Control Engineering
Experiment - 9

Controller design for disturbance rejection on Simulink

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Objective

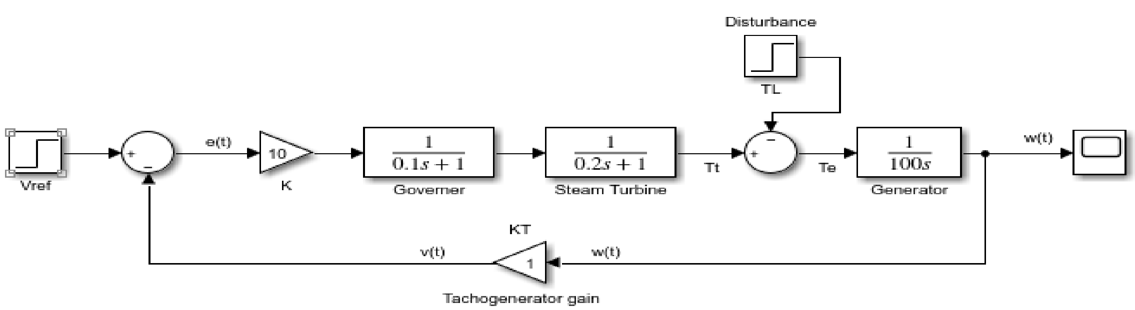
Design of analog control parameters for a turbine speed regulation system.

Our System

On the electrical side, time constants of a generator are typically small (mainly decided by inductance and resistance of the generator windings) in comparison to those of the turbine unit. So if electrical side dynamics are taken to be largely redundant, then

- The generator can be approximately represented by a transfer function ω(s)/Te(s) = 1/Js, where ω is the shaft speed, Te is the net electrical driving torque on the shaft, and J is the moment of inertia. If all variables are expressed as fraction of rated quantities (dimensionless), then typically J = 100.
- Te(s) = TT(s) − TL(s), where TT is the turbine output torque and TL is the arbitrary load torque (disturbance !) on the shaft − both as fractions of rated turbine torque.
- For the same normalisation as above, the turbine can be represented as a first order lag transfer function TT(s)/x(s) = 1/(1 + 0.2s), where x(t) is the fractional steam valve opening in time domain.
- The valve opening is the output of the governor, which has a transfer function x(s)/e(s) = K/(1 + 0.1s), where e(t) is a control voltage error that operates the governor. The gain K is one of the parameters to be designed (set by the operator).
- A tachogenerator converts the shaft speed signal ω(t) to feedback voltage v(t) in real time as v(t)/ω(t) = KT, which is again to be designed (set by the operator).
- Needless to say, e(t) = vref(t) − v(t), where vref(t) is the reference value of control voltage to the governor.

Our system in simulink :



Plots and Analysis

We can calculate zeta(damping factor) for a second order system as follows:
Where PO stands for peak overshoot value, which we can determine from the plots.

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

Where PO stands for peak overshoot value, which we can determine from the plots.

$$PO = \left[e^{\left(-\pi\zeta / \sqrt{1-\zeta^2}\right)} \right] \cdot 100\%$$

Part 1 : For K =10, we need to compute KT for which zeta = 0.7070

For this zeta we can calculate the the required Peak overshoot as follows
zeta= 0.7070
PO = 4.32 %

Now we increase the value of KT to get the desired peak overshoot for step input.

