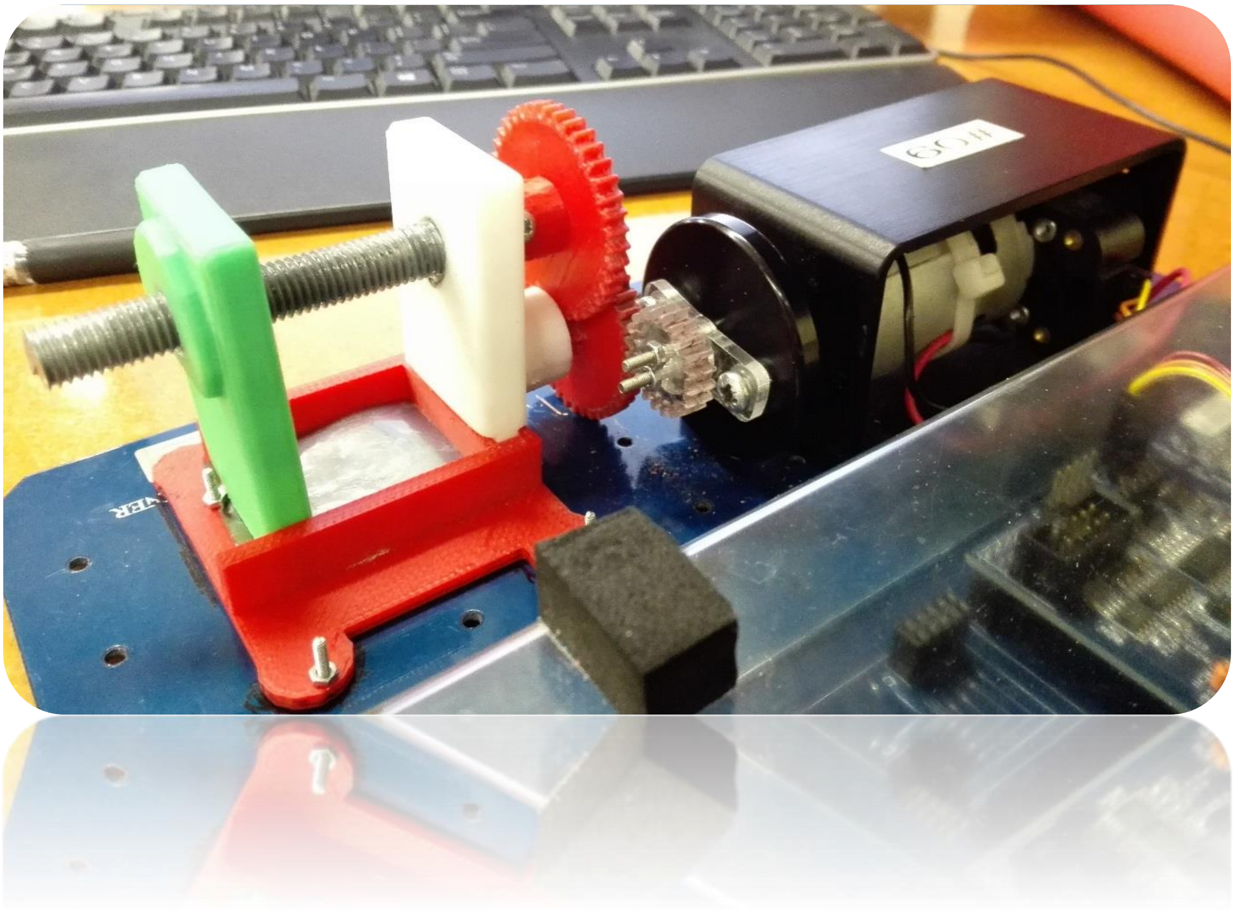

MECHENG 705 PROJECT ONE: MECHATRONICS SYSTEMS

ROBOTIC GRIPPER ASSIGNMENT

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1. Mechanical design

A gripper was designed to be able to grip an object whose size fits inside the dimension of 30mm x 30mm x 10mm.

The designed gripper uses four spur gears which has a gear ratio of 1:8. The gear attached onto the motor has a number of teeth of 20. This gear has an adjustable thickness because it was manufactured using laser cutting and the parts are glued together to be screwed onto the motor. The second and the third gear are fixed at the lower part of the base with a number of teeth of 40 and 10 respectively. These two gears have a same rotating axes. The forth gear which is fixed at the top of the base has a teeth of 40 and is in contact with the third gear. A screw shaft is fixed onto the forth gear which rotates to enable the movement of one of the clamp.

The gripper have two clamps, one is fixed onto the base near the motor, one can move towards or away from the motor when the screw is rotating. Steel screw shaft and its pairing nut were used to make sure the friction is kept as low as possible and all other parts of the gripper except the first gear were manufactured using 3D printer for ease of assembly.

There are small features which help the functionality of the gripper. A small pin extruding from the end of the second and the third gear along with the slot inside the base make sure the gear can be fixed onto the base without interfering with the rotational motion. A large slot at the bottom of the base was designed to fix the moving clamp to prevent it from rotating around the screw. This design also enables the object that will be gripped can be put close to the screw to minimize the influence of the gripping force generated on the other parts of the gripper which makes the gripping easier and more reliable.

3D modelling and analysis using PTC Creo was done to prove the feasibility of the gripper and the schematic drawing with detailed dimensions can be found in Appendix.

A problem that has been encountered with the mechanical design is the steel screw is too heavy which caused the rotating axis of the screw unparallel to the base, this increases the difficulties of the movement of the moving clamp. To solve this problem a much lighter screw can be considered such as using a smaller steel screw or a plastic screw. The material of the 3D printer is very easily to worn out after a long period of execution with high velocities and causes the instability of the gripper and the inaccuracy of the control system. By changing the manufacture method of the gripper such as using laser cutting may fix this problem.

The calculation of the maximum static force which can be applied to the object was 5V applied to the motor can be found in Appendix.

2. Simulation and tuning of controllers

To simulate the position and force response of the design, a closed loop control system consist of a standard PID controller and transfer function is built using Labview as shown below in figure 2 and 3 in Appendix. And the input of the system is the voltage.

For the **Position Simulation**, according to the equation:

$$\text{Transfer Function} = \frac{K_m}{R_m J_{eq} s + {K_m}^2} = \frac{\Omega}{V}$$

We can get the angular velocity Ω, and by integrating the angular velocity, we can get the angular displacement.

The gain of position control is calculated based on the design of the gripper. A linear displacement of 1.6mm is corresponding to 8 times round of the shaft.

$$\text{Position Gain} = \frac{1}{8} \times 1.6 = 0.2$$

For the **Force Simulation**, according to the equation below:

$$\mathrm{V} - R_m I_m - K_m \omega = 0 \text{ and } \omega = 0 \text{ when motor cannot move}$$

Therefore,

$$\text{Transfer Function} = \frac{1}{R_m s} = \frac{I_m}{V}$$

Since

$$\text{Force} \times \text{Radiu} = \text{Torque} = K_m \times I_m$$

Therefore

$$\text{Force gain} = \frac{K_m}{Radiu} = \frac{0.058}{0.03} = 1.933$$

The PID parameters (K_p , K_i and K_d) can be dynamically updated as the program runs. As observed from the simulation results, the effect on the system response of the three parameters are showing in the Appendix:

- K_p will contribute to the decrease of the rise time, increase of the overshoot and the decrease of the steady-state error.
- K_i will contribute to the decrease of the rise time, increase of the overshoot and the elimination of the steady-state error.
- K_d will contribute to the decrease of overshoot and settling time.

Comparison of plots of position responses using different combinations of P, I and D controllers are shown in the Appendix.

