ECE 311 - Lab 3

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1 - INTRODUCTION

This lab is an extension of lab 2. We are given a list of technical specifications and we design a cruise control system for a car to satisfy these. We use the root locus method to design two PI controllers, one aggressive (with a high gain K) and one non-aggressive (with a lower gain K). We then compare these with respect to their settling times, overshoots, magnitudes, and rejection of disturbances. The parameters we use are taken from lab 2, and are listed below:

- a = 3.75
- b = 17

2 - EXPERIMENTS

In this section you will report all your experimental simulation: discuss your hypothesis and results.

2.1 CONTROLLER DESIGN USING MATLAB

In this section you will describe all the steps performed to design your controller using the root locus method with MATLAB.

Be sure to include the following material and discussions:

1. Your first root locus plot with the initial choice of $T_I=1$. Why doesn't there exist K > 0 such that the closed-loop has two poles on the real axis with the real part ≤ −20? Justify your answer using the root locus plot.

   A root locus plot shows the poles of a system as a function of K. In the plot below, the green and blue lines represent the possible values for the two poles. The green line showing the values for the first pole takes on values from -infinity to -10. Thus, this pole can have a value with the real part <= -20. However, the blue line showing values for the second pole takes on values only from 0 to -2. Thus, this pole cannot have a value with the real part <= -20. So, in this closed loop system, there does not exist a K>0 such that both poles have a real part <=-20.

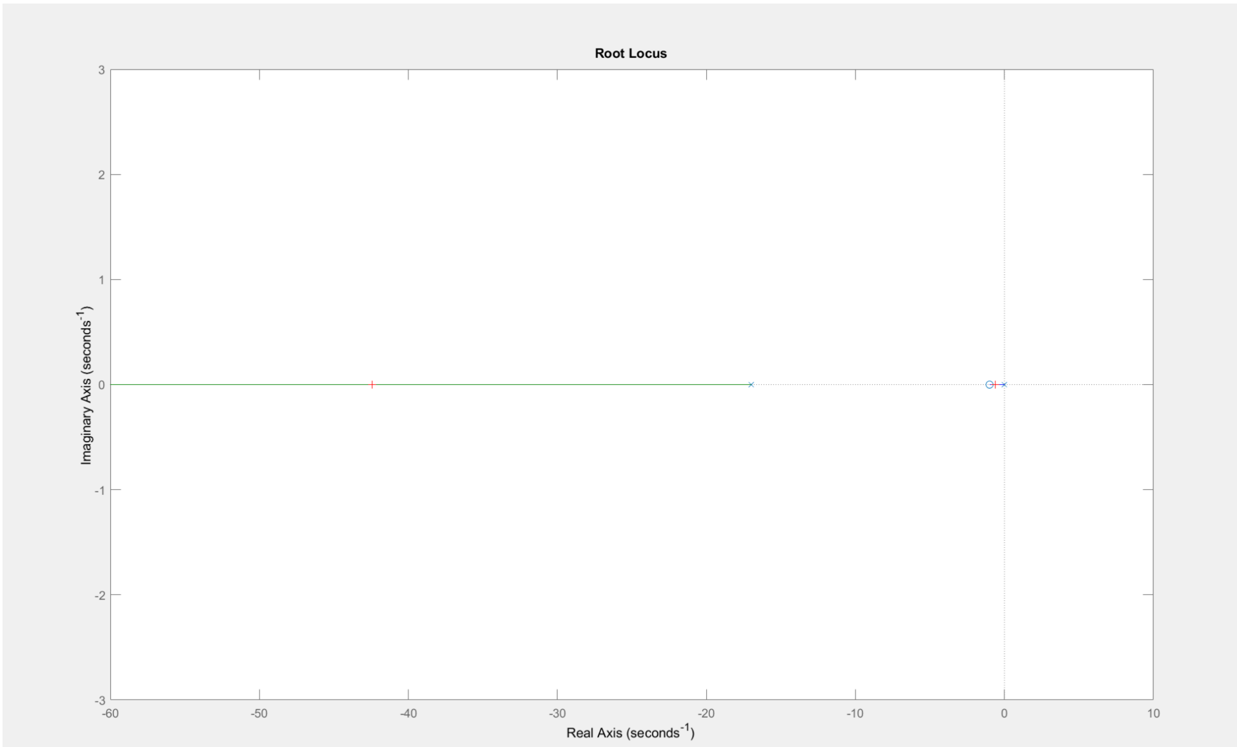


Figure 2.1.1: Root locus plot for T_I = 1.

2. Your final choice of T_I and the corresponding root locus plot.

For $\mathbf{T_I}$ **= 0.057**, we get the following root locus plot (shown in Figure 2.1.2), with at least two poles on the real axis close to s = -20.

