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Feedback Control System Report

Embedded Systems 3 (T3-CB01)

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Abstract

This document is written based on the design of a feedback control system for a rotor tuning by Simulink designing app. The document will mostly explain about the system design of a rotor, the tuning creation and implementation, also the base theory from Ziegler-Nichols approach formula.

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1. Introduction

This experiment is about designing a feedback control system using the Simulink add-on in MATLAB IDE. The design is used to tuning a system, so it can be helpful for the system building and safety, and to decrease the over-use of power that can be wasted during the running of the system program.

1.1. Equipment

And in this experiment, one equipment that can be used is:

1. Laptop + Working MATLAB IDE + Simulink extension.

1.2. Document

And the document that can be needed is:

1. ParallaxStepResponse Excel document.

2. Procedure

There are 3 main steps that should be done to make the design in this assignment. Those steps are Reading the record data of a rotor example, calculating the system data requirement, and tuning the system speed by frequencies.

2.1. Reading the data

In this step, before directly open the data excel file of the ParallaxStepResponse record, the data that should be taken from it should be understood first.

This step can be done by doing one of the sub-step first, which is looking at the graph of the speed that is needed for the system, such as this Figure 2. 1. 1 below.

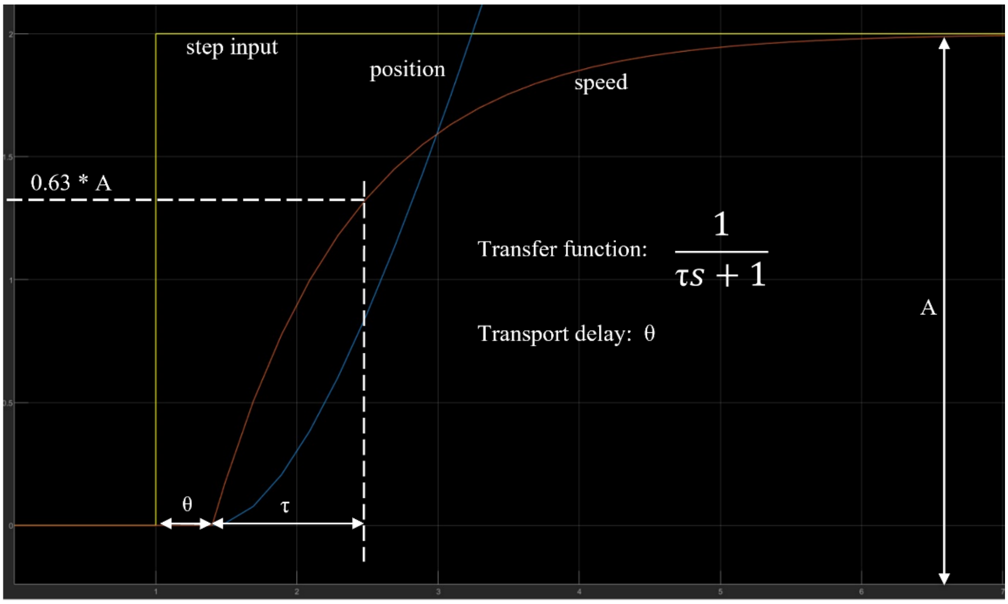

Figure 2. 1. 1 Step Response Transfer Graph

From this Figure 2. 1. 1, it can be seen that:

$A = Highest\ Speed$

$S = Desired\ Speed = 0.63 * A$

$\theta = Transport\ Delay$

$\tau = Time\ aproach\ to\ the\ desired\ speed$

After looking at this graph, now it can be decided that the thing that can be found in the excel data first is the highest speed needed, and the time delay of when the system just started to run. In this case, Figure 2. 1. 2 has been decided to be the chosen highest speed of the system, and Figure 2. 1. 3 has been decided to be the start of the system run.