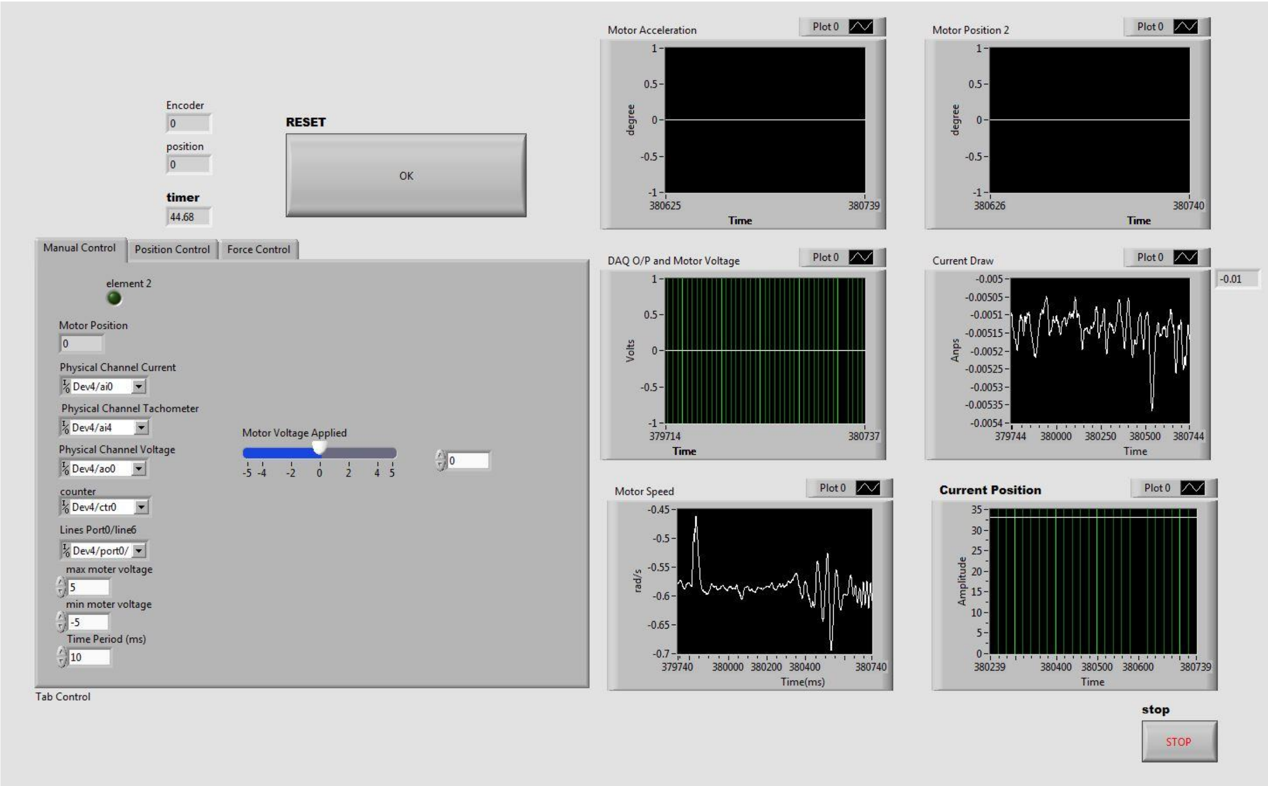
The final controller chosen for position control is $K_p = 5.5, K_i = 0, K_d = 0$.

The final controller chosen for force control is $K_p = 18, K_i = 0.3, K_d = 0.5$.

The analysis tools used are bode plots, time response, step response plot, simulated data plot and a comparison plot between current value and desired value as shown in Appendix.

3. User interface

The User interface front panel is shown in the figure below with all the graphs and buttons are labelled to make it easier for the user to use it for the first time.



This program allows user to manually control the speed of the motor by changing the voltage applied, the distance between the two clamps and the force applied to the object being gripped by using the tab panel which allows users easy switching between those functions.

Graphs showing the motor voltage applied, current drawn, motor position, motor speed, motor acceleration, motor torque, gripper position, gripper force have been displayed on the front panel. The value of the time that takes to grip and all the controller's parameters and sampling time are also displayed.

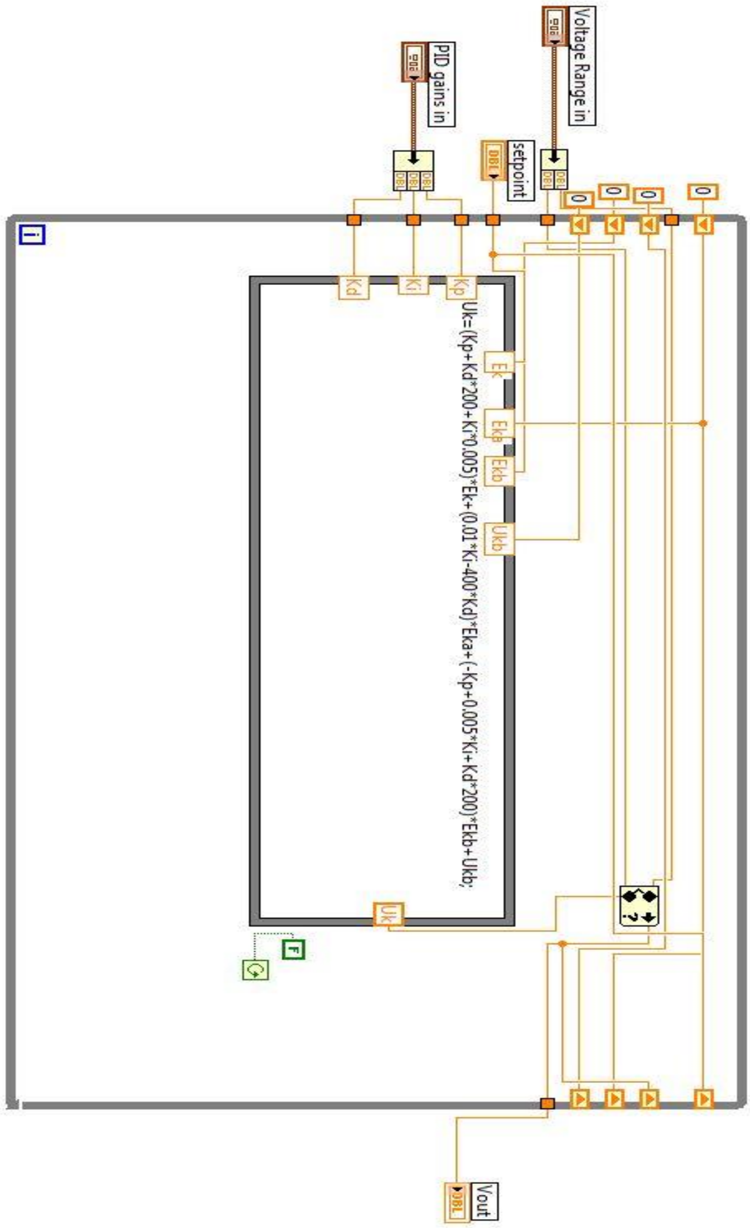
There are also a stop button and reset button which help users stop the programme immediately and reset the gripper to the original position without manually going back to the zero point.

4. Digital Controller and Implementation

Bilinear approximation has been used to convert the continuous PID controller to a digital Controller. The detailed calculation is shown below. This formula shows a better performance than backword or forward approximation and increase the reliability of the PID controller.

The PID controller takes errors, the voltage range of -5V to 5V, three PID gains as inputs and then using the formula derived from bilinear approximation method to calculate the desired voltage that has to be input to the motor to make the motor stop at the desired position for position control or generating the desired force for force control.

The figure shown below is the digital PID controller subvi.