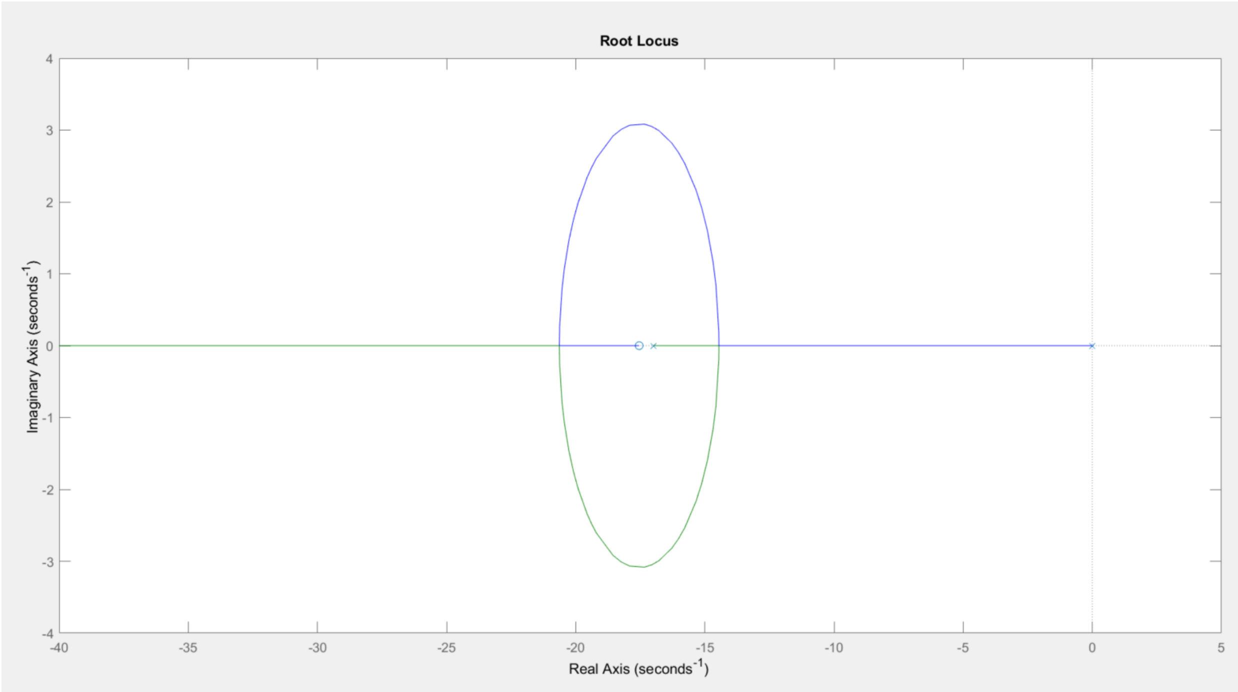


Figure 2.1.2 : Root locus plot of poles for $T_I = 0.057$

3. The values of *K* you obtained using the function **rlocfind.**

Using the function rlocfind, we get **K = 6.47**.

4. Report the response of the closed loop system with the PI controller. What is the settling time T_s you estimated from your plot? Is the control specification **approximately** met?

The response of the output v(t) relative to the reference signal r(t) is shown in Figure 2.1.3 below.

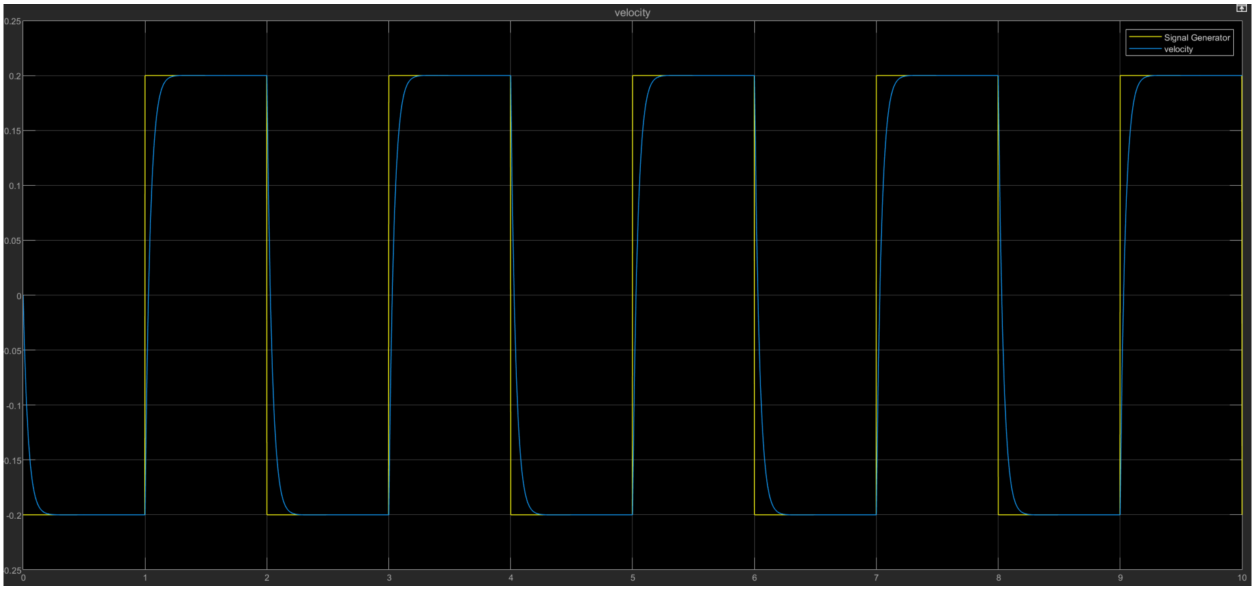


Figure 2.1.3 : Plot showing the reference signal r(t) and the response of the output v(t)

Zooming in, we see that the settling time is 0.23 s which is approximately 0.2 s. This is shown in Figure 2.1.4. Hence SPEC4 is **approximately** met.