3.00	1020.00	2.11
2.00	1022.00	2.11
3.00	1025.00	2.16
2.00	1027.00	2.11
2.00	1029.00	2.11

Figure 2. 1. 2 HIghest Speed of Loaded Rotor

37	35	0.00	0.00	0.05	0.00	0.00	0.00
38	36	0.00	0.00	0.05	0.00	0.00	0.00
39	37	0.00	0.00	0.05	0.00	0.00	0.00
40	38	0.00	0.00	0.05	0.00	0.00	0.00
41	39	0.00	0.00	0.05	0.00	0.00	0.00
42	40	0.00	0.00	0.11	0.00	0.00	0.00
43	41	0.00	0.00	0.11	0.00	0.00	0.05
44	42	1.00	1.00	0.16	0.00	0.00	0.05
45	43	0.00	1.00	0.16	0.00	0.00	0.05
46	44	0.00	1.00	0.16	0.00	0.00	0.05
47	45	0.00	1.00	0.21	0.00	0.00	0.11

Figure 2. 1. 3 Rotor Start Time

That makes the system highest speed is 2.16 rad/ms and the transport delay is 41 ms.

And the speed that is calculated in Desired Speed (S) from the A value is 1.3608 rad/ms. And then, there can be seen in the data file in Figure 2. 1. 4 below, that the closest speed from 1.3608 rad/ms is 1.37 rad/ms. From here, the time period (P) that can be taken, based on the data is 138 ms.

139	137	2.00	105.00	1.63	2.00	83.00	1.37
140	138	2.00	107.00	1.63	1.00	84.00	1.37
141	139	2.00	109.00	1.63	2.00	86.00	1.42

Figure 2. 1. 4 Rotor Normal Speed

And the time approach to the desired speed (τ) that can be received from the Time Approach to The Desired Speed (τ) calculation is 97 ms.

Now that the transport delay (θ) and the time approach to the desired speed (τ) have known, it is time for putting them to the manual tuning and draw the design such as in the Figure 3. 1. 1 of Simulink System Design below this Procedure part. However, it should be reminded that the Simulink system is using the s value instead of ms.

2.2. Calculations

2.2.1. Desired Speed (S)

$S = 0.63 \times A$

$S = 0.63 \times 2.16$

$S = \mathbf{1.3608}$ **rad/ms**

2.2.2. Time Approach to The Desired Speed (τ)

$T = \tau + \theta$

$138 = \tau + 41$

$\tau = 138 - 41$

$\tau = \mathbf{97}$ms

2.2.3. Real P Value

$P = 0.6 \times K_u$

$P = 0.6 \times 23.354$

$P = \mathbf{14.0124}$

2.2.4. Time Range (T_u)

$T_u = T_1 - T_0$

$T_u = 1.603 - 1.150$

$T_u = \mathbf{0.453}$ s

2.2.5. I Value

$K_i = 1.2(K_p/T_u)$

$K_i = 1.2(23.354/0.453)$

$K_i = \mathbf{61.8649}$

2.2.6. D Value

$$K_d = 3(\frac{K_p \times T_u}{40})$$

$$K_d = 3(\frac{23.354 \times 0.453}{40})$$

$$K_d = \mathbf{0.7934}$$

2.3. Manual and Auto Tuning

In this part, the founded θ and τ value from the calculation can be added to the system design such as these Figure 2. 3. 1 and Figure 2. 3. 2 down below.

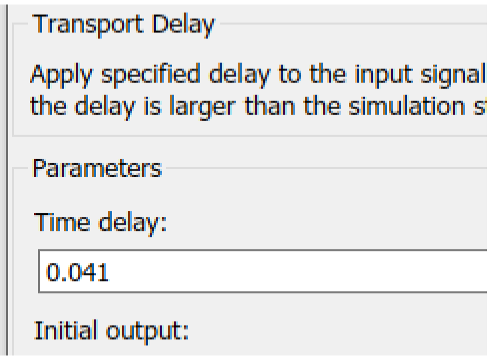

Figure 2. 3. 1 Transport Time Delay

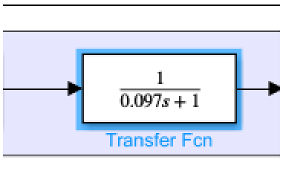

Figure 2. 3. 2 System Discrete Transfer Function

The θ in the picture above is become 0.041 because the value that is available on the Simulink is in second (s) instead of millisecond (ms). And so, the same with the τ value in the transfer function design which become 0.097.

After placing these calculation values to the correct place, a manual tuning to find the perfect PID value for the rotor system can be done. This tuning method that being used in this experiment is the Ziegler-Nichols closed loop method. This method is also described as a conducted tuning technique with the controller in the automatic mode, but with the integral values and derivative actions shut off. Therefore, the integral of the PID must be used, and the derivative action should be checked on the system tuning IDE during the whole process.