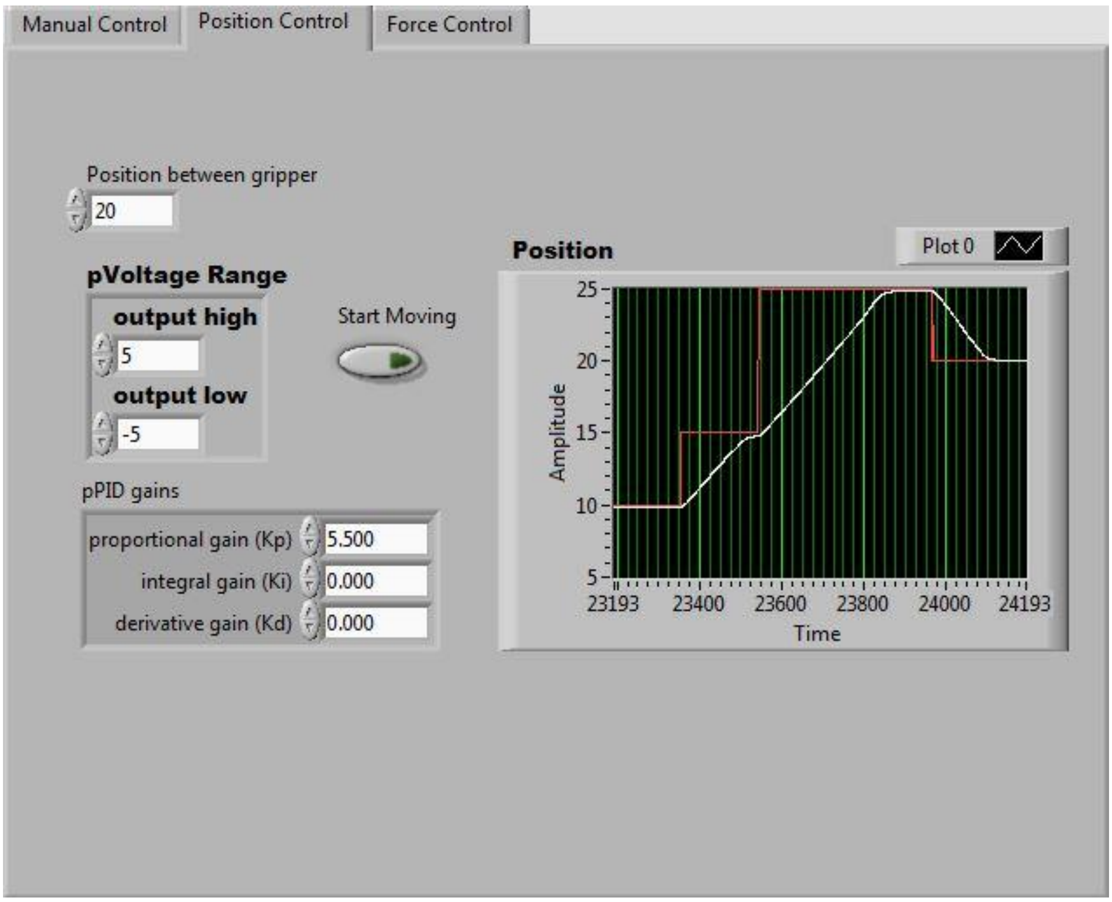


5. Position Control

The start button has to be pressed to be able to use the position control. If the status for button press is false, 0V will be applied to the motor.

After the button been pressed, the position control takes the user defined desired voltage and compare it with the current position between the two clamps. This difference will be the input of the digital PID controller which will then give a desired output voltage applied to the motor to control the position between the clamps. The PID has been fine tuned to make the moving clamp stop at the user defined desired position. Only P control is need with Kp equals to 5.5, this gain gives a rising time smaller than 20ms with no overshoot. This gain also matches the Kp gain generated using the position control simulator. To decrease the possibility of oscillation, I and D gains are set to be zero. However, a longer rising time is invoked by zero I & D and large ratio of the real gripper model.

The position graph showing the desired position and the current position between the two clamps was plotted against time on the same graph for the user to be able to visualize the changes more clearly. The graph was updated every 10ms.



6. Force Control

Force Control is very similar to position control. The user has to press the start button before he/she can start using the force control otherwise 0V will be send to the motor.

The encoder values are first compared with its previous value to check whether the gripper has gripped something and the motor has come to a stop. This is done by using the current encoder value minus the previous encoder value which gives how many degrees the motor has rotated in the past 10ms. This value is then compared with 200 to determine whether the motor has moved or not. Even when the motor has gripped an object, it will oscillated before it comes to a complete stop and this is why the counter difference has to be compared with 200 instead of 0. An XOR and an OR gate are then used to determine the execution status of the force control (i.e. the force control will not execute only when the motor is not rotating at the moment and 10ms before).

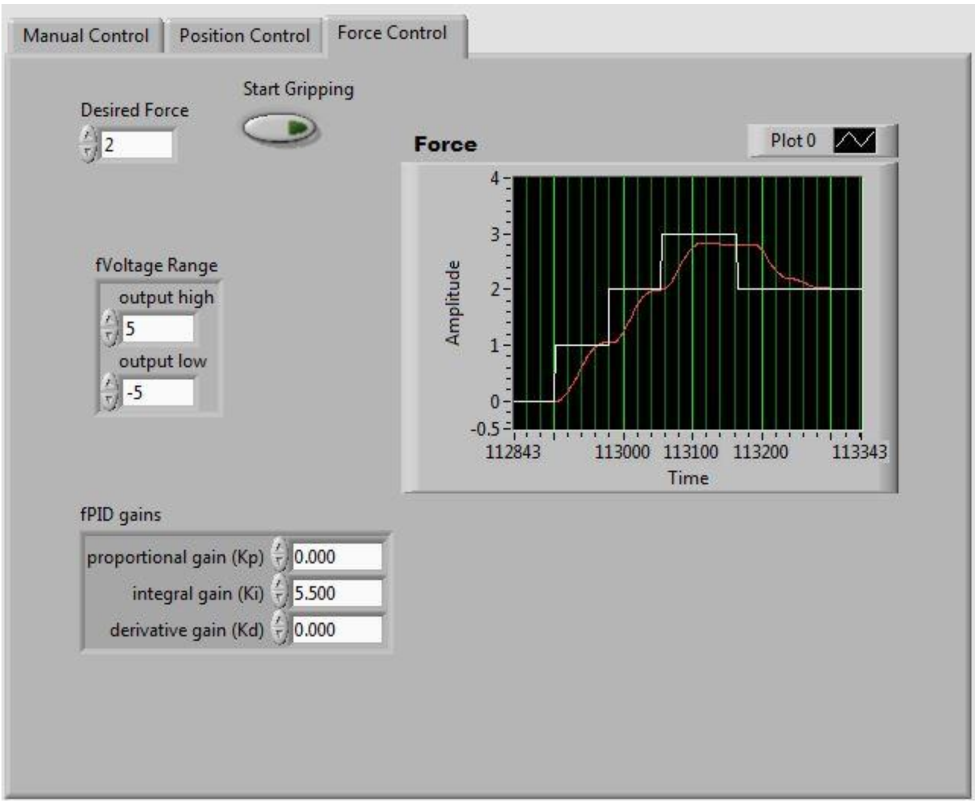
After the program detect that an object has just been gripped, it will take the desired force, voltage range of -5V to 5V and PID gains as input to the digital controller and output a voltage that will be applied to the motor to control the force of the gripper applied to the object, otherwise it will output 5V to the motor.

The formula used to calculate convert force and voltage are shown below:

$$\text{Torque} \ = \text{Force} * \text{radius}$$

$$\text{Torque} \ = \text{Km} * \text{stall current}$$

Where r is the distance from the axis of the screw to the point when the force will be applied and Km is the motor torque constant.



7. Other Features

A reset button has been made to enable the user reset the position of the gripper. While the program is running and the reset button being pressed, the program will continuously check its current position with the a specified position value (i.e. 8mm, 4mm and 0mm) and a voltage will be applied to the motor (i.e. 5V, 3.5V and 2.9V) if the position is larger than the specified position. The 0V will be applied to the motor only when the position equals to 0.

The Butterworth amplifier has been used to filter the current and the motor speed to make the calculated force more stable as the force is dependent to the current. The sampling frequency was set to 1000Hz with low cutoff frequency of 20Hz.

The motor position was calculated using the encoder value instead of the sensor to make the position control more accurate. The encoder runs 0.088 degrees/count and when the motor rotates 8 cycles, the clamp move forward/backward by 1.4mm. These values have been used to convert the encoder value to the linear position of the gripper.

Motor acceleration has also been calculated and displayed, the program uses the derivative of the difference between the motor velocity and the motor velocity before 10ms with regard to time of 10ms to calculate the acceleration.