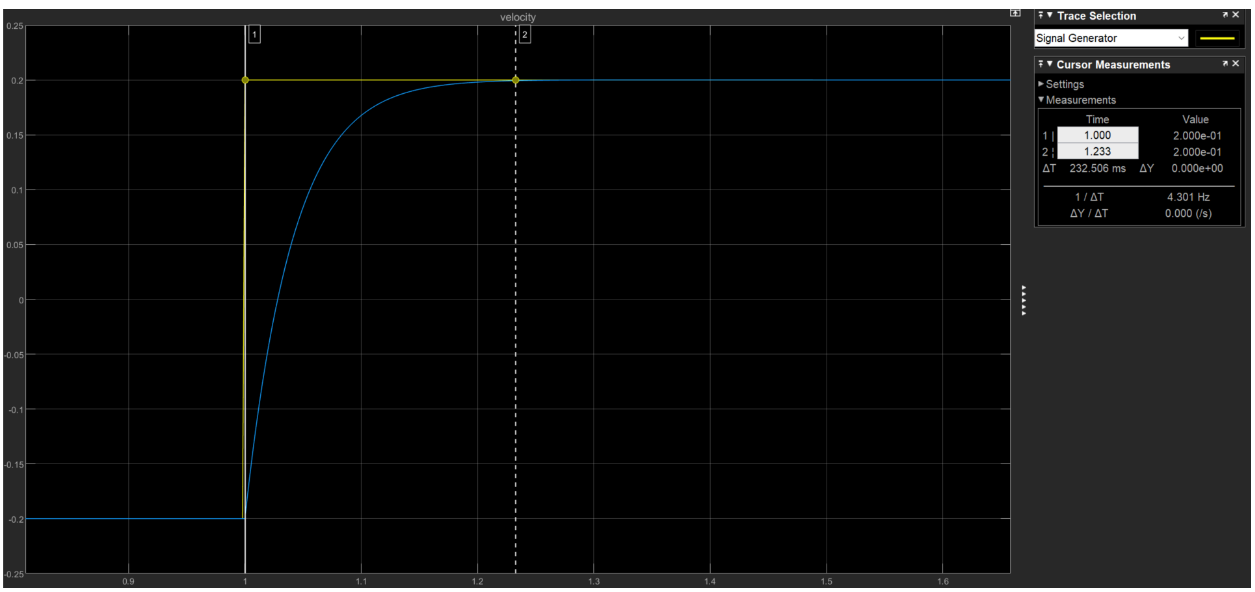


Figure 2.1.4: Zoomed-in plot of the velocity response showing the settling time.

5. Is SPEC5 met? Include the plot of your voltage input to support your claim

To meet SPEC5, the magnitude of the voltage $v_m(t)$ must be less than 11.75 V. From Figures 2.1.5 and 2.1.6, we see that the amplitude of $v_m(t)$ does not exceed 1.7 V. Since this number is much smaller than 11.75 V, we can assume that SPEC5 is met.

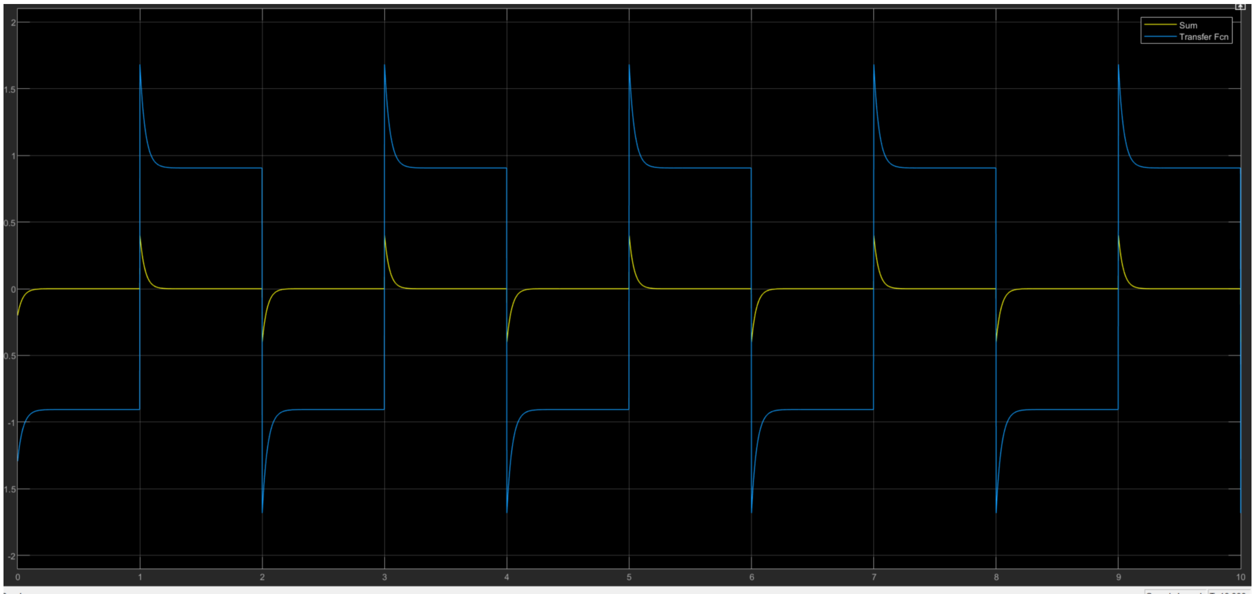


Figure 2.1.5: Plot showing the response of the voltage input $v_m(t)$.

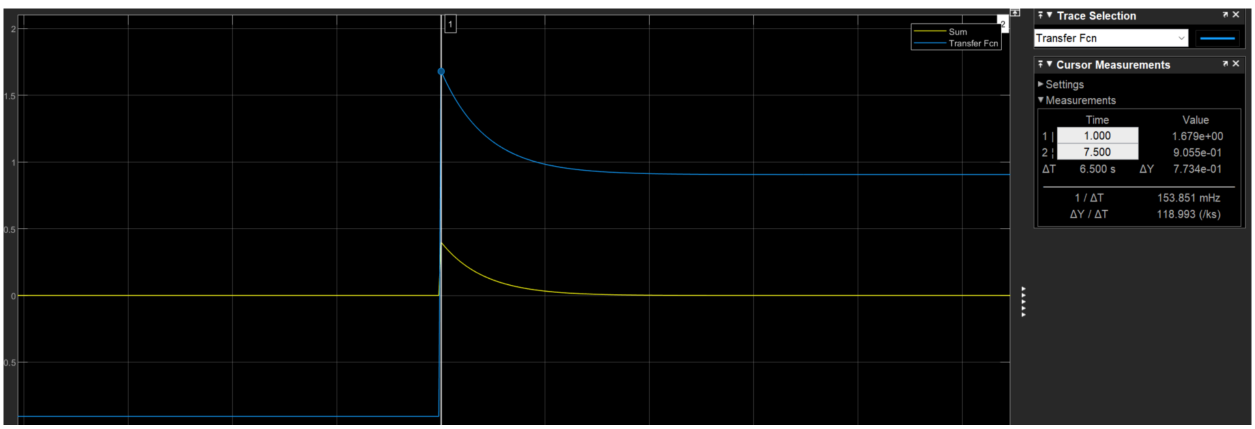


Figure 2.1.6: Zoomed-in plot showing the amplitude of the voltage input $v_m(t)$.

More aggressive controller »

6. Report here the value of T_I such that there exists K > 0 such that the closed-loop system has two poles close to s = – 30 and the corresponding root locus plot.

For $\mathbf{T_I = 0.038}$, we get the following root locus plot (shown in Figure 2.1.7), with at least two poles on the real axis close to s = -30.

