Control Engineering
Experiment - 10

Controller design for disturbance rejection on Simulink

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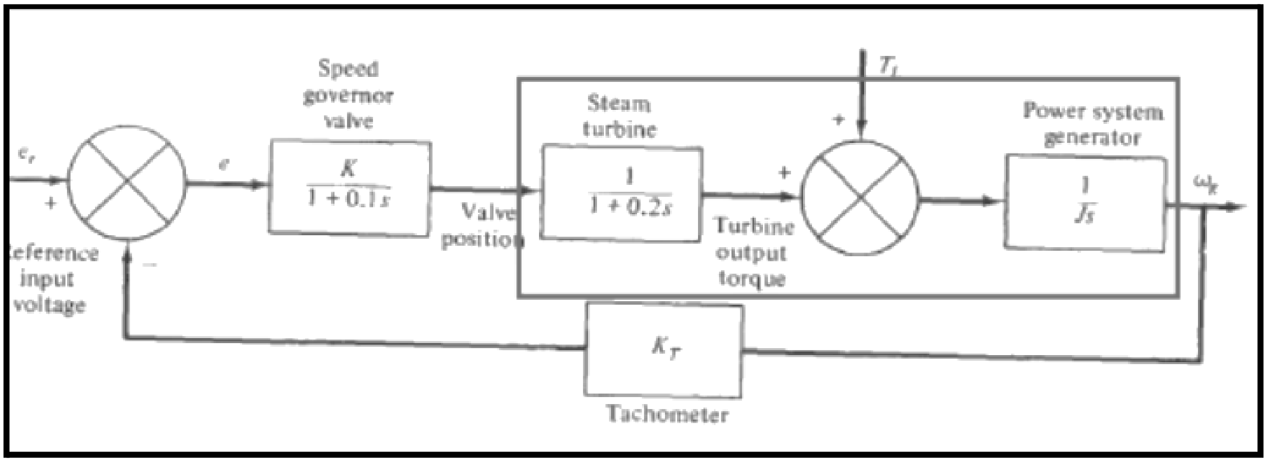
Objective

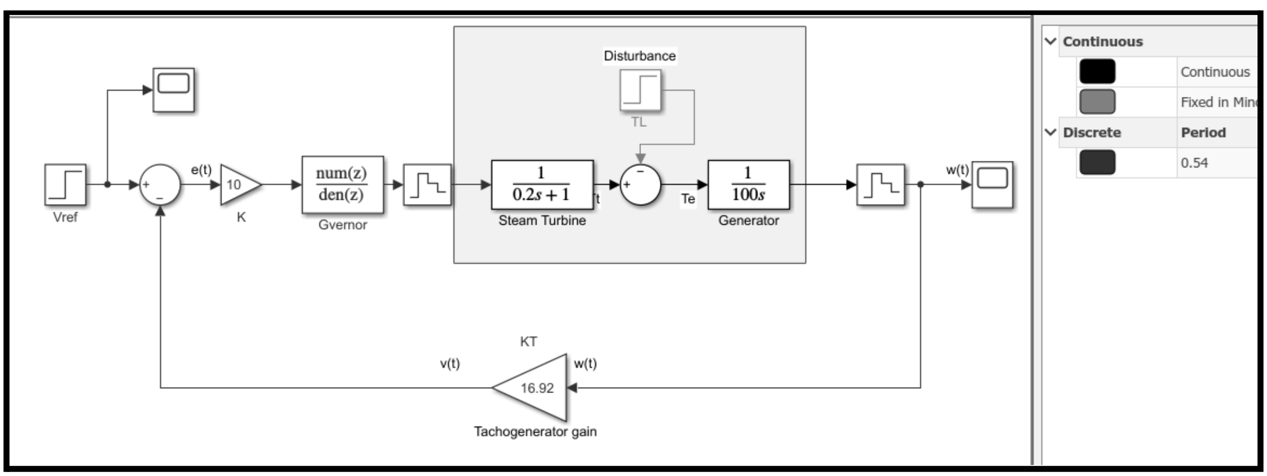
Design of analog control parameters for a turbine speed regulation system.

Our System

The CL system as described in Expt 9 is shown in the figure below, where the part that must be retained as analog (essentially the OLTF) is enclosed by a box.