To do this, the P value from the PID system should be changed manually until the system graph can get this most critical oscillations such as shown in this Figure 2. 3. 3 below. And to get these oscillations, based on the θ and the τ, the P value from the PID input is approximately around 23.354.

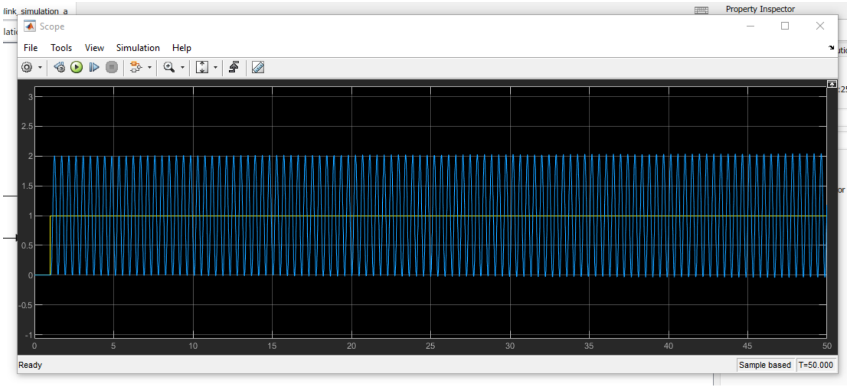

Figure 2. 3. 3 Steady Max Oscillations

To get the nice critical oscillations such as Figure 2. 3. 3 above, the only thing that should be written in the PID controller is the P value. The rest of the PID value such as the I and the D should be set to be 0 like this Figure 2. 3. 4 below.

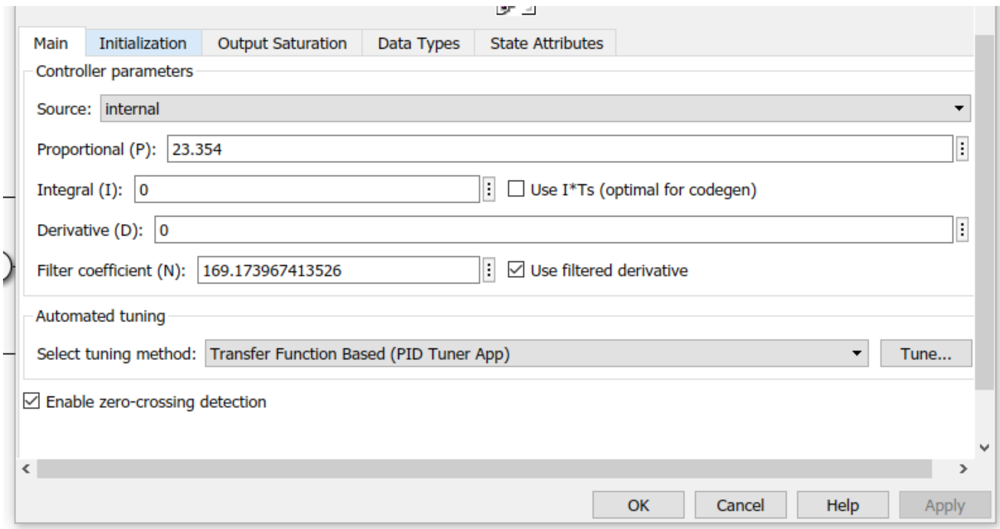

Figure 2. 3. 4 P tuning for perfect oscillations

And by this, the P value can be calculated in the Real P Value, at Calculations above using the 0.6 value from this Figure 2. 3. 5 below.

Ziegler–Nichols method[1]

Control Type	K_p	T_i	T_d	K_i	K_d
P	$0.5K_u$	–	–	–	–
PI	$0.45K_u$	$T_u/1.2$	–	$0.54K_u/T_u$	–
PD	$0.8K_u$	–	$T_u/8$	–	$K_uT_u/10$
classic PID[2]	$0.6K_u$	$T_u/2$	$T_u/8$	$1.2K_u/T_u$	$3K_uT_u/40$
Pessen Integral Rule[2]	$7K_u/10$	$2T_u/5$	$3T_u/20$	$1.75K_u/T_u$	$21K_uT_u/200$
some overshoot[2]	$K_u/3$	$T_u/2$	$T_u/3$	$0.666K_u/T_u$	$K_uT_u/10$
no overshoot[2]	$K_u/5$	$T_u/2$	$T_u/3$	$2/5K_u/T_u$	$K_uT_u/15$

Figure 2. 3. 5 Zieger-Nichols Method

After that, the T_u value for the system should be found first by looking at the time range between a one wave movement. And by using the number that is being shown in this Figure 2. 3. 6 down below, the T_u value that is calculated in Time Range (T_u) above have results 0.453.