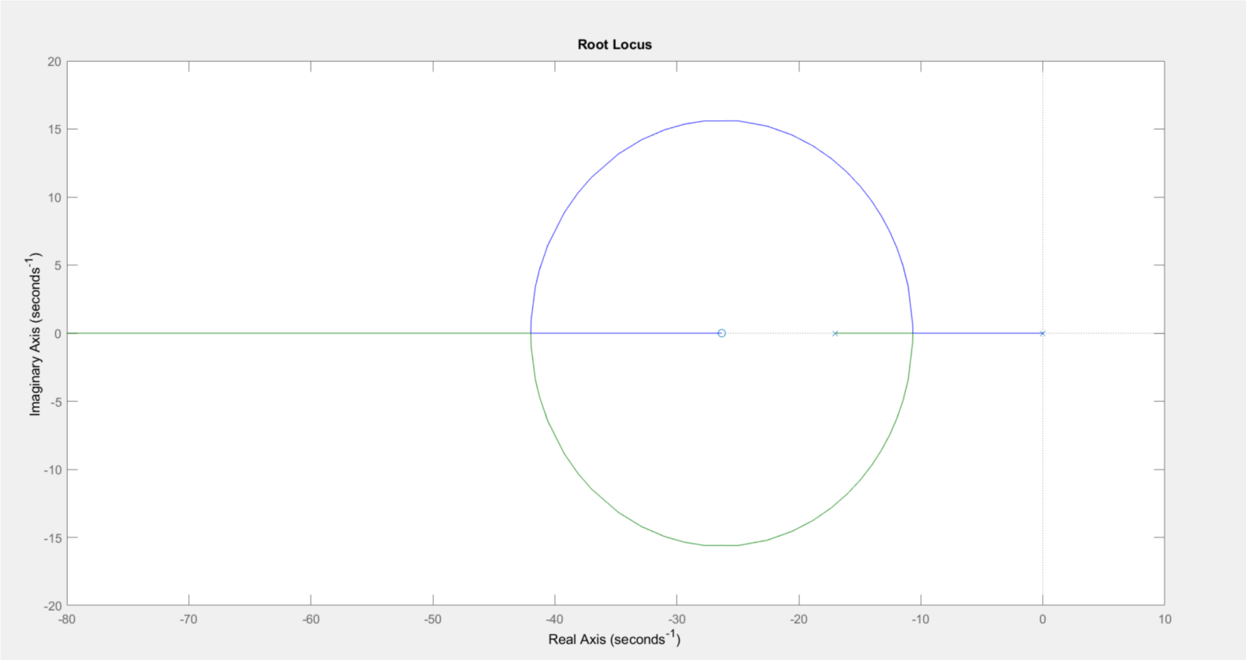


Figure 2.1.7: Root locus plot for TI = 0.038

7. Your final choice of T_I and the corresponding root locus plot.

   Our final choice is $\mathbf{T_I = 0.038}$ with the corresponding root locus plot given in Figure 2.1.8.