Appendix

Maximum Force can be Applied

Current drawn when motor speed is ~~@~~ 5V = 1.65A

$K_m = 0.058$

$\text{Torque} = K_m \times I$

$= 0.058 \times 1.65$

$= 0.066\ \text{Nm}$

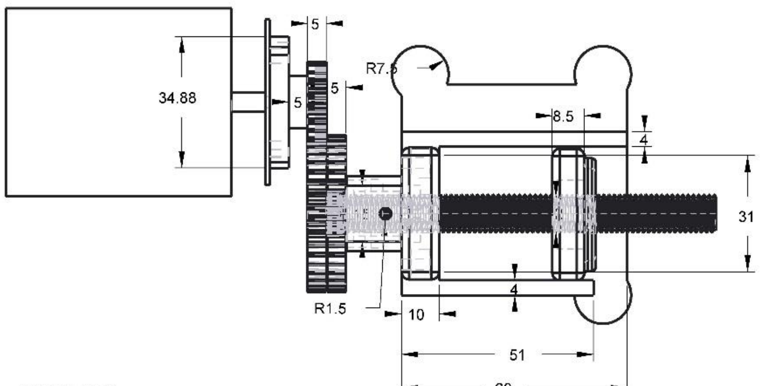
$$\text{Force} = \frac{\text{Torque}}{r}$$

where r is the distance between the centre of the shaft and the bottom of the gripper which is approximately 0.03 m

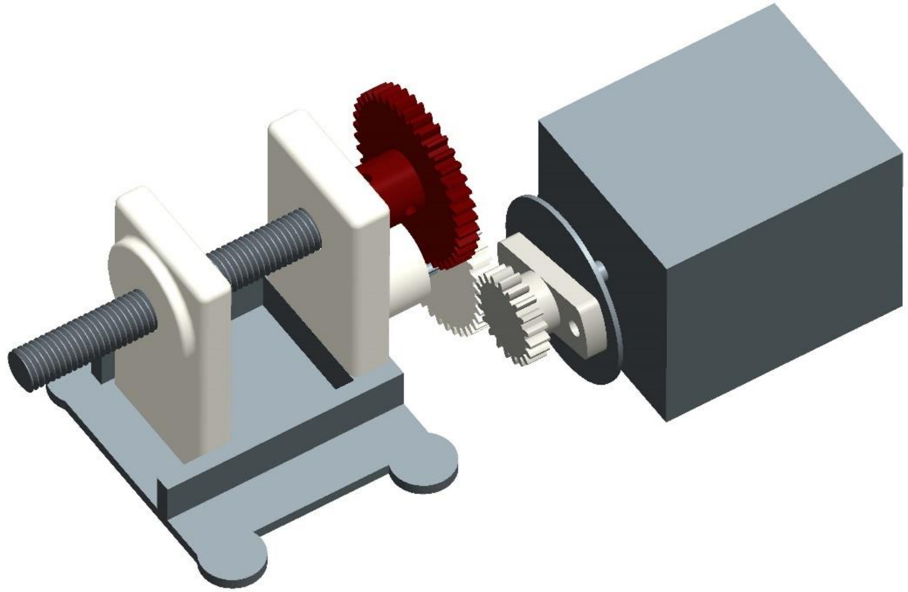
$$= \frac{0.066}{0.030}$$

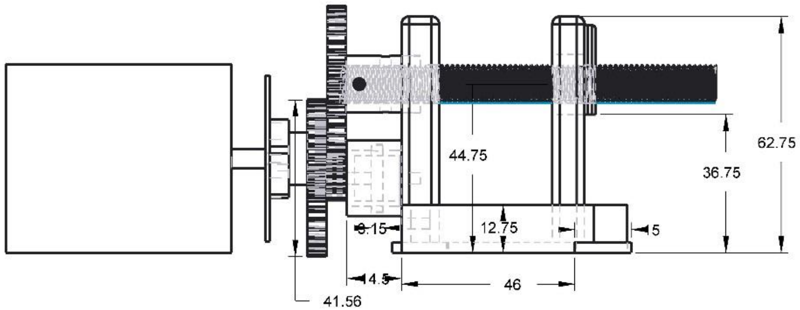
$= 3.19\text{N}$

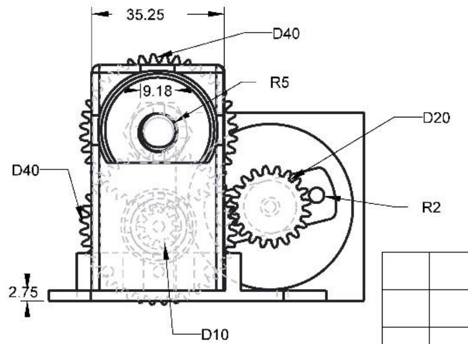
Figure 1: Maximum Static Force Calculation



SCALE 0.800







Part No.	Name of Part	Qty.	Material

Change No.	Name of Item	Changes Made	OK	DATE

ALL TOLERANCES ARE ±0.1mm UNLESS OTHERWISE SPECIFIED | ALL DIMENSIONS IN MILLIMETRES

THE UNIVERSITY OF AUCKLAND NEW ZEALAND

DRAWN BY	TITLE FOE_A3-Size_Template				
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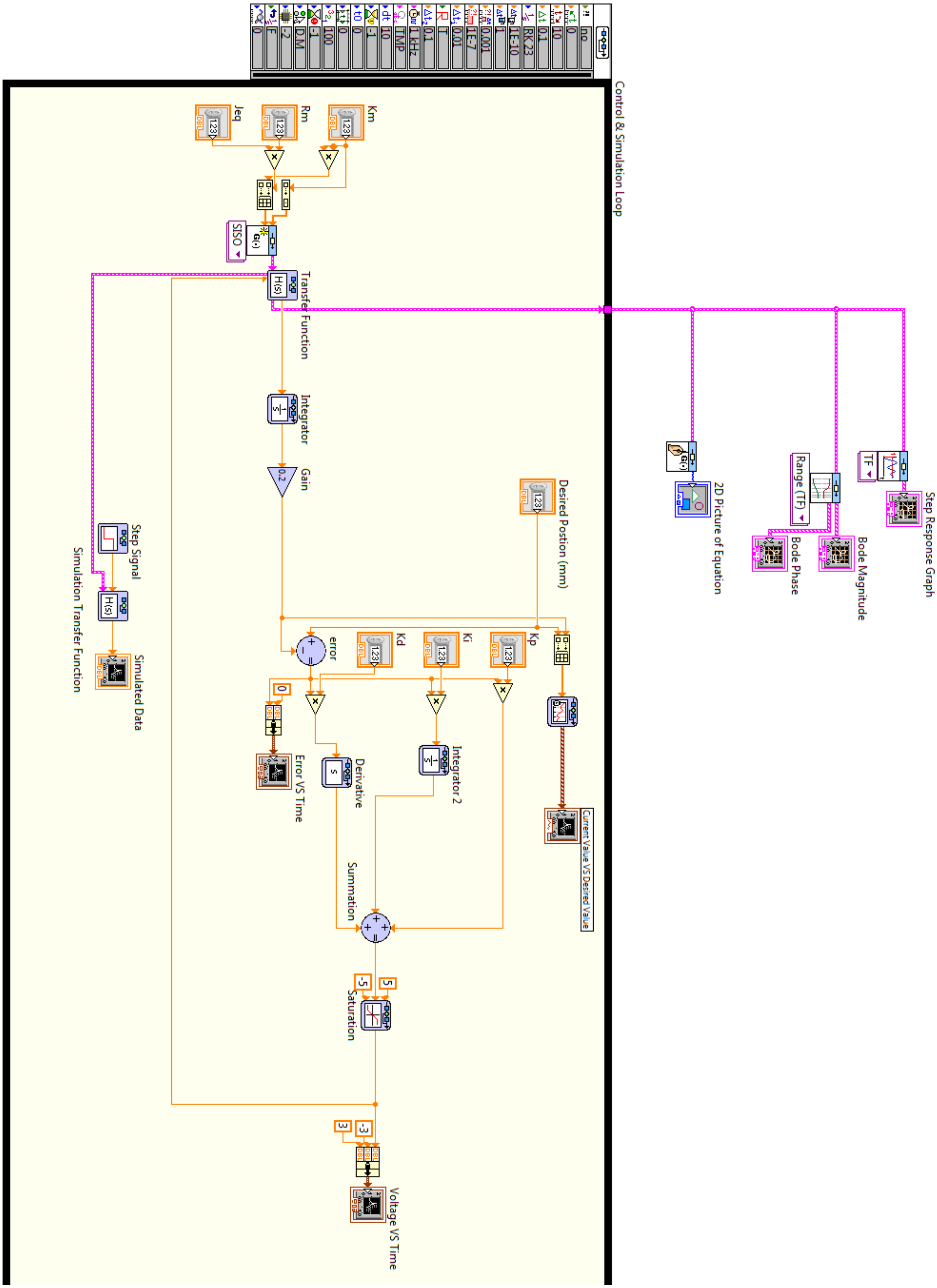