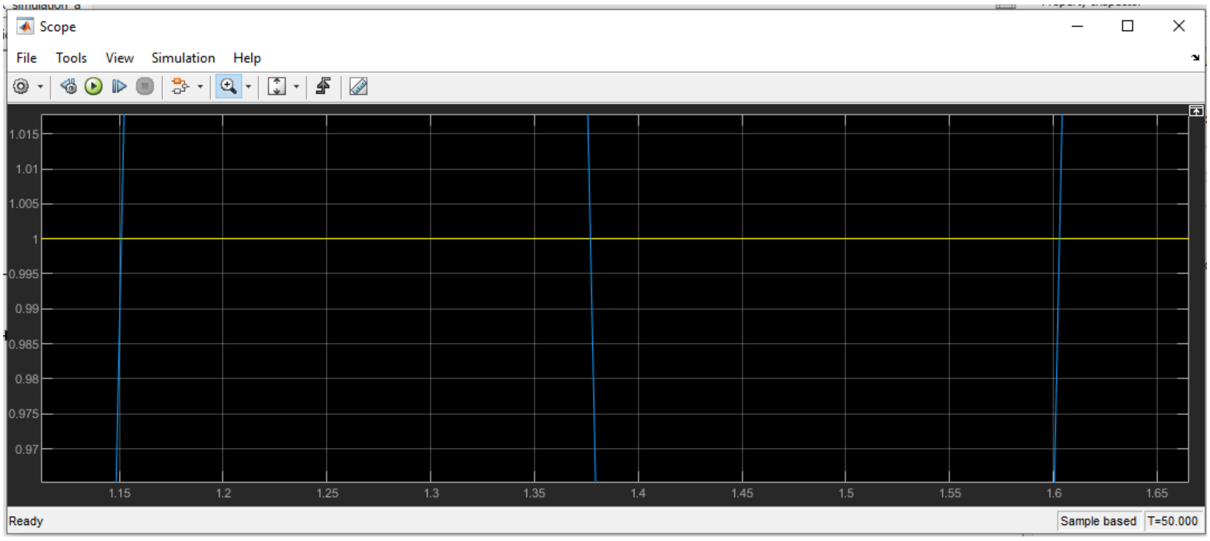

Figure 2. 3. 6 Wave Time Range

After calculating all the needed value in the Calculations above, P value is now become 14.0124, I value is 61.8649, and D value is 0.7934 as what is shown on Figure 2. 3. 7 down below.