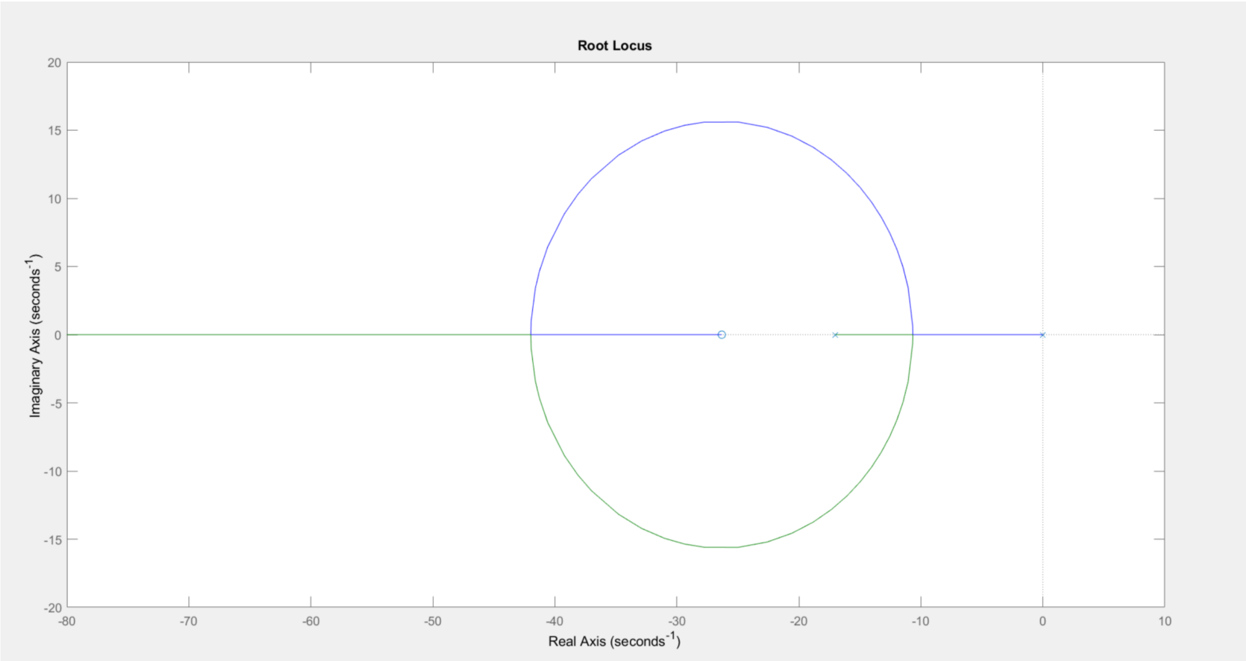


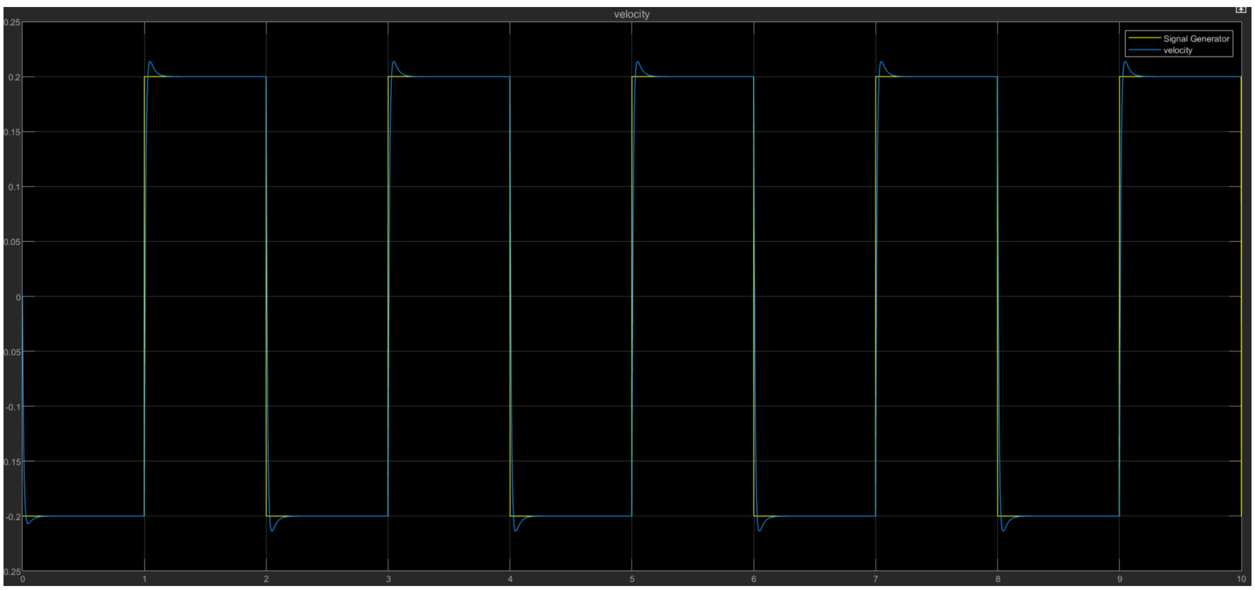
Figure 2.1.8: Root locus plot for TI = 0.038

8. <u>The values of *K* you obtained using the function **rlocfind**</u>

Using the function rlocfind, we get **K = 28.2**

9. <u>Report the response of the closed loop system with the new PI controller. What is the settling time T_s you estimated from your plot? Is the control specification **approximately** met?</u>

From Figures 2.1.8 and 2.1.9, we estimate the settling time T_s to be **0.169 s**, which is much less than 0.2 s. Hence, the control specification SPEC4 is **thoroughly met**.



<u>Figure 2.1.9:</u> Plot showing the reference signal r(t) and the response of the output v(t) for a more aggressive controller.

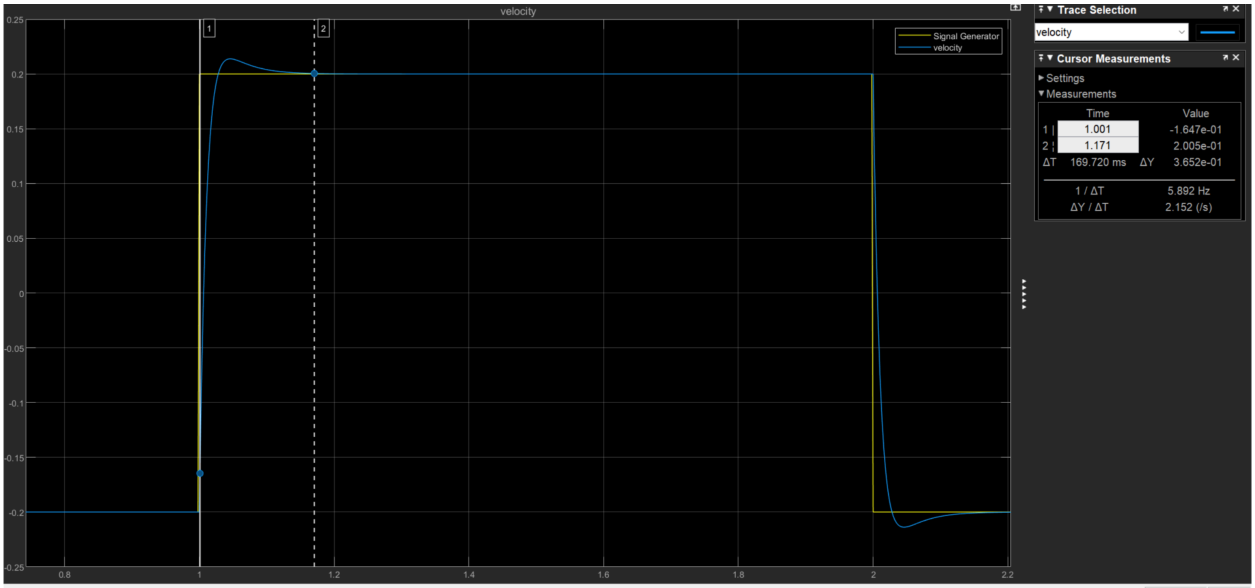


Figure 2.1.10: Zoomed-in plot of the velocity response showing the settling time for a more aggressive controller.

10. <u>Is SPEC5 met? Include the plot of your voltage input to support your claim</u>

From Figures 2.1.10 and 2.1.11, we see that the amplitude of $v_m(t)$ is at 10 V. Hence, we can assume that the magnitude of the input voltage will not exceed 11.75 V. SPEC5 is met.