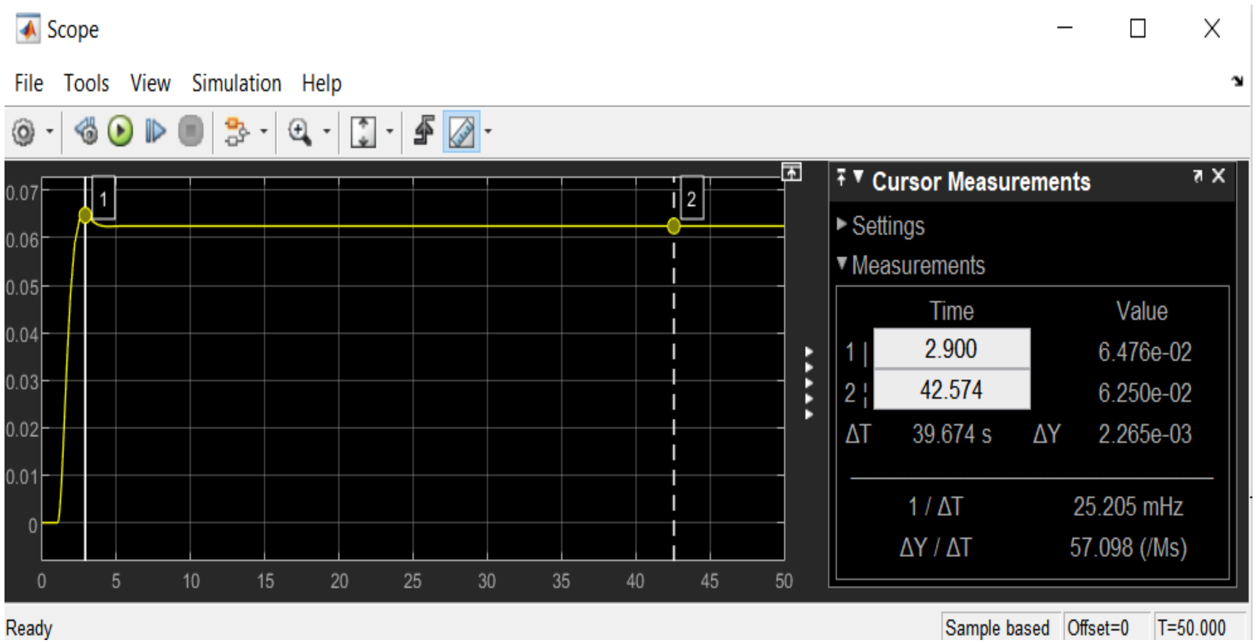


Figure 1 : KT =16 PO = (2.265e-3 / 6.25e-2)x100 = 3.62%

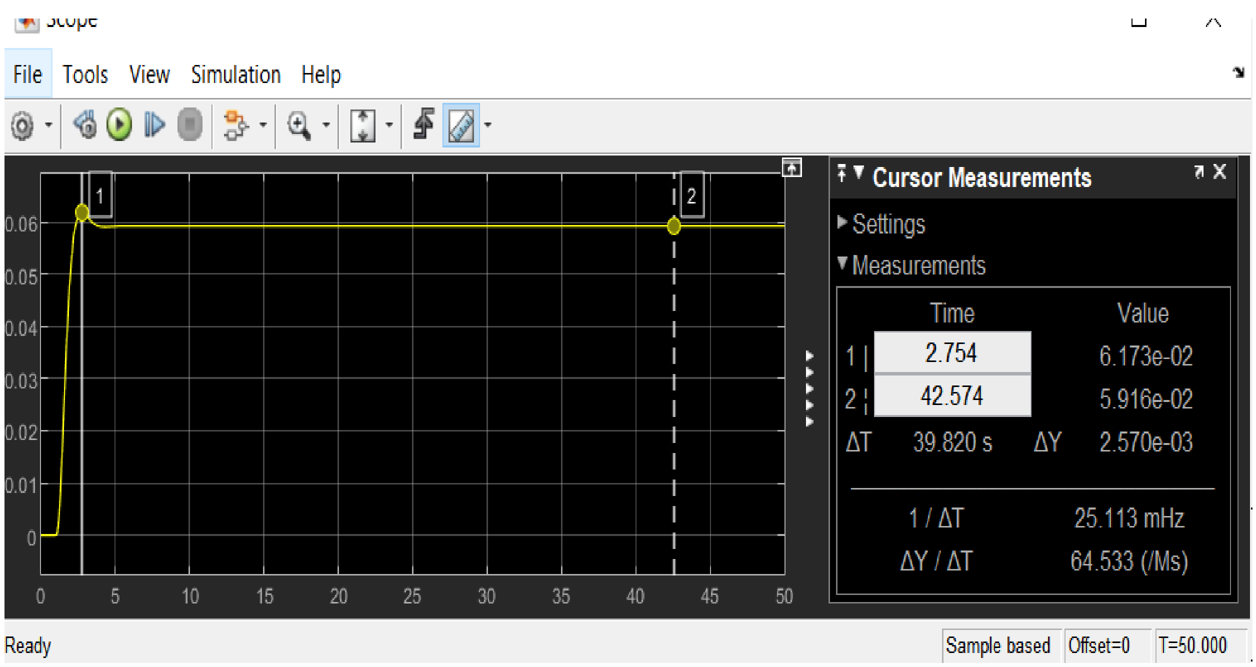


Figure 2: ***KT = 16.9*** PO = (2.57e-3 / 5.916e-2)x100 = 4.34% ***(close to required PO)***

Part 2:

Now for KT =6.9 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:

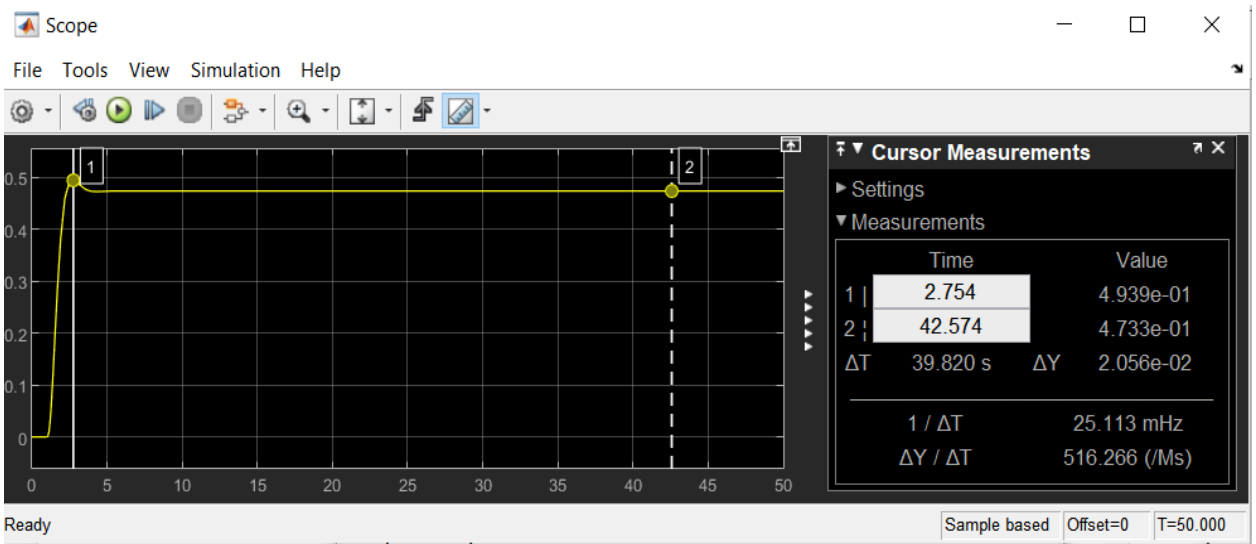


Figure 3: vref(t) = 8u(t) results in w(t) = 0.473