Figure 2: Position Simulation

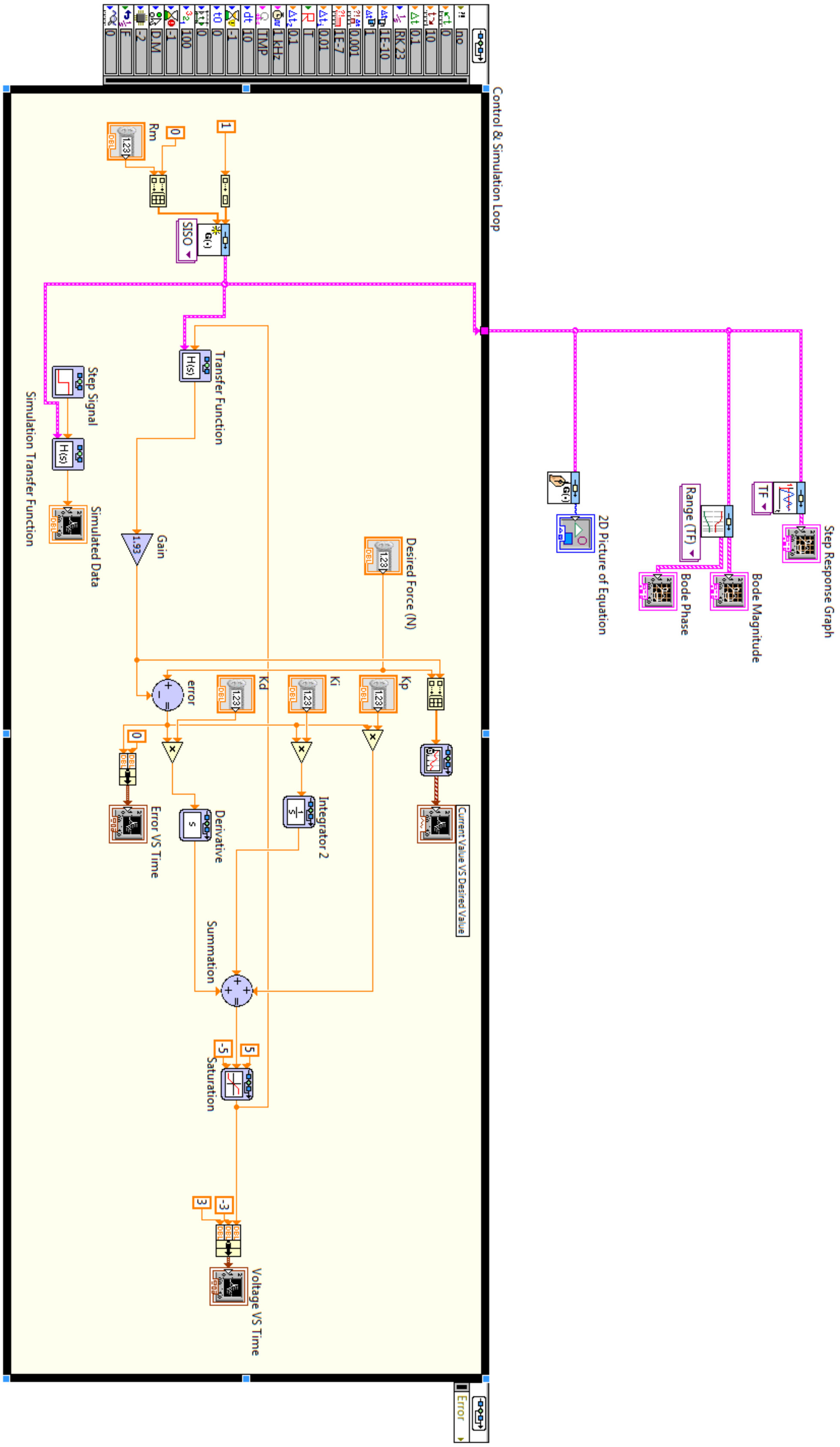

Figure 3: Force Simulation

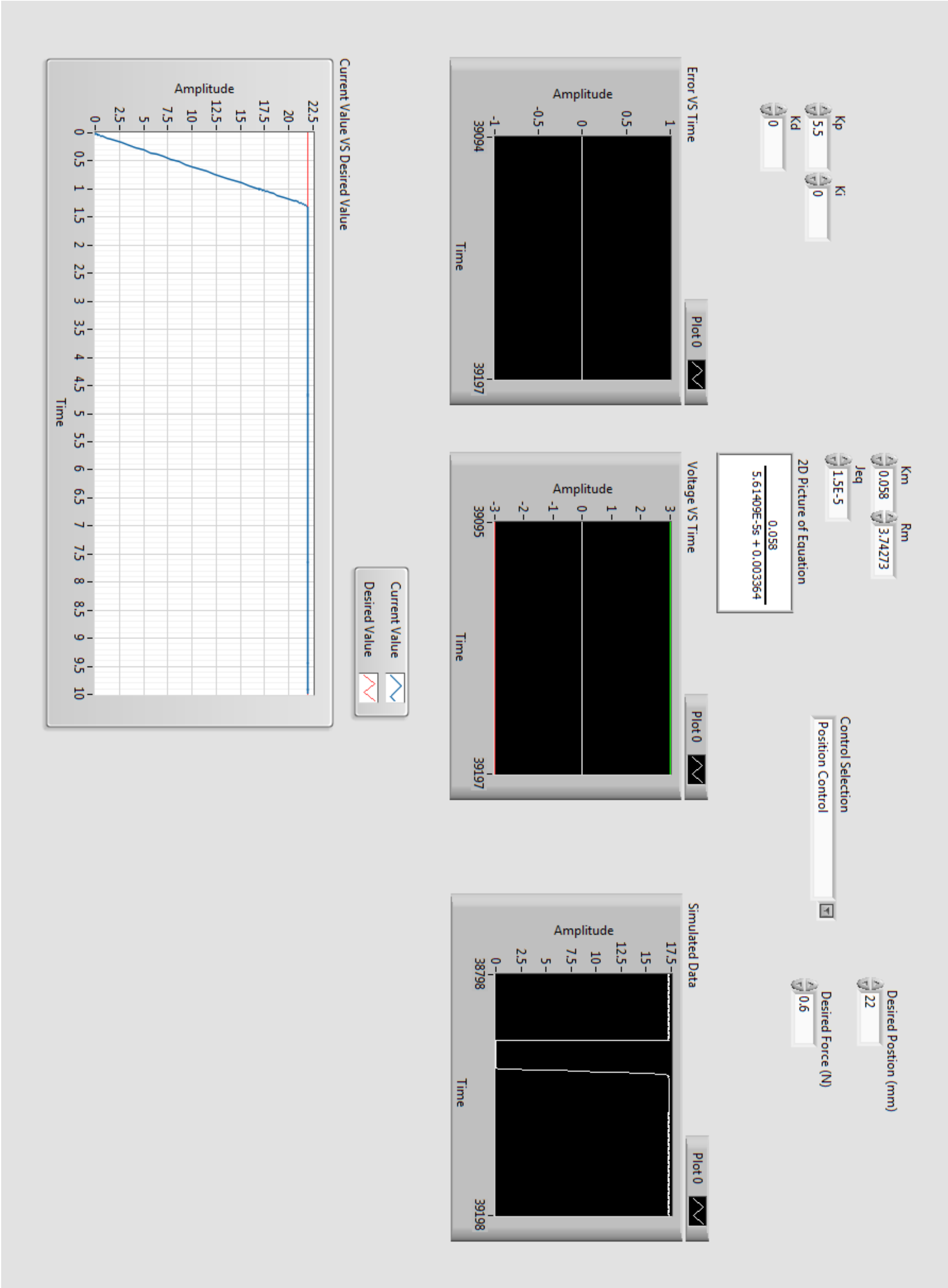

Figure 4: Desired parameter for Position PID gains=5.5, 0, 0

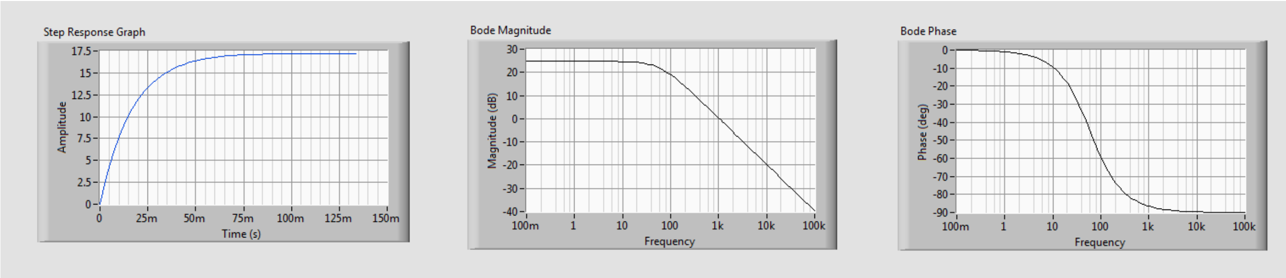

Figure 5: Bode Plot of desired parameter

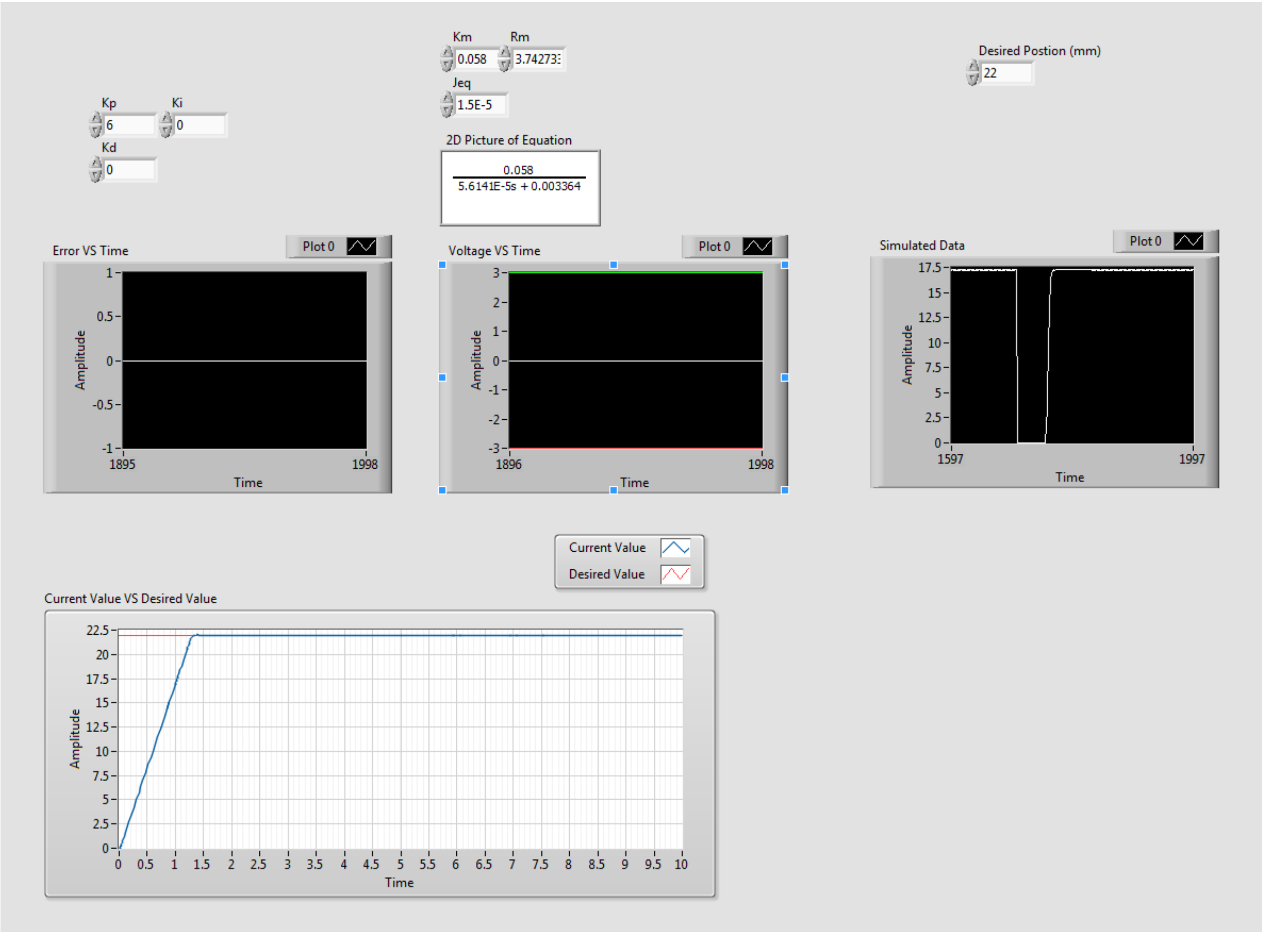

Figure 6: Other PID Option: 6, 0 , 0

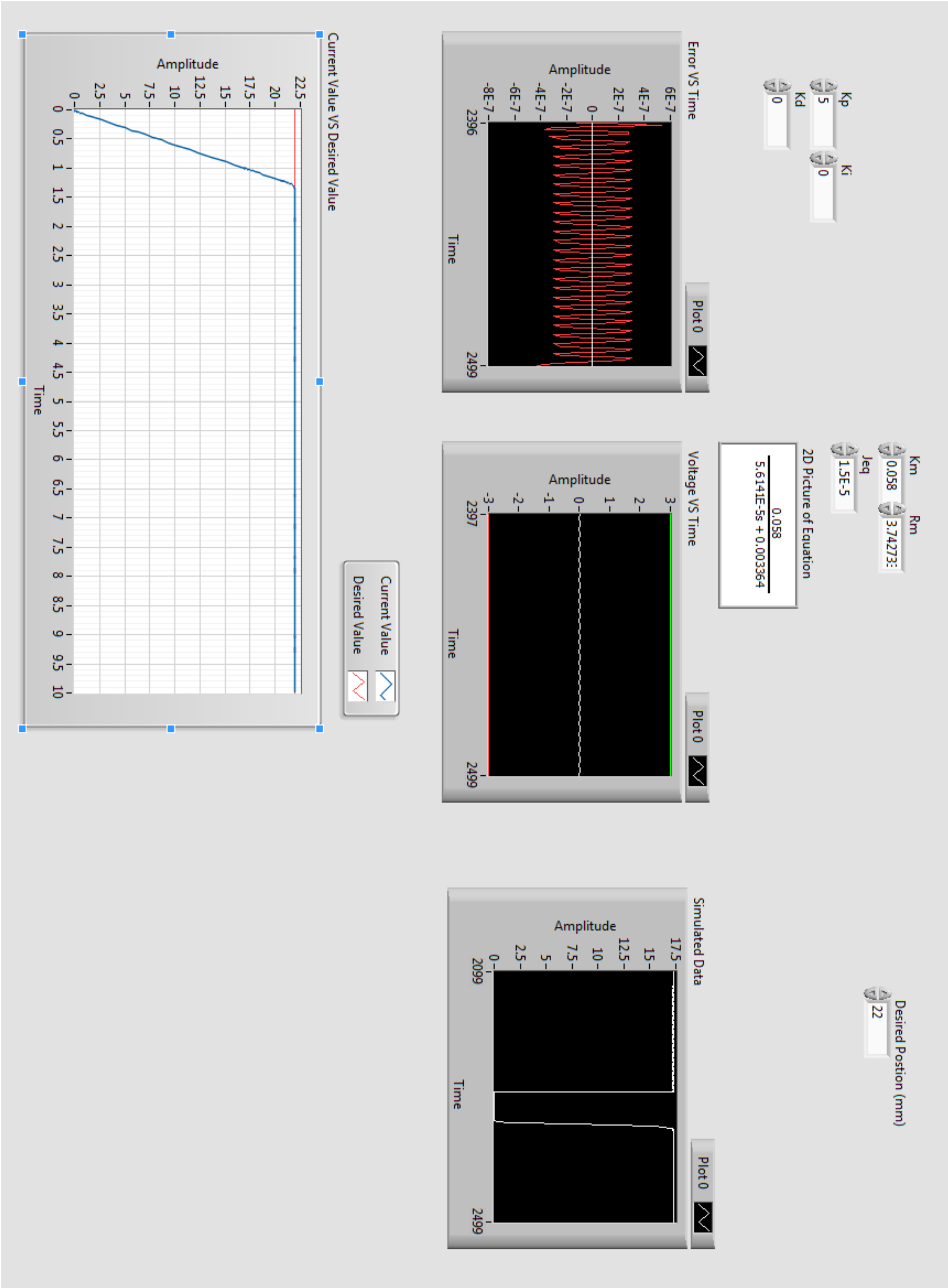

Figure 7: Other PID Option : 5, 0, 0

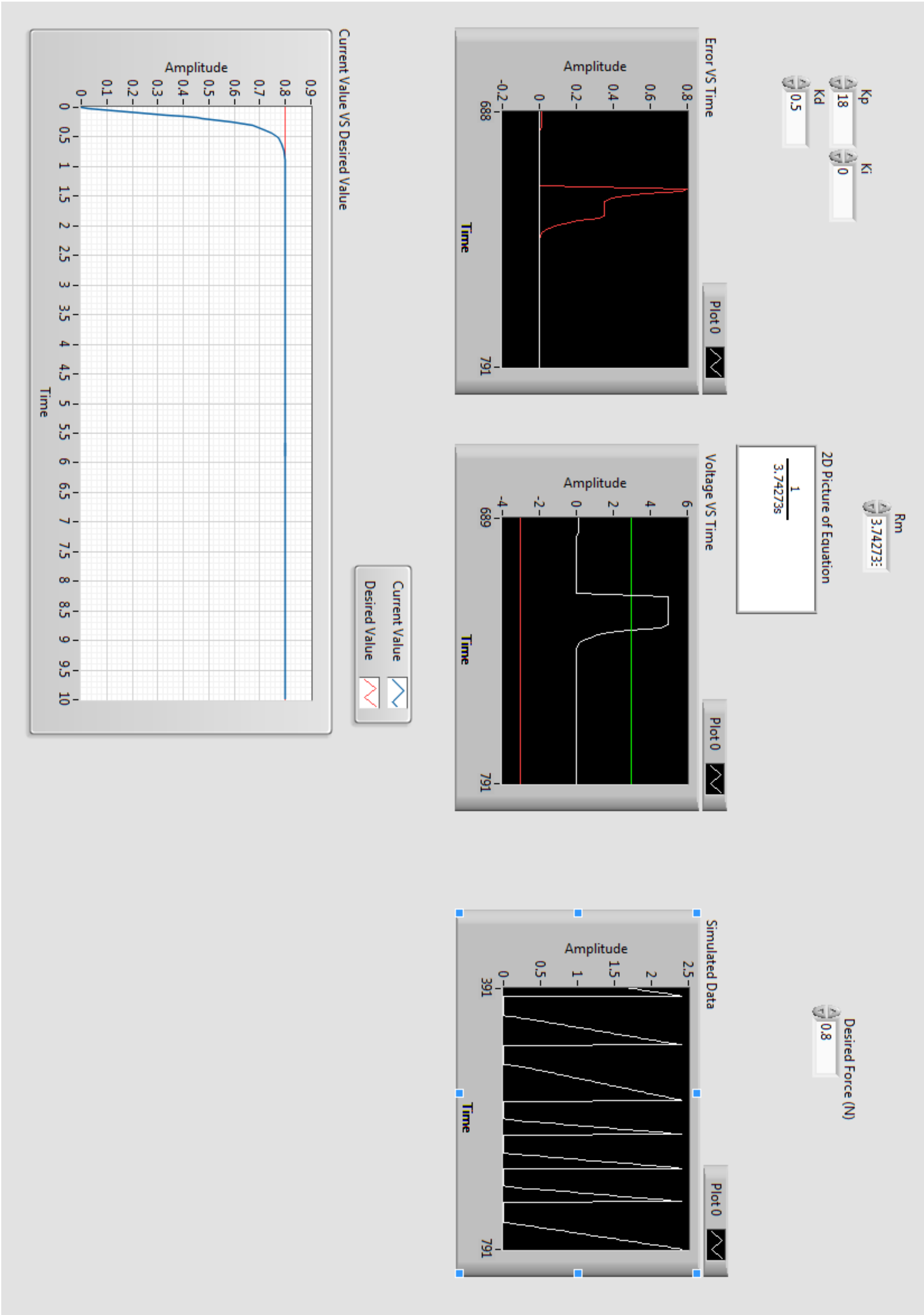

