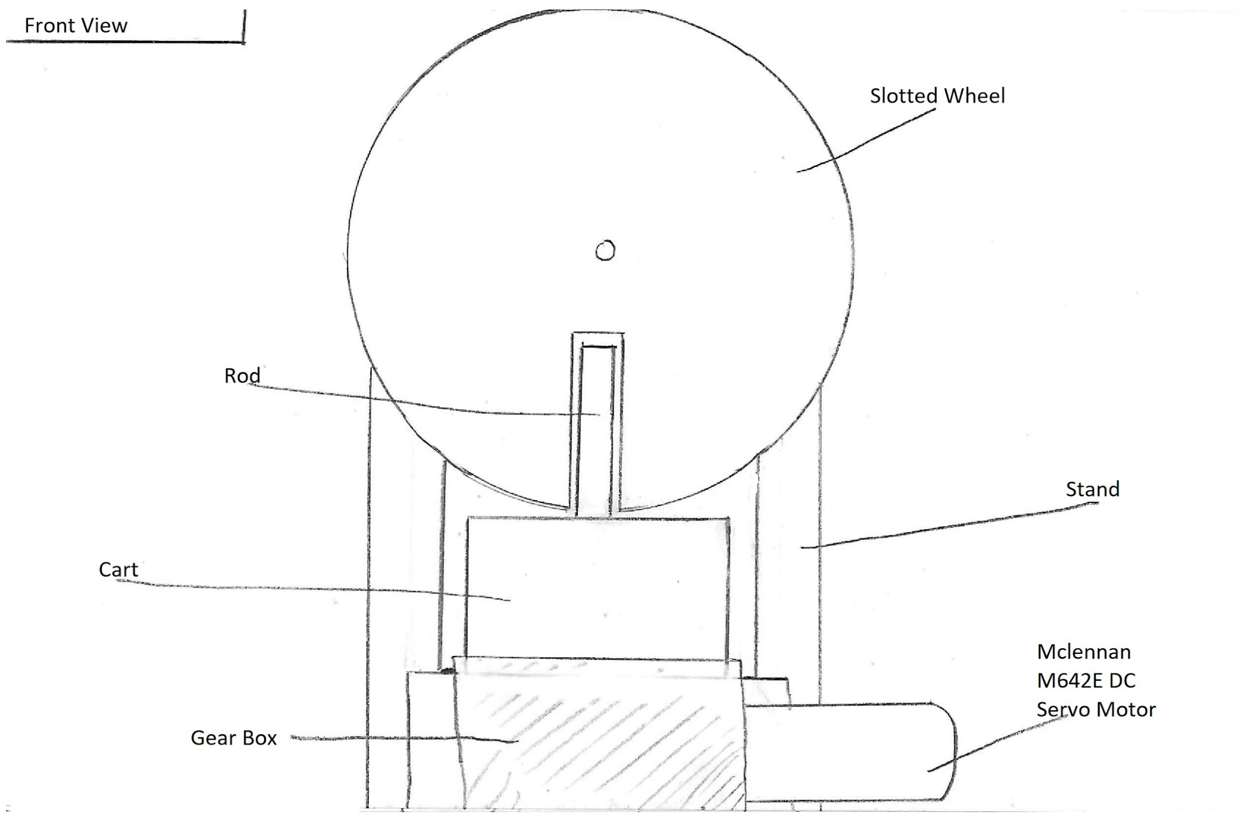
Appendix



Side View
Mclennan M642E
DC Servo Motor
Slotted
Wheel
Stand
Gear
Wheel
Conveyor Belt
Rod
Cart
Wheel Box
Mclennan
M642E
DC Servo
Motor
Bearing


Front View
Slotted Wheel
Rod
Stand
Cart
Mclennan
M642E DC
Servo Motor
Gear Box