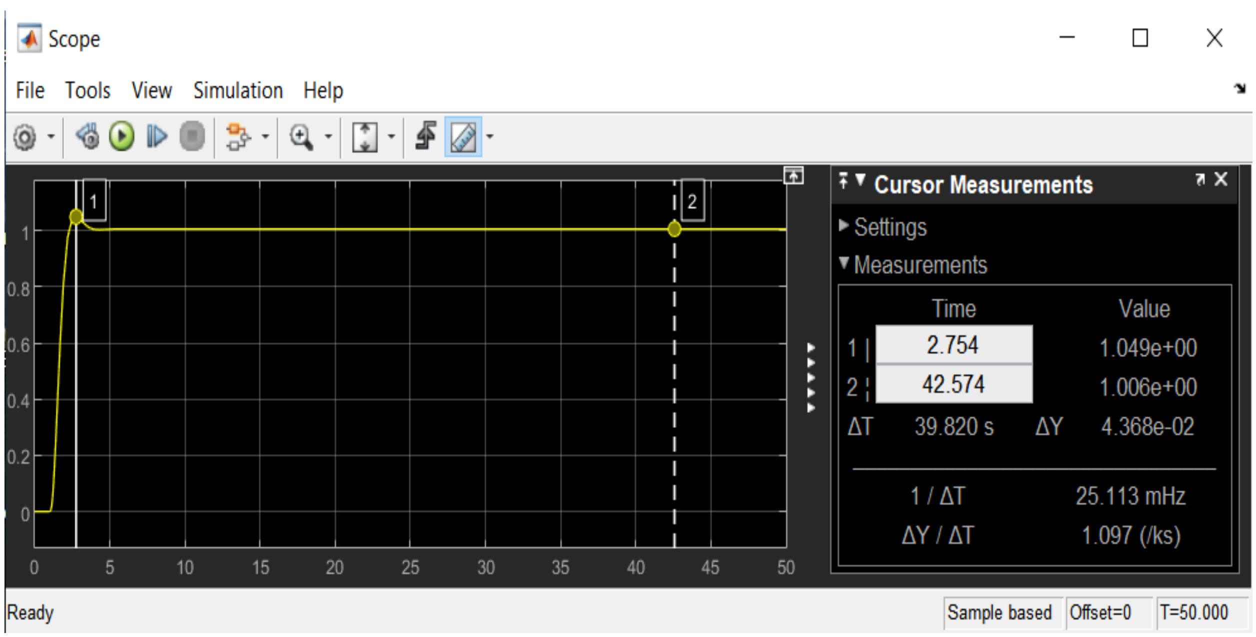
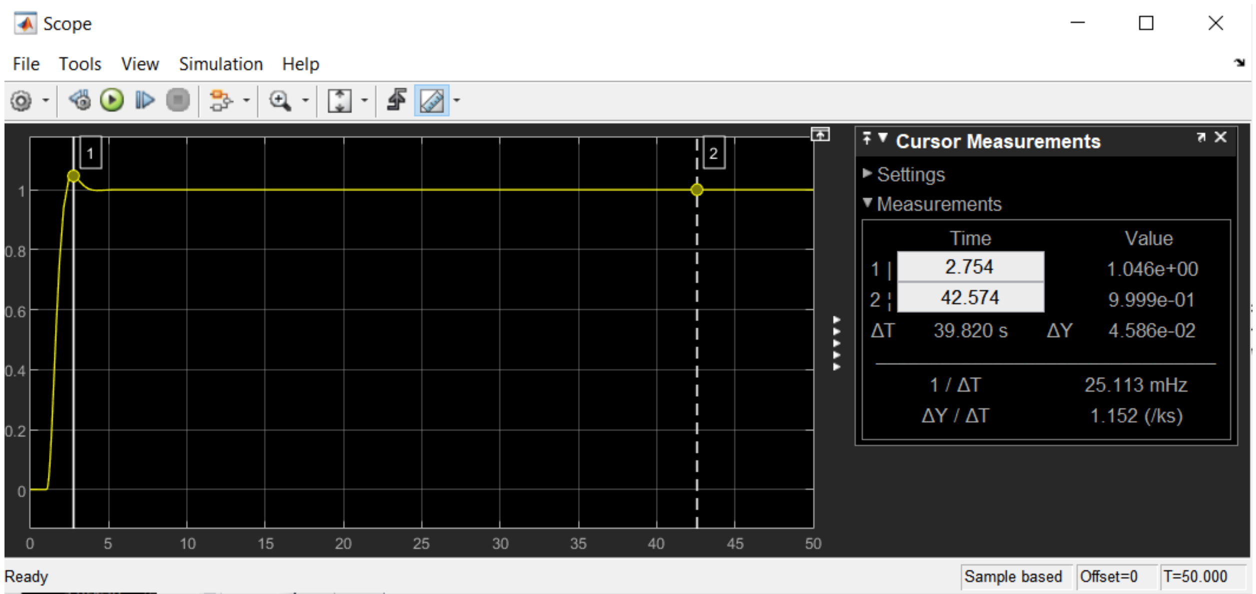