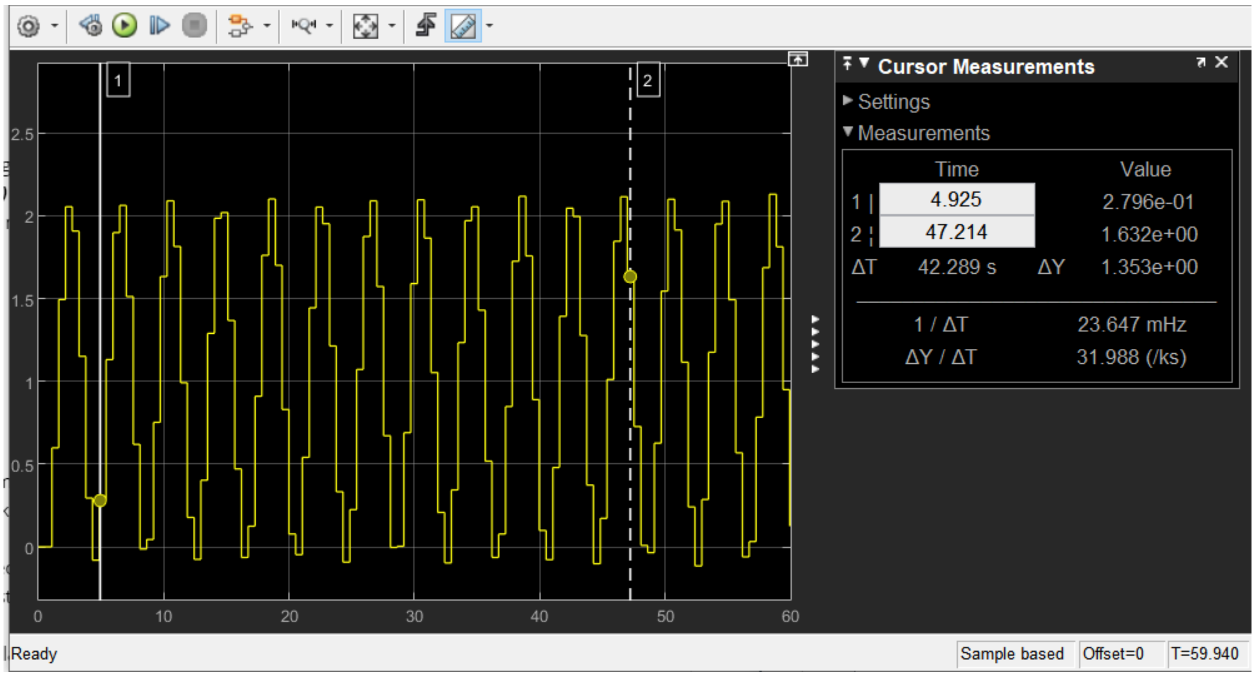


Our simulink model is as follows :



Plots and Analysis

From experiment 9, taking K = 10, KT comes out to be ***16.9*** resulting in a damping ratio of 0.7070 and vref(t) = ***17u(t)*** results in ω(t) = 1.0 . We take these values and increase our sampling time to find the maximum possible sampling time as follows



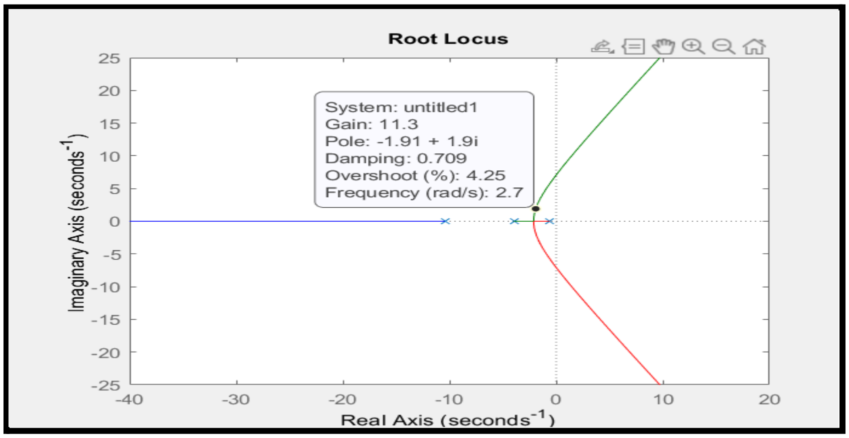
We observe that at sampling time T =0.54 the system becomes oscillatory i.e. if we further increase the value of sampling time the system will become unstable for the above values of K and KT.

We consider 0.54 as the maximum possible sampling time and solve the rest of the parts accordingly.As we considered earlier also the system shows dominant pole dynamics and thus can be approximated to a second order system. Thus we can calculate damping factor as follows

$$\zeta = \frac{-\ln\left(\frac{\mathrm{PO}}{100}\right)}{\sqrt{\pi^2 + \ln^2\left(\frac{\mathrm{PO}}{100}\right)}}$$

Part 1 :

For K =10, we need to compute KT for which zeta = 0.7070
PO = 4.32 %
We get the following bode plot for ***KT = 4.898***.



We also note that the system has a peak overshoot of 4.25%
Taking vref = 1*u(t)
Now we increase the value of KT to get the desired peak overshoot for step input.