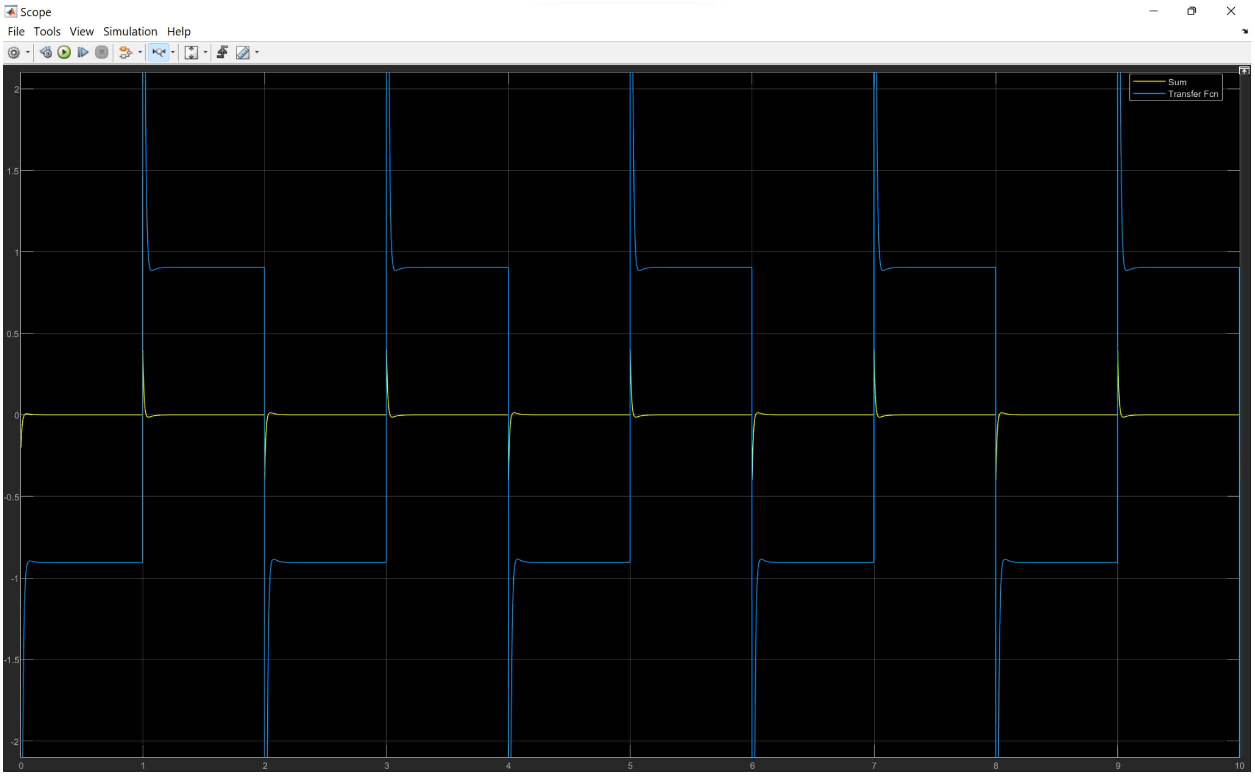


Figure 2.1.11: Plot showing the response of the voltage input $v_m(t)$ for the more aggressive controller.

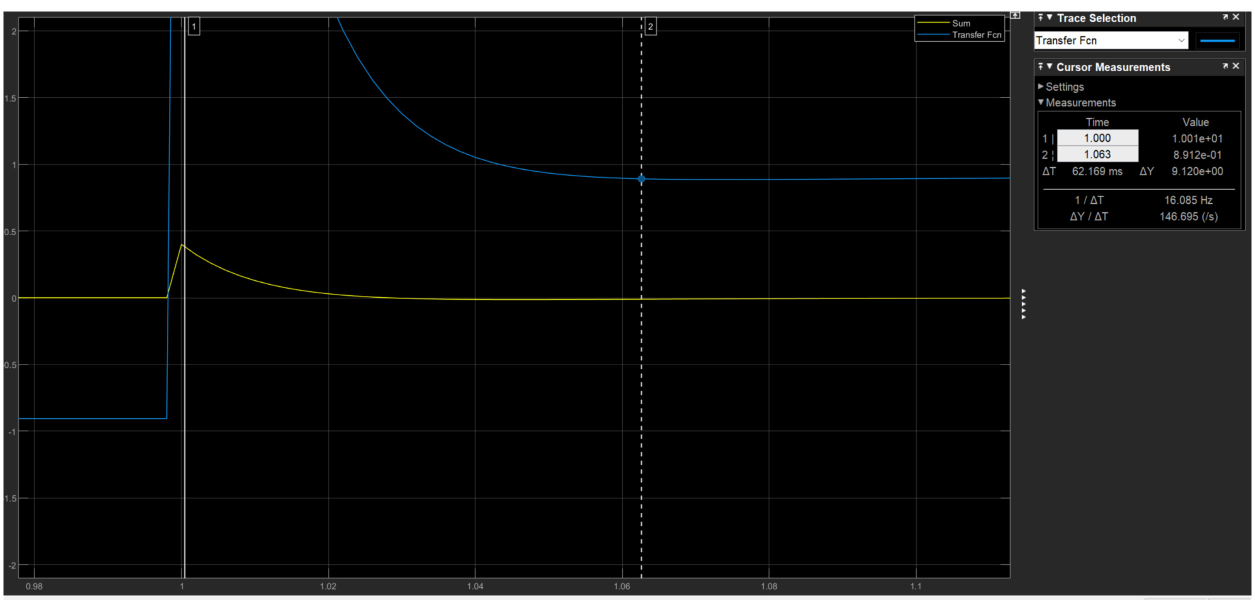


Figure 2.1.12: Zoomed-in plot showing the amplitude of the voltage input $v_m(t)$ for the more aggressive controller.