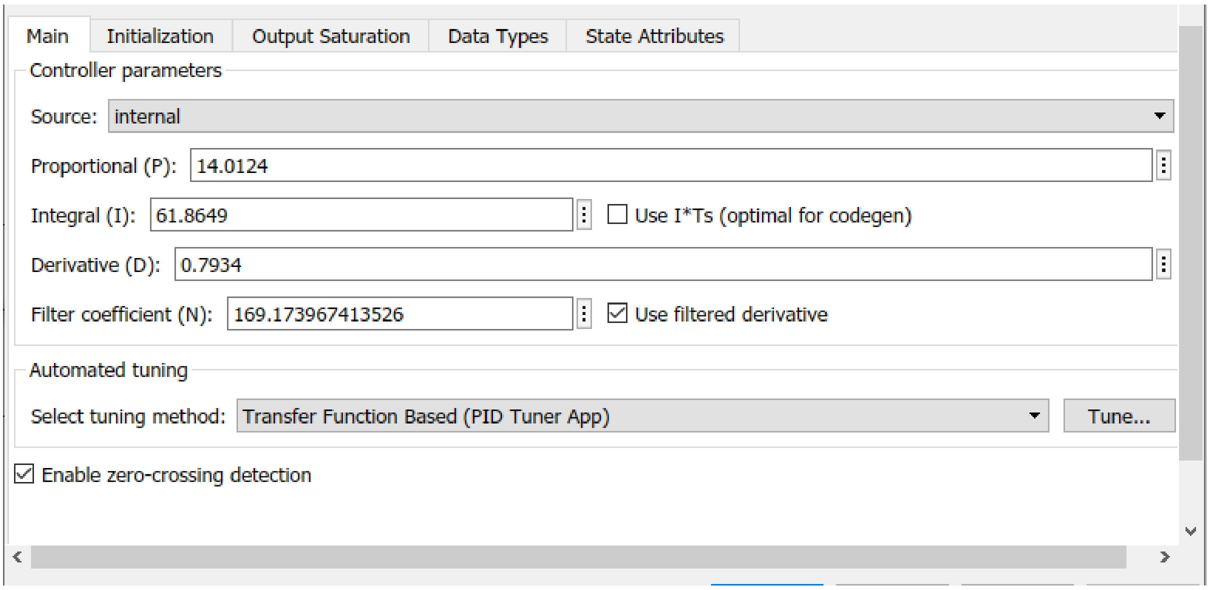

Figure 2. 3. 7 Manual PID value

Now that the manual tuning can be built, the result of the tuning can be seen in Figure 3. 2. 1 of the Design.

However, with such high Integration from the start, the system must be tuned down a little bit to make it keep steady. Therefore, an auto Tuning such as this Figure 2. 3. 8 below can be used.

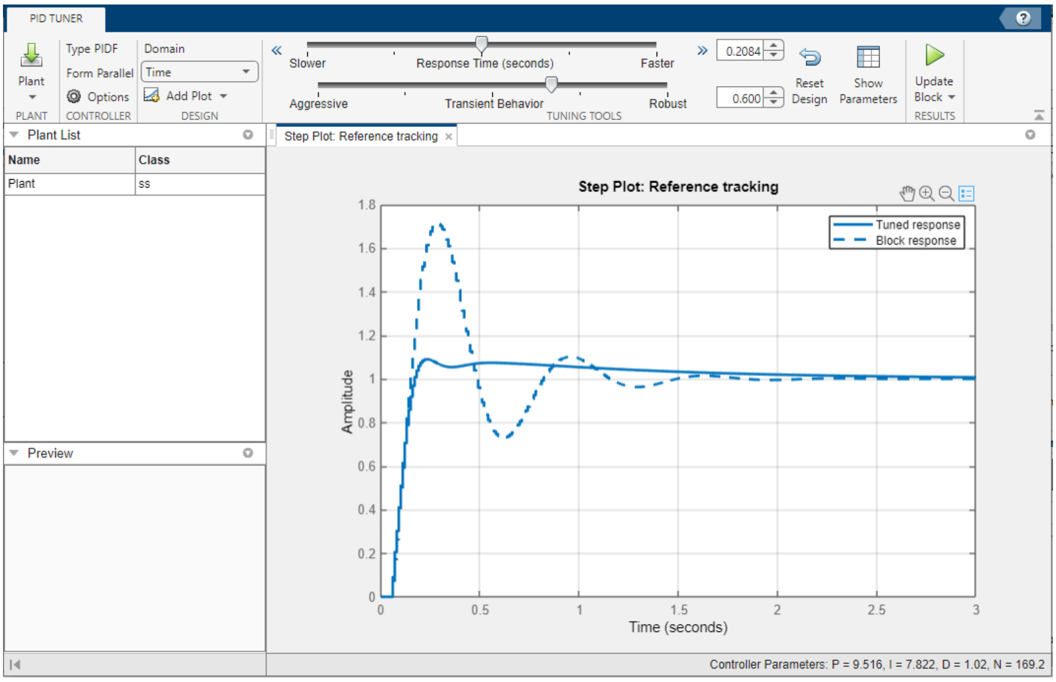

Figure 2. 3. 8 Auto Tuning Option

And as the result, the end design of the system tuning can be seen in Figure 3. 3. 1 in the Design part, where the PID value changes can be read in this Figure 2. 3. 9 below.