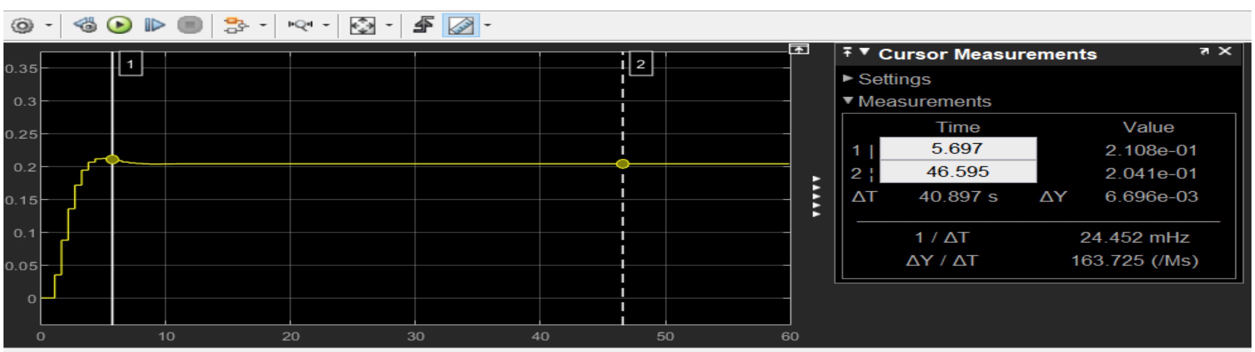


Figure 1 : KT =4.9 PO = (6.696e-3 / 2.041e-1)x100 = 3.34%

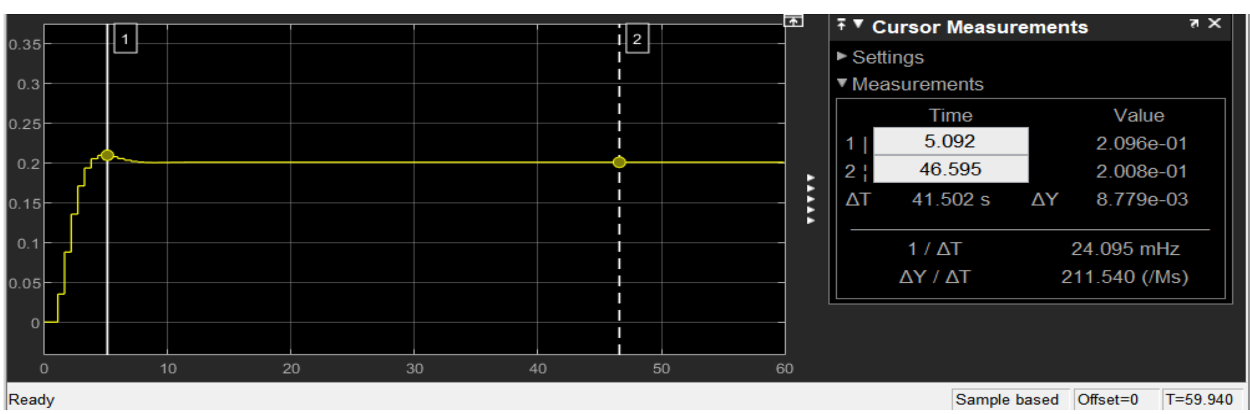


Figure 2: ***KT = 4.98*** PO = (8.779e-3 / 2.008e-2)x100 = 4.37% ***(close to required PO)***

Part 2:

Now for KT =4.98 we need to obtain vref(t) for which w(t) = 1. So we increase the magnitude of step input i.e. vref(t) as follows:

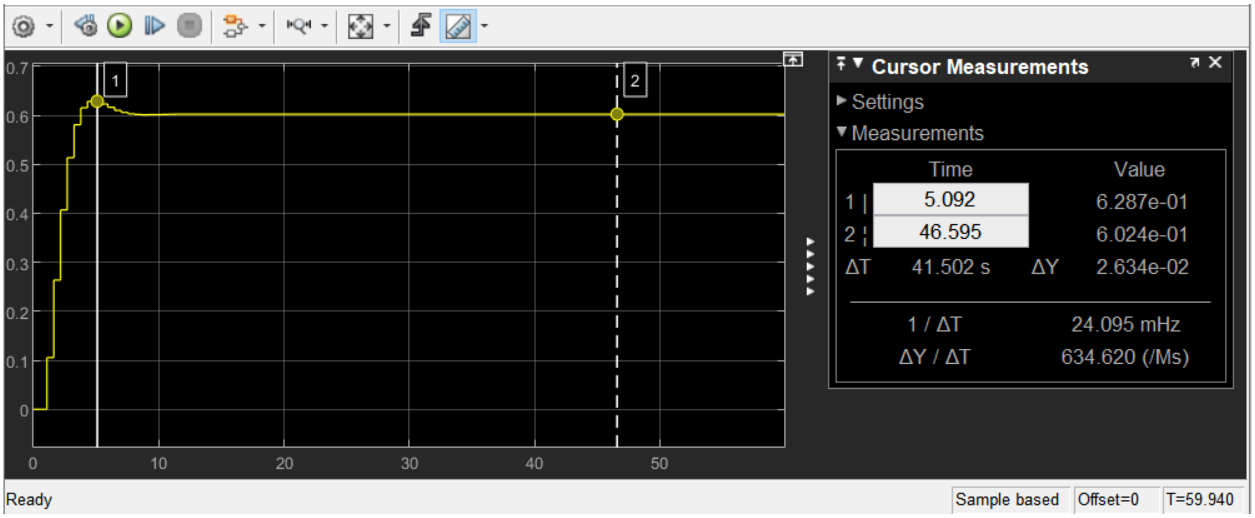


Figure 3: vref(t) = 3u(t) results in w(t) = 0.6024

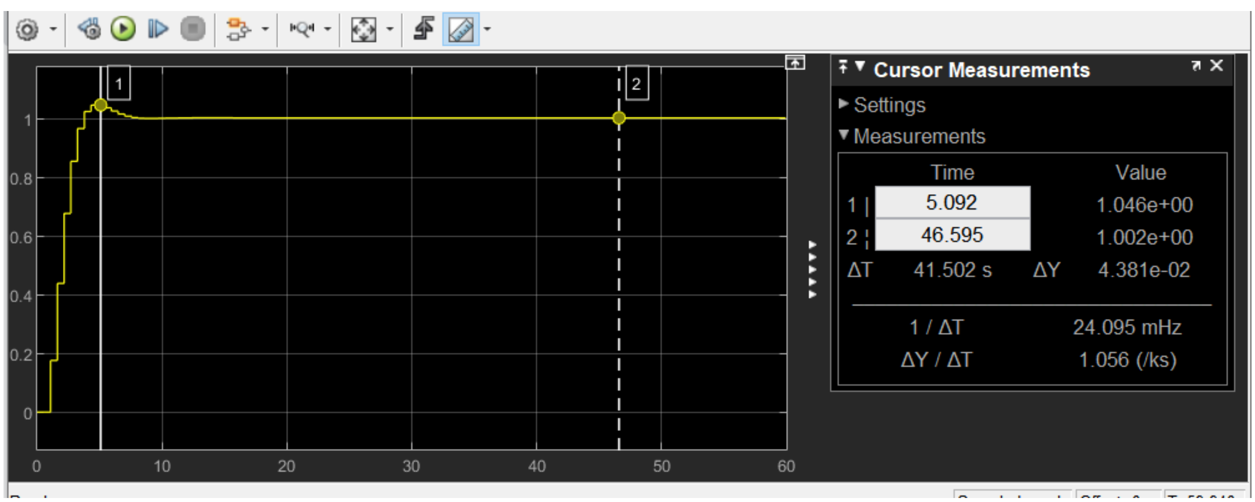
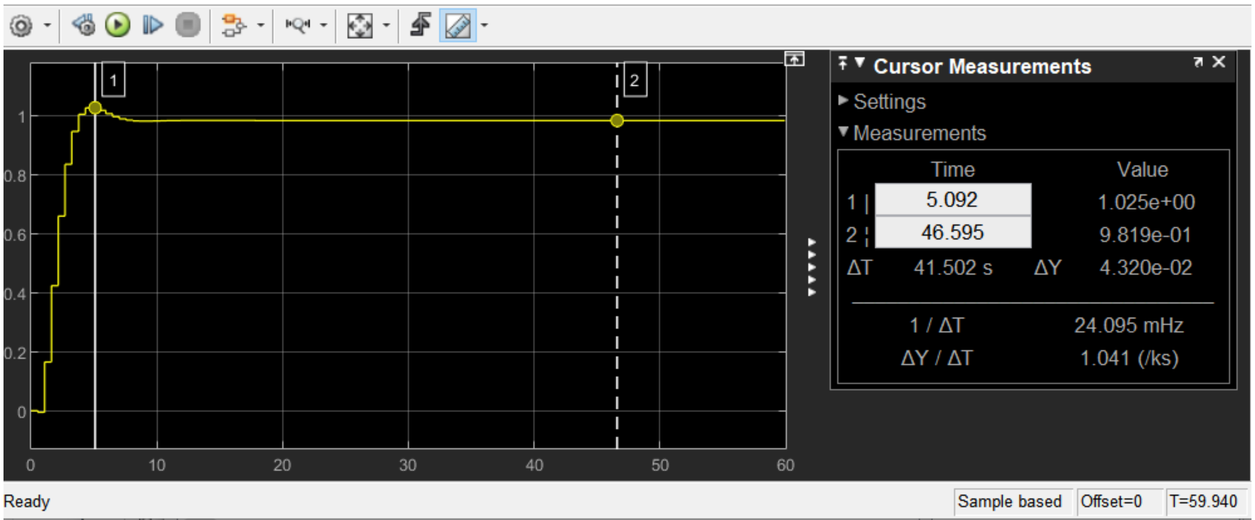