2.2 REJECTION OF DISTURBANCES

Be sure to include the following material and discussions:

1. Include the closed loop responses for both controllers

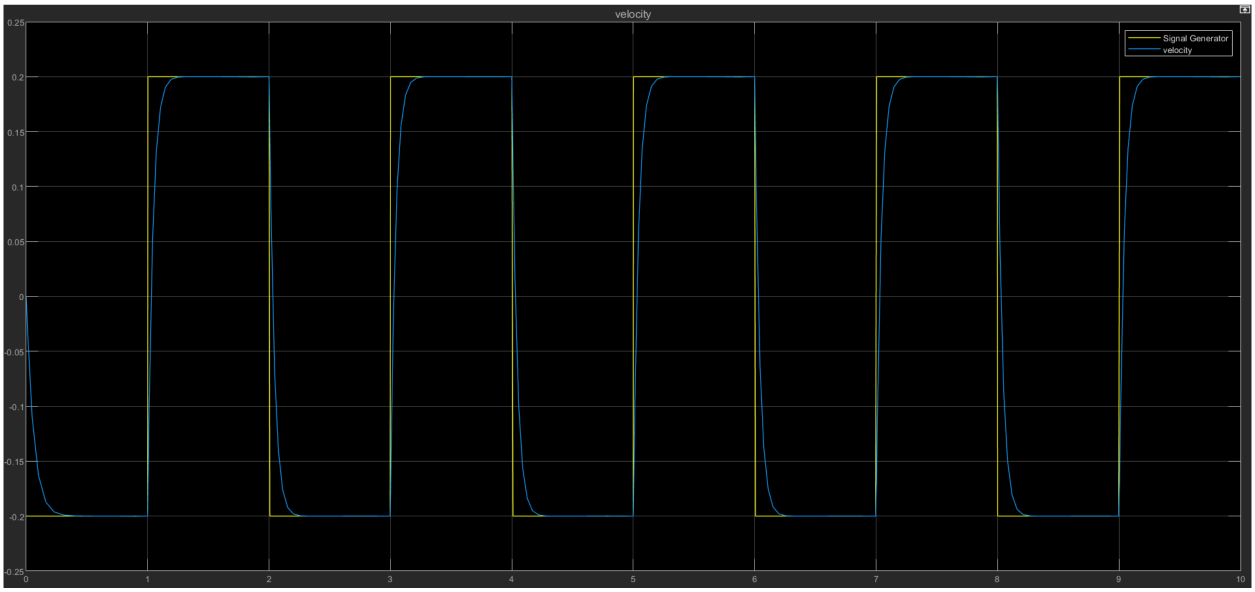


Figure 2.2.1: Plot showing the closed loop velocity response for the non-aggressive controller.

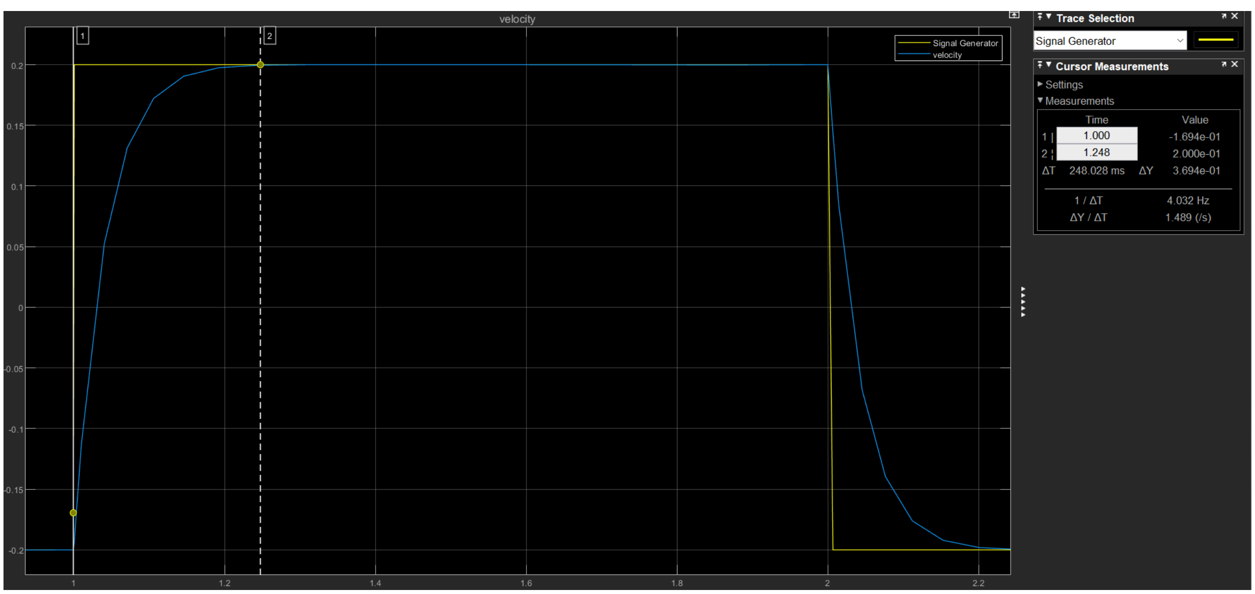


Figure 2.2.2: Zoomed in plot showing the closed loop velocity response for the non-aggressive controller.

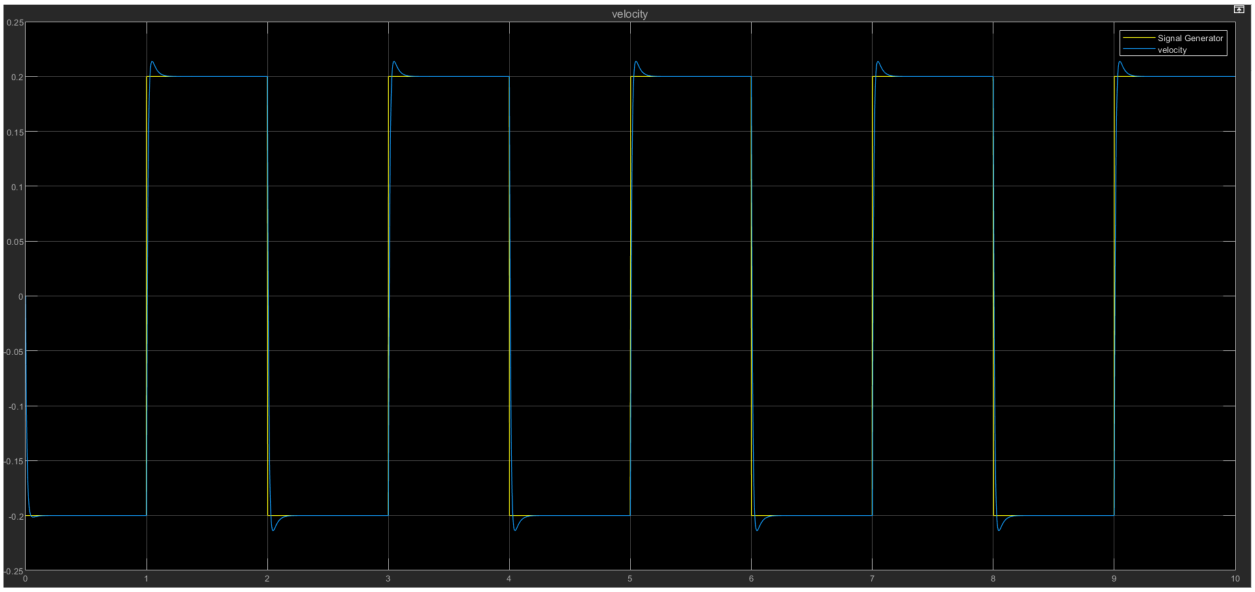


Figure 2.2.3: Plot showing the closed loop velocity response for the aggressive controller.