Figure 3: ***vref(t) = 17u(t)*** results in ***w(t) = 1.006***

Part 3:

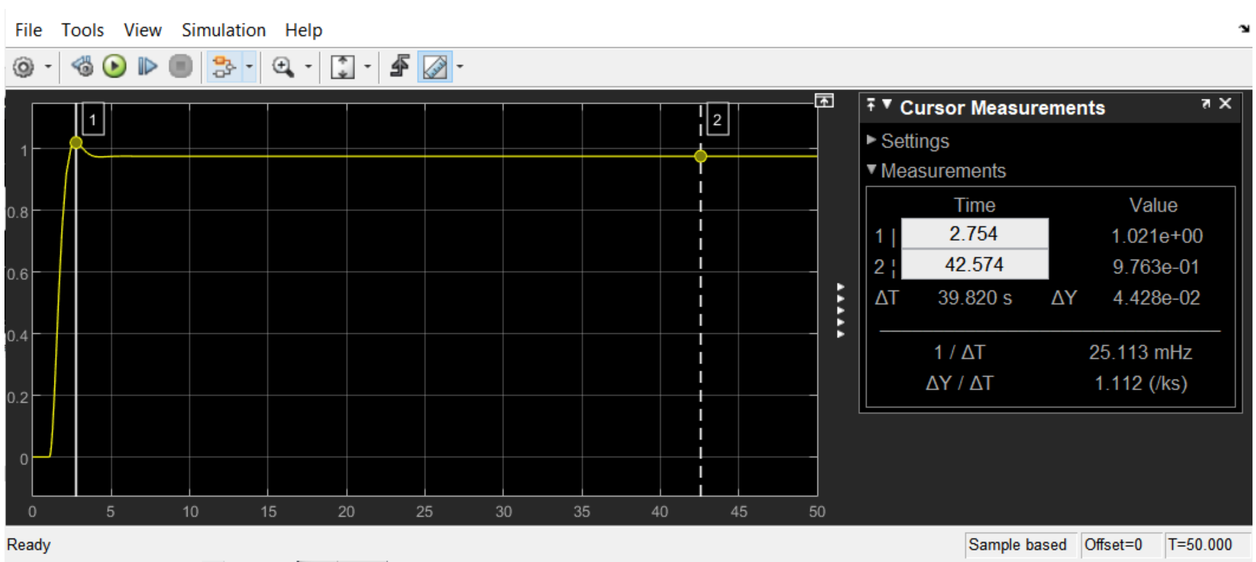
Now for ***vref(t) = 17u(t)*** and ***KT = 16.9*** we introduce step changes of disturbance load TL.

Case 1: TL = 1.u(t)