Figure 4: ***vref(t) = 4.99u(t)*** results in ***w(t) = 1.002***

Part 3:

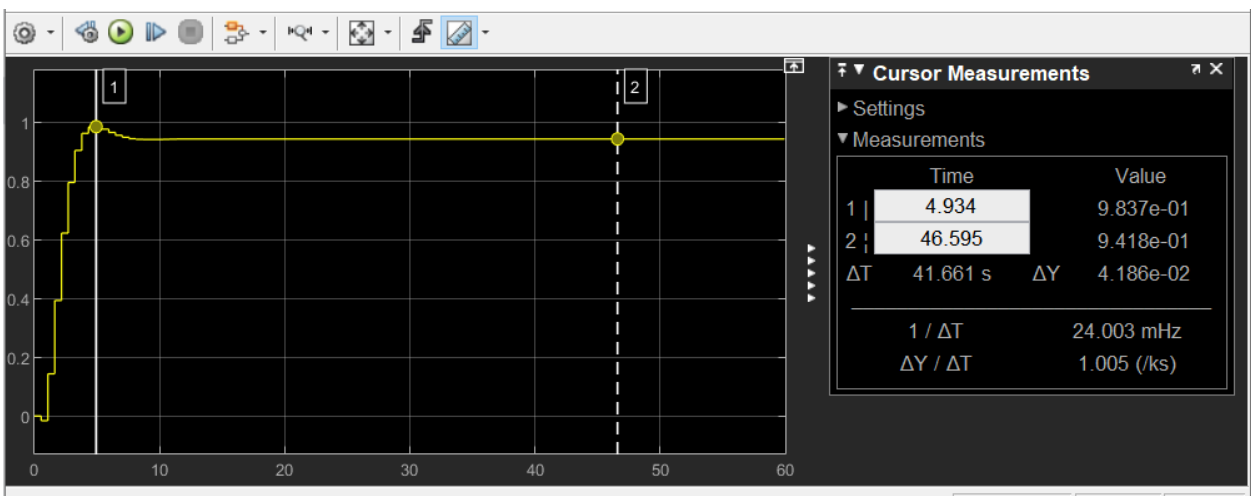
Now for ***vref(t) = 4.99u(t)*** and ***KT = 4.98*** we introduce step changes of disturbance load TL.

Case 1: TL = 1.u(t)



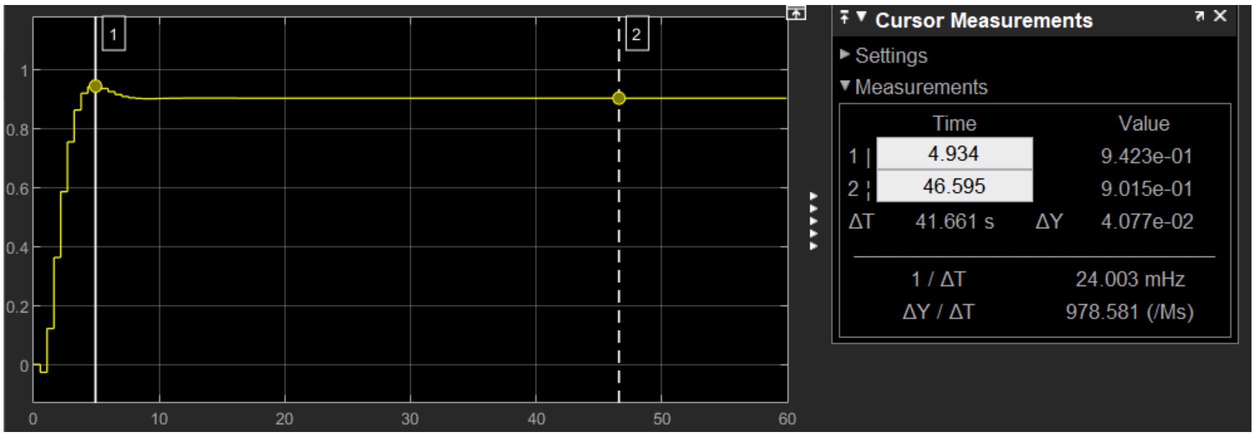
In this case the steady state value is w(t) = 0.981 i.e. steady state error = 0.019.