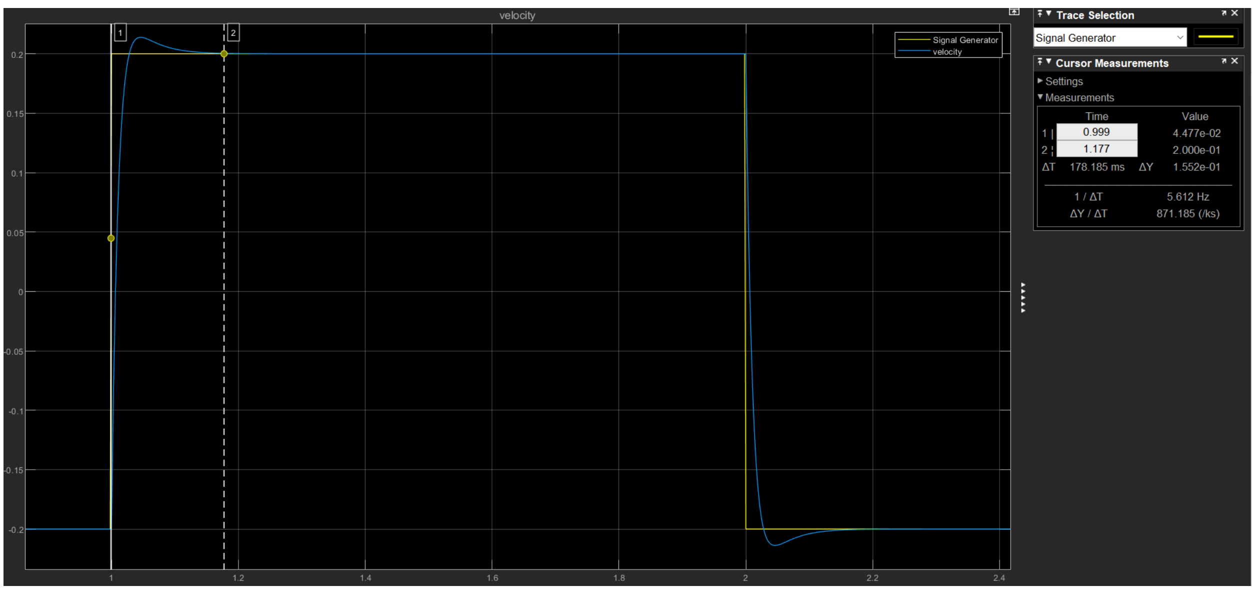


Figure 2.2.4: Zoomed in plot showing the closed loop velocity response for the aggressive controller.

2. Are the two controllers able to reject the disturbance?

   Yes, both controllers are able to reject disturbances. This can be verified by comparing their settling times to those obtained when the model was run without any disturbances. For the non-aggressive controller, the settling time without disturbances is

0.23s≈0.2s, while that with disturbances is 0.248s≈0.2s. These are approximately the same, thus the non-aggressive controller rejects disturbances. For the aggressive controller, the settling time without disturbances is 0.169s, while that with disturbances is 0.178s. These are approximately the same, thus the non-aggressive controller rejects disturbances.

3. How do the two controllers compare, with respect to disturbance rejection? Support your arguments referring to the velocity responses you obtained.

   The aggressive controller is better in terms of disturbance rejection. The change in settling time with and without disturbances is lesser for the aggressive controller (0.009s) than for the non-aggressive controller (0.018s). The aggressive controller is better as despite the disturbances the settling time doesn't change much.

3 - CONCLUSIONS

In this section you need to answer the following questions:

1. How do the settling times and overshoots compare?

   Settling Time: the aggressive controller has a lower settling time (0.169s) than the non-aggressive one (0.23s≈0.2s). Both meet the given specifications

   Overshoot: the non-aggressive controller has a lower overshoot than the aggressive one. Both meet the given specifications.

2. Which controller is best suited to meet the specs?
   The non-aggressive controller is best suited to meet the specs. The aggressive controller has lower settling times, however it has a limited room for error for the peak value of $v_m(t)$ as it draws 10V, which is quite close to the maximum magnitude of voltage of 11.75V that can be provided. As the non-aggressive controller requires much less input voltage of 1.7V, it is better suitable to meet our design specifications.

3. What is the cause of the differences you observe?
   When compared to the non-aggressive controller, the aggressive controller decays faster due to its exponential component. We know this because the poles of the aggressive controller have a higher magnitude (s≈-30) than those of the non-aggressive controller

($s \approx -20$). This faster exponential decay results in a lower settling time for the aggressive controller. As the poles depend on the gain (K), the aggressive controller has a high gain, and thus a larger overshoot and a larger $v_m(t)$.

4. Are both controllers able to reject the disturbances?

   Yes, both controllers are able to reject disturbances. This can be verified by comparing their settling times to those obtained when the model was run without any disturbances. For the non-aggressive controller, the settling time without disturbances is 0.23s≈0.2s, while that with disturbances is 0.248s≈0.2s. These are approximately the same, thus the non-aggressive controller rejects disturbances. For the aggressive controller, the settling time without disturbances is 0.169s, while that with disturbances is 0.178s. These are approximately the same, thus the non-aggressive controller rejects disturbances.