Figure 8: Desrired Parameter for Force control PID gains : 18, 0, 0.5

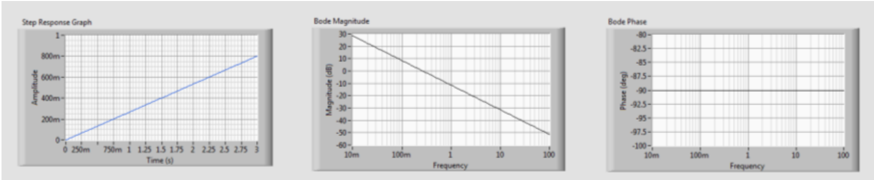

Figure 9: Bode Plot for desired force simulaion

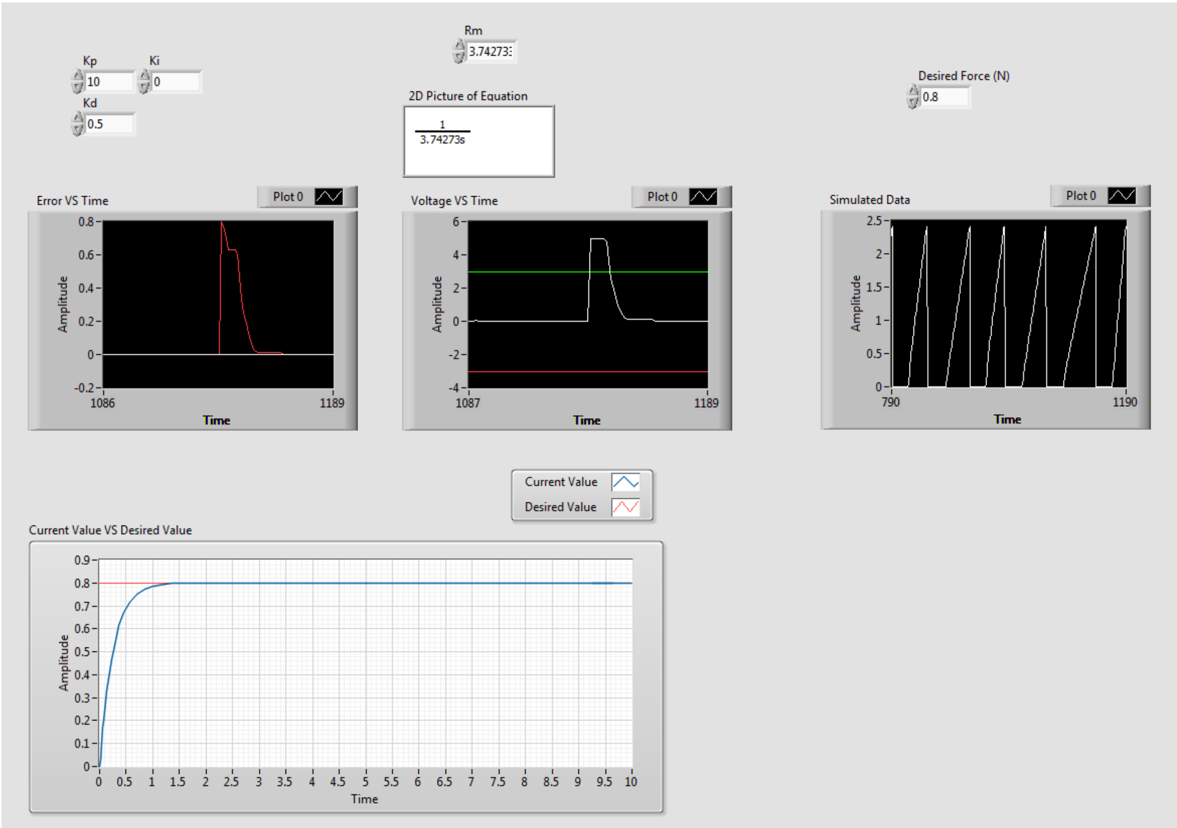

Figure 10: Other parameter combinatio 10, 0, 0.5

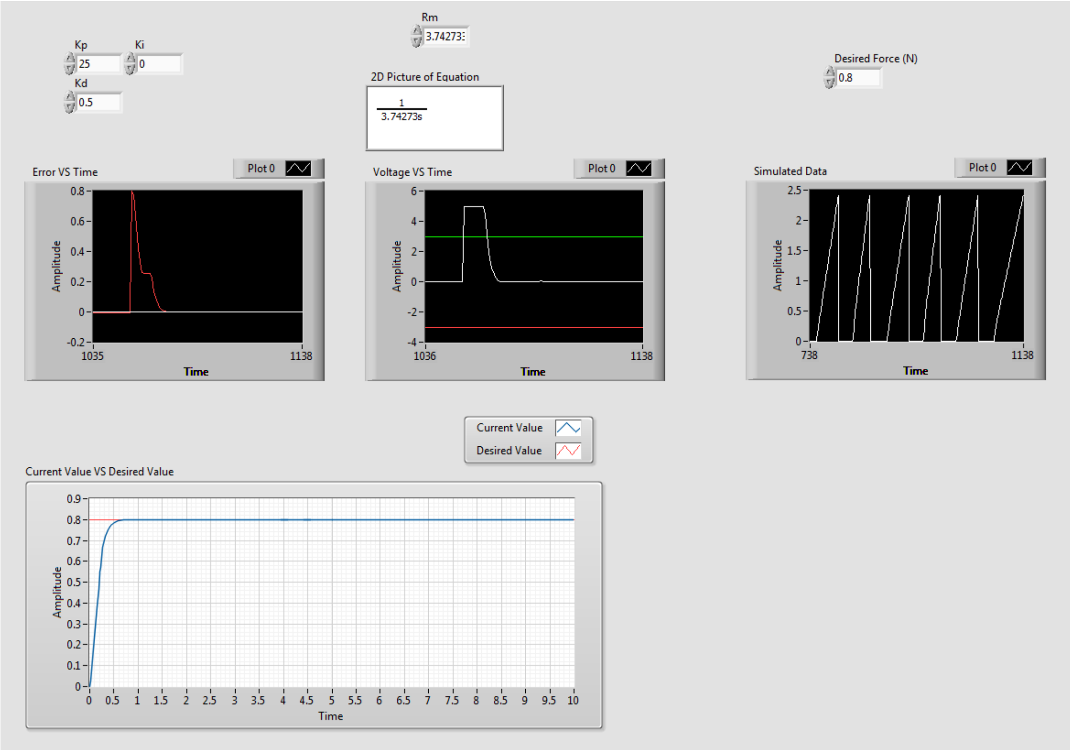

Figure 11Other parameter combinatin 25, 0, 0.5

Bilinear Approximation

$$\begin{cases} U_{(s)} = K_p + \frac{K_i}{s} + K_d s \\ s = \frac{2}{T} \cdot \frac{z-1}{z+1} \end{cases}$$

Substitute