Case 2: TL = 3.u(t)



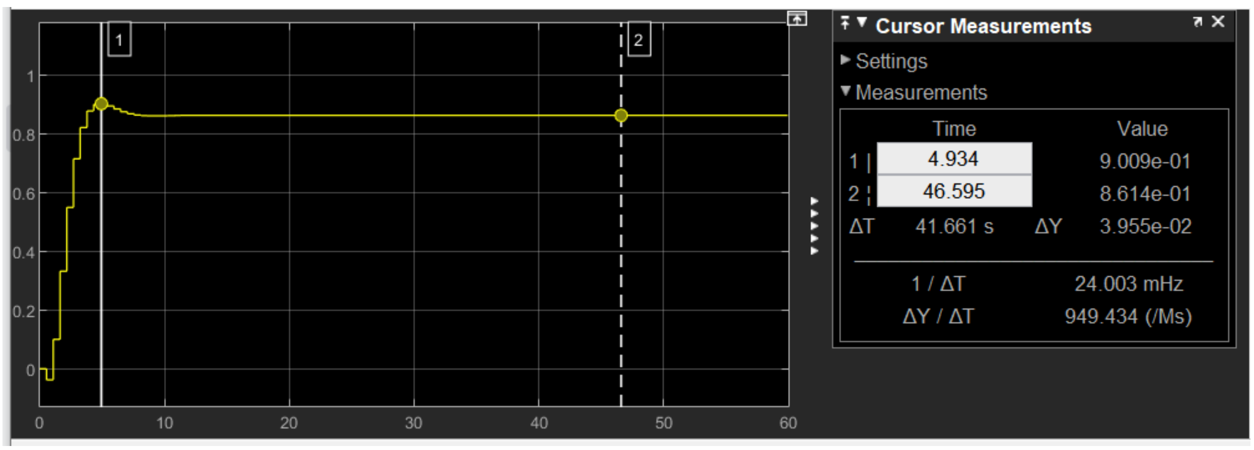
In this case the steady state value is w(t) = 0.941 i.e. steady state error = 0.0582.

Case 3: TL = 5.u(t)



In this case the steady state value is w(t) = 0.902 i.e. steady state error = 0.099.

Case 4: TL = 7.u(t)



In this case the steady state value is w(t) = 0.861 i.e. steady state error = 0.139

Table for with change in load TL for K=10 and KT =4.98

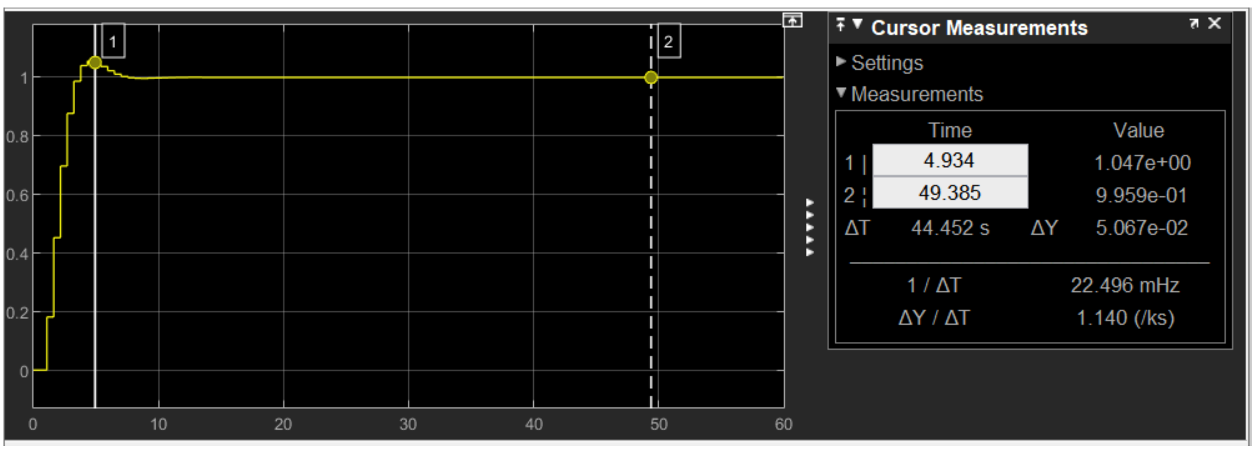
TL	w(t)	S.S. error
TL = 1.u(t)	0.981	0.019
TL = 3.u(t)	0.941	0.059
TL = 5.u(t)	0.901	0.099
TL = 7.u(t)	0.861	0.139

Part 4 :

The design constraints for this part is that damping ratio = 0.707, w(t) = 1 with steady state speed changes are confined to the range ±0.001 (taking TL =0) for different values of K and KT.