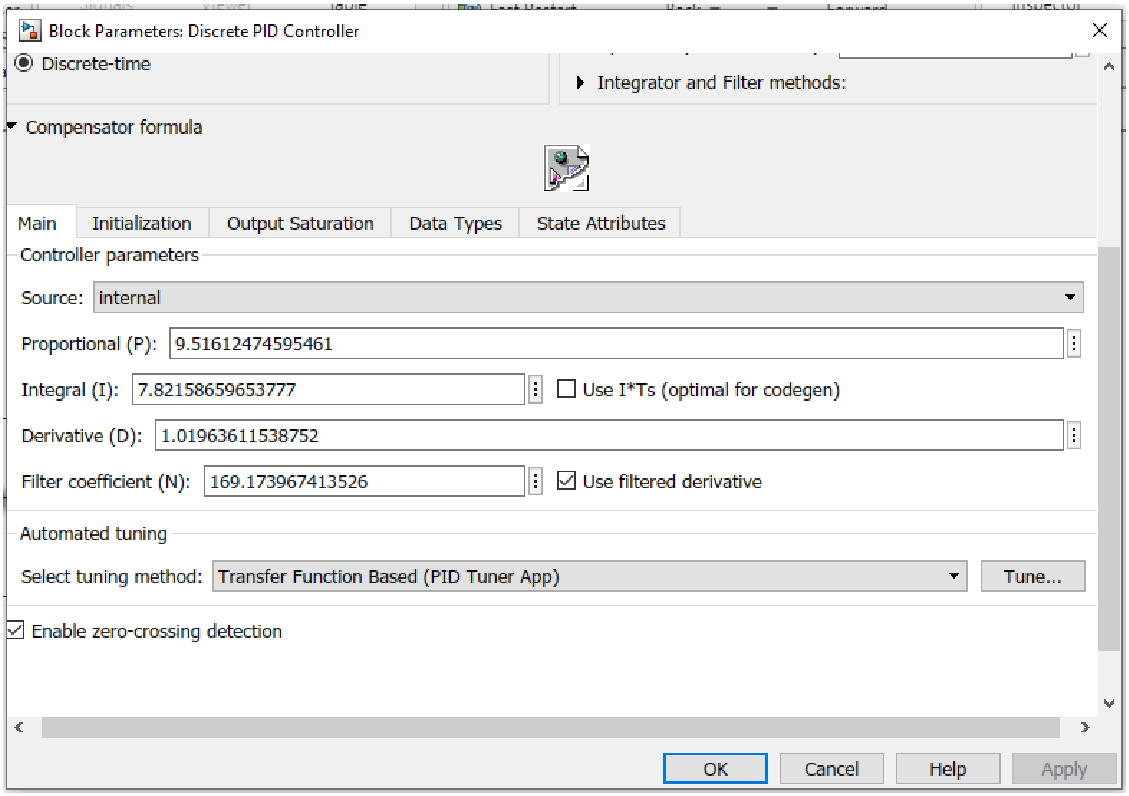

Figure 2. 3. 9 Auto Tuning Result

3. Design

3.1. Simulink System Design

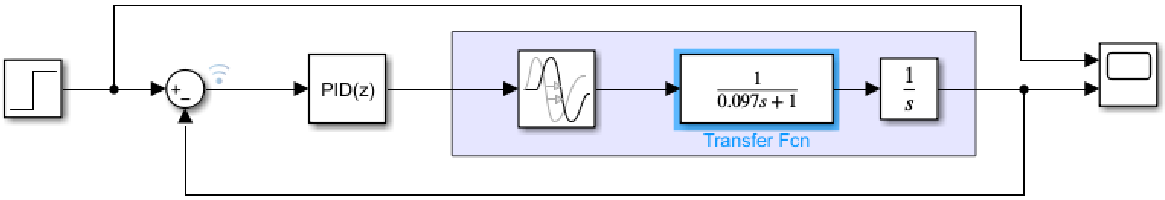

Figure 3. 1. 1 Simulink System Design

3.2. PID manual Tuning Result

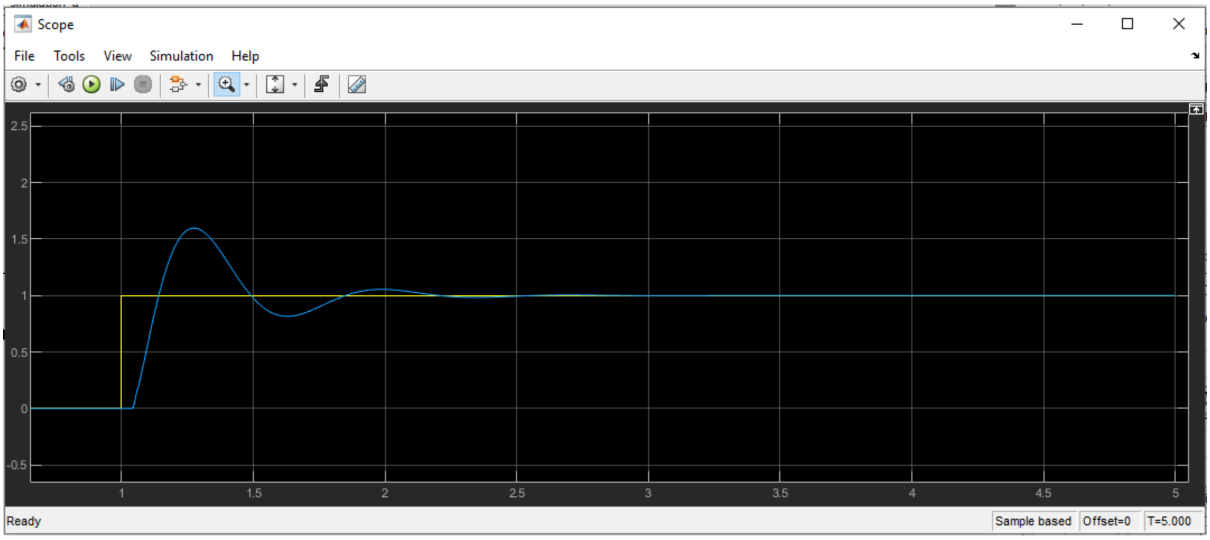

Figure 3. 2. 1 PID Manual Tuning

3.3 Auto Tuning Result

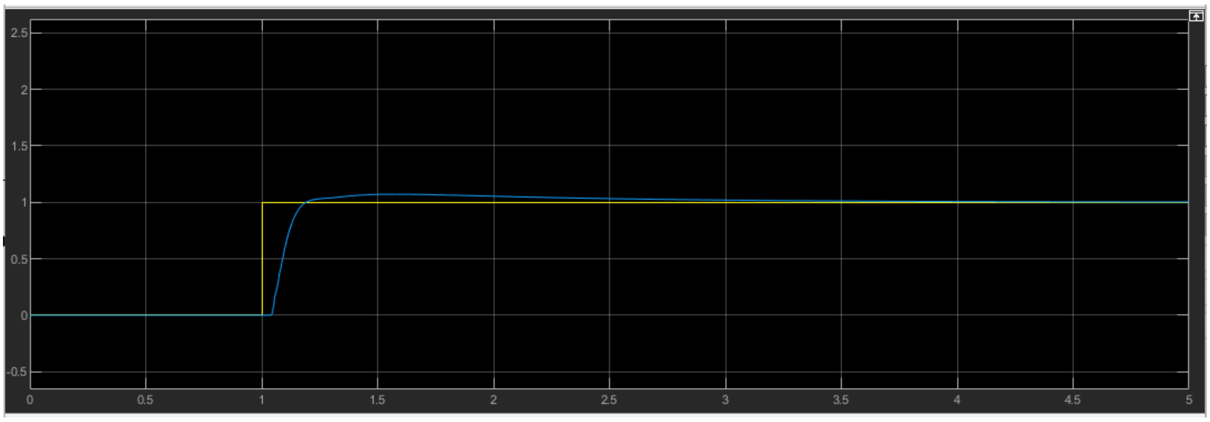

Figure 3. 3. 1Auto Tuning Result

4. Retrospective & Recommendation

By doing this experiment, multiple tuning results can be produced depending on the time range choices of the desired speed based on the provided data. And the tuning itself is not truly ideal to use for the system at raw. Even the Ziegler-Nichols method itself still have flaws in the end with the integration start of the system, even after the max oscillations for the system have been tuned perfectly at start. However, the auto tune system of the Simulink can be used to fix these flaws.

In the end, the tuning system for speed based on the time is really needed to make sure that the system is not over used the power and keep its movement in secure condition.

5. References

Electronics-Tutorial, Kirchhoff’s Circuit Law,

RM016 Reference Manual
(ST, January 2017)

UM1724 User Manual Doc
(ST, April 2019)

Cortex-M4 Devices Generic User Guide Doc
(ARM, 2010)