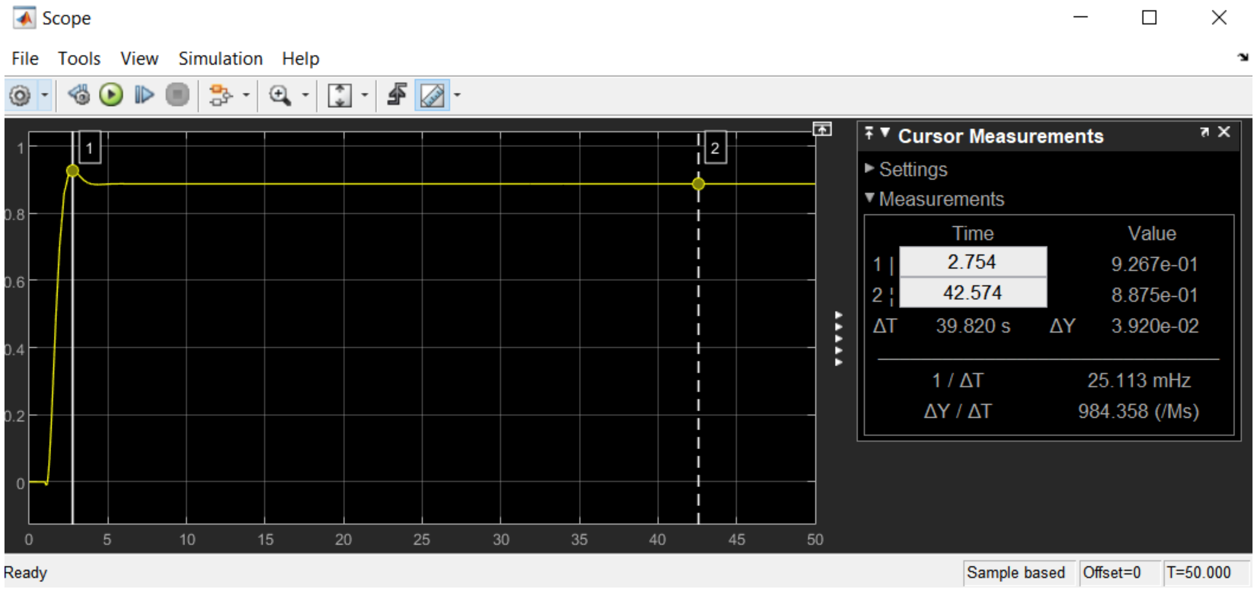
In this case we observe that the steady state value is quite close to 1 i.e.e the steady state error is negligible.

Case 2: TL = 5.u(t)



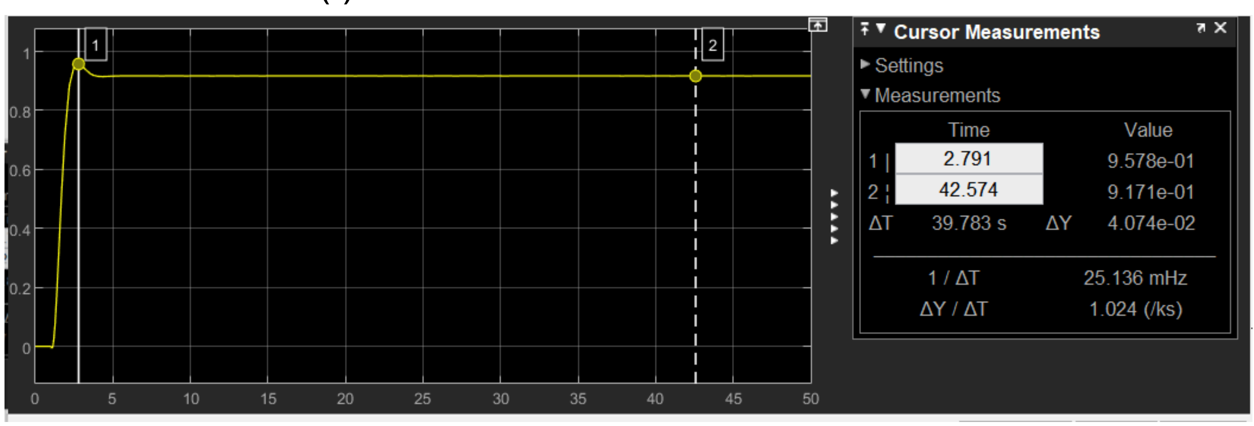
In this case the steady state value is w(t) = 0.976 i.e. steady state error = 0.024.