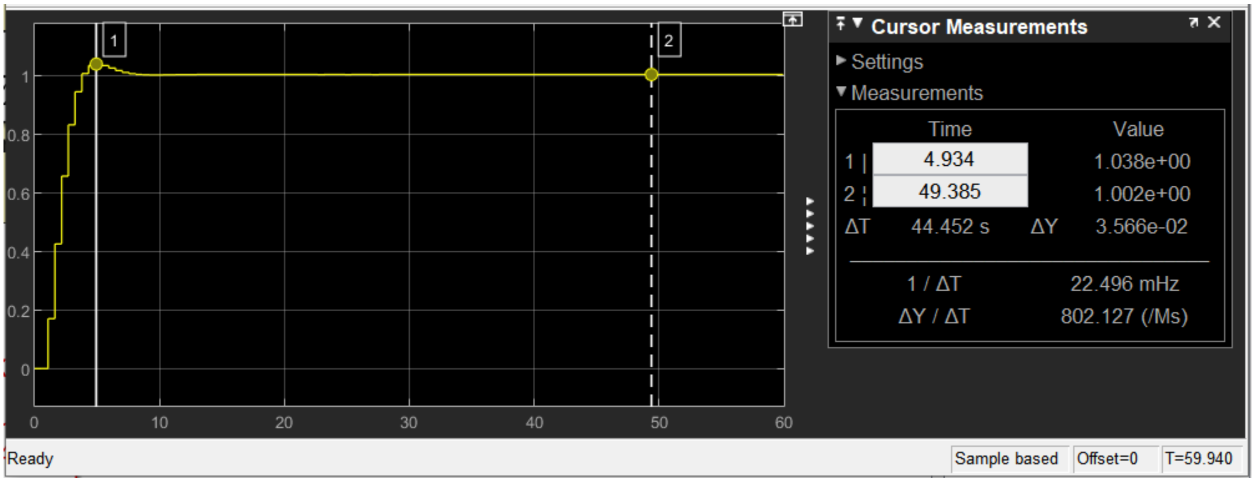
K = 10 KT = 4.98

To get a steady state error less than 0.001 we get value of KT =4.98 when K=10.



K = 10.3 KT = 5

Now we try to take K =10.3. We know that to keep zeta =0.707 we require a peak overshoot of 4.25% but in the above plot we get overshoot greater than 5%. In order to decrease the overshoot we increase KT to 5% but this leads to steady state error greater than 0.001 (0.041 in above plot).