$$U_{(z)} = K_p + K_i \frac{T}{2} \frac{z+1}{z-1} + K_d \frac{2}{T} \frac{z-1}{z+1}$$

$$= \frac{K_p z^2 - K_p}{z^2-1} + \frac{\frac{K_i T}{2}(z+1)^2}{z^2-1} + \frac{\frac{2K_d}{T}(z-1)^2}{z^2-1}$$

$$= \frac{K_p z^2 - K_p + \frac{K_i T}{2} z^2 + K_i T z + \frac{K_i T}{2} + \frac{2K_d}{T} z^2 - \frac{4K_d}{T} z + \frac{2K_d}{T}}{z^2-1}$$

$$= \frac{(K_p + \frac{2K_d}{T} + \frac{K_i T}{2}) z^2 + (K_i T - \frac{4K_d}{T}) z + (-K_p + \frac{K_i T}{2} + \frac{2K_d}{T})}{z^2-1}$$

$$U_{(z)} z^2 - U_{(z)} = (K_p + \frac{2K_d}{T} + \frac{K_i T}{2}) z^2 + (K_i T - \frac{4K_d}{T}) z + (-K_p + \frac{K_i T}{2} + \frac{2K_d}{T})$$

Inverse Z transform:

$$U_{(k)} - U_{(k-2)} = (K_p + \frac{K_i T}{2} + \frac{2K_d}{T}) e_{(k)} + (K_i T - \frac{4K_d}{T}) e_{(k-1)} + (-K_p + \frac{K_i T}{2} + \frac{2K_d}{T}) \quad e_{(k-2)}$$

T: sampling time

$e_{(k)}$: error

Figure 12: bilinear approximation calculation

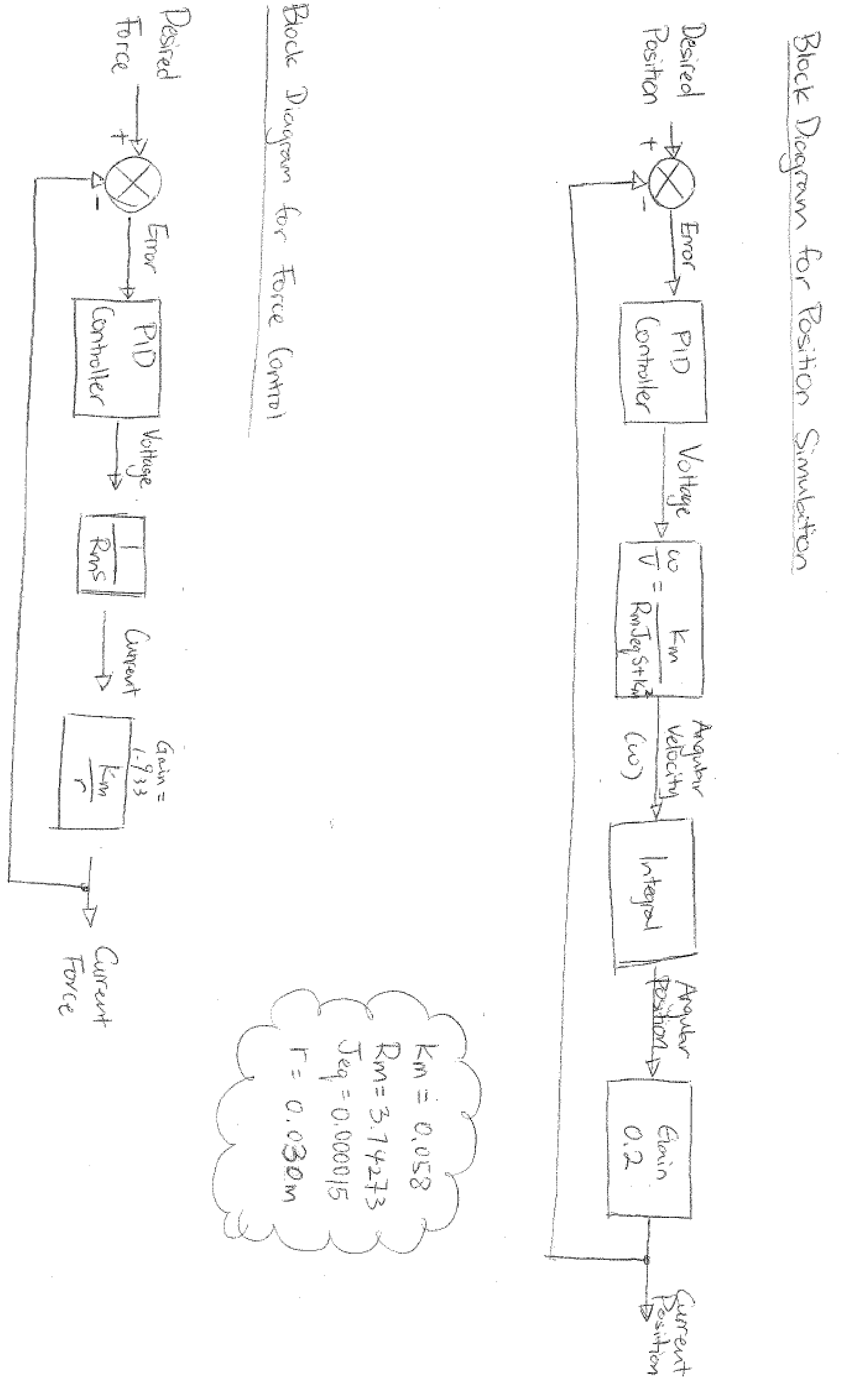

Figure 13: Simulation block diagram