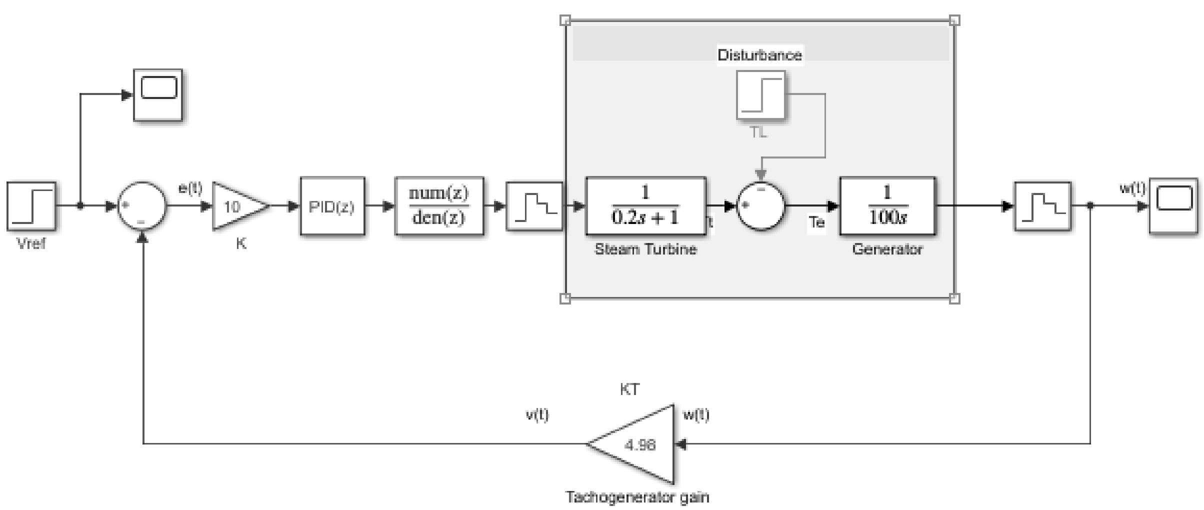
K= 9.7 KT =4.97

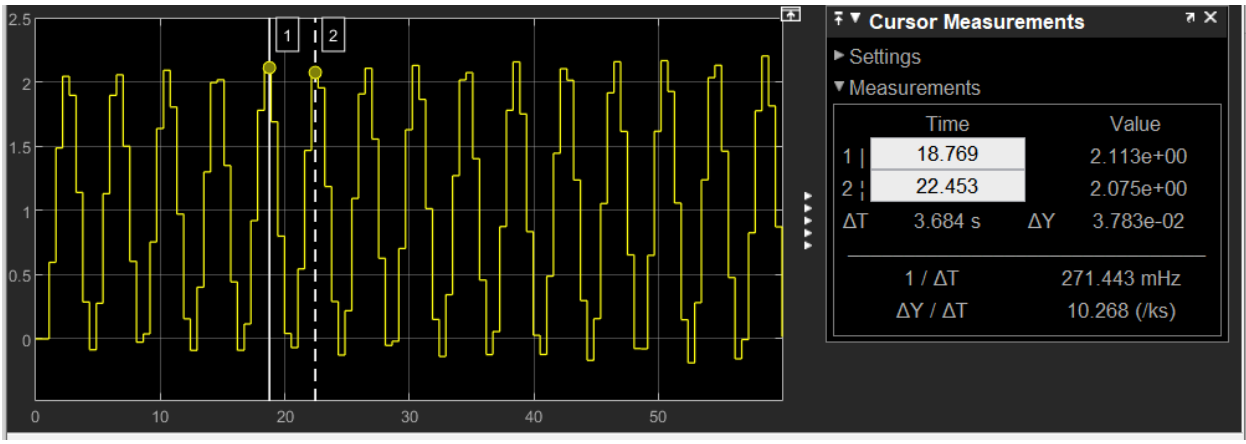
We also try taking K=9.7. But this gives us an overshoot less than 3.8%. In order to increase the overshoot to 4.36% we decrease the KT to 4.97 but observe that again the steady state error increases more than 0.001(0.002 in above plot). From the above two points we observe that it is very difficult to obtain the design constraints by some other values K and KT (i.e. other than K = 10 KT = 16.98). This leads us to use a PID controller to obtain the required design constraints.

Part 5:

Part 5: Design a cascaded series controller for the forward path that should possibly achieve the requirements specified in part 4.

We cascade a PID controller to the system (K and KT are considered part of the previous system so we consider PID gains different from them) as follows





Now using a continuous cycling method (CL ZN method), to calculate gains we get kcr =3.4 and Pcr = 4.580 sec.

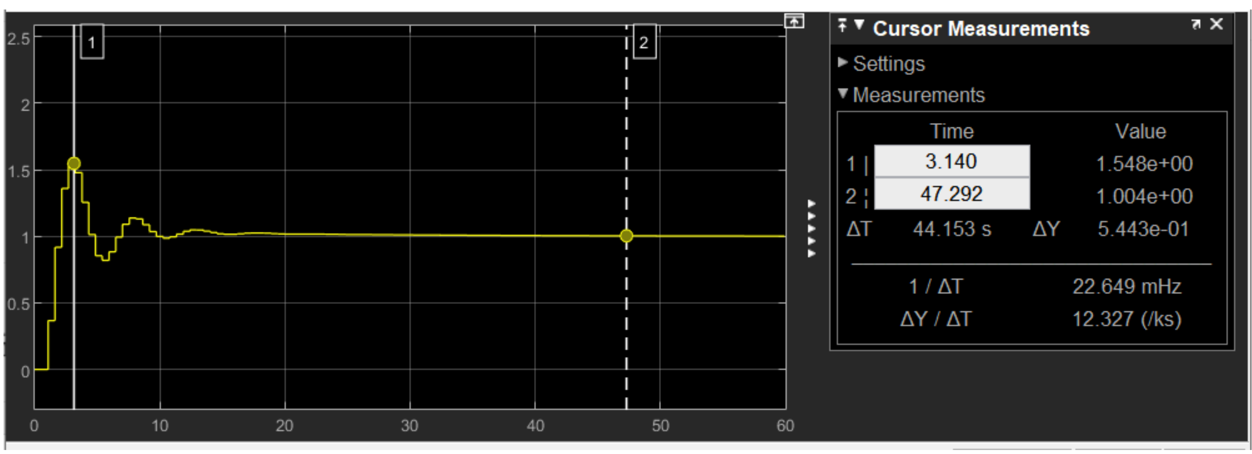
Ti = Pcr /2 = 0.1920

Td = kcr / 8 = 0.5725

Kp = 0.6kcr = 2.04

Ki = Kp/Ti = 0.11087

Kd = Kp/Td = 0.9384



Dynamic response for above Kp,Ki and Kd keeping K=10 and KT =4.98.

Trying to get a steady state error for less than 0.001, keeping K = 10 for different values of KT, we get a very small range of valid KT ∈ (4.94,5.06).

Observations and Discussions

1. For K = 10, KT comes out to be ***4.98*** resulting in a damping ratio of 0.7070.

2. For KT as designed in the first step,the value of vref(t) = ***4.99u(t)*** results in ω(t) = 1.0.

3. With tachogenerator gain and reference control voltage set as above, we introduce step changes of disturbance load TL and observe the steady state errors ranging from 1.9% for TL = u(t) to 13.9 % for TL = 10.u(t).

4. We get value of KT =4.98 when K=10 to ensure that steady state speed changes are confined to the range ±0.001 over and above the specification in #2.
5. Using a PID controller with Kp= 2.04, Ki = 0.11087 and Kd = 0.9384 we get a very small range of valid KT ∈ (4.94,5.06) for the given constraints.