Case 3: TL = 15.u(t)



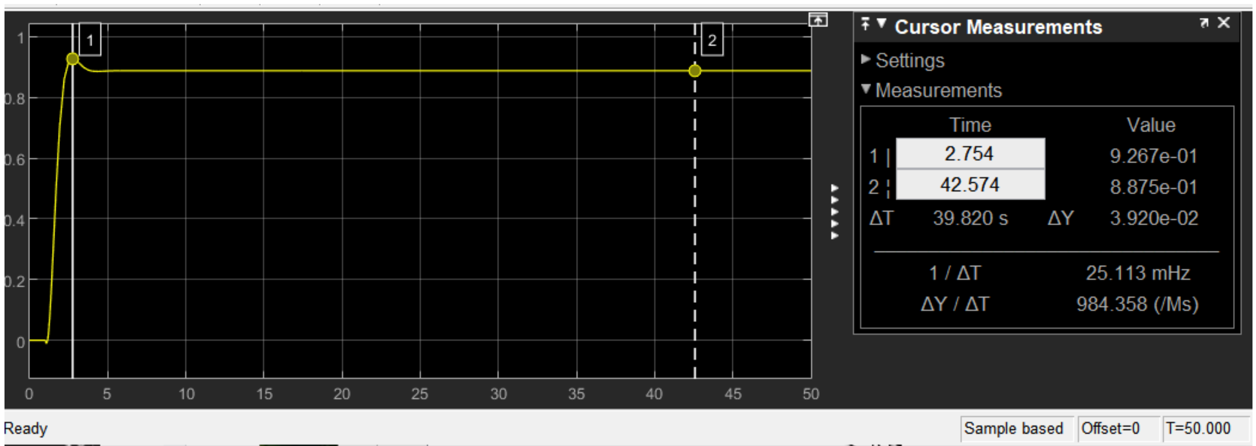
In this case the steady state value is w(t) = 0.887 i.e. steady state error = 0.113

Case 4: TL = 15.u(t)



In this case the steady state value is w(t) = 0.917 i.e. steady state error = 0.083

Case 5: TL = 20.u(t)



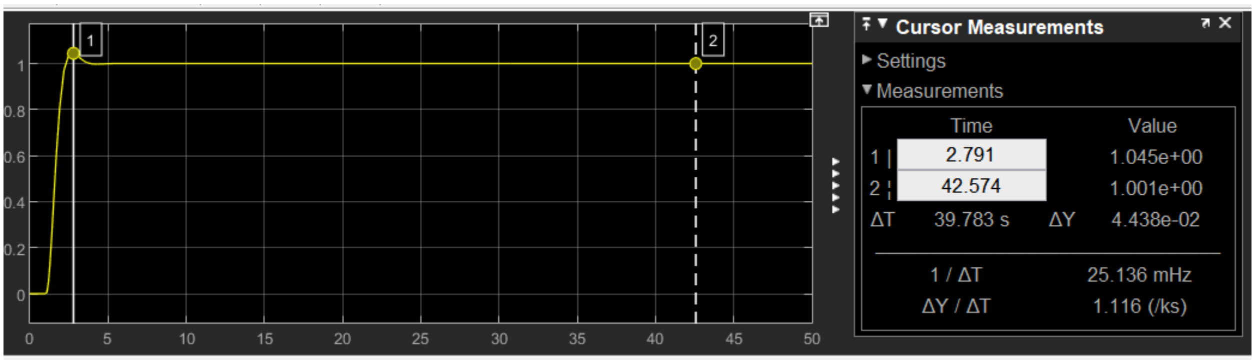
In this case the steady state value is w(t) = 0.887 i.e. steady state error = 0.113.

Table for with change in load TL for K=10 and KT =16.9

TL	w(t)	S.S. error
TL = 1.u(t)	0.9999	0.00001
TL = 5.u(t)	0.976	0.024
TL = 10.u(t)	0.940	0.060
TL = 15.u(t)	0.917	0.083
TL = 20.u(t)	0.887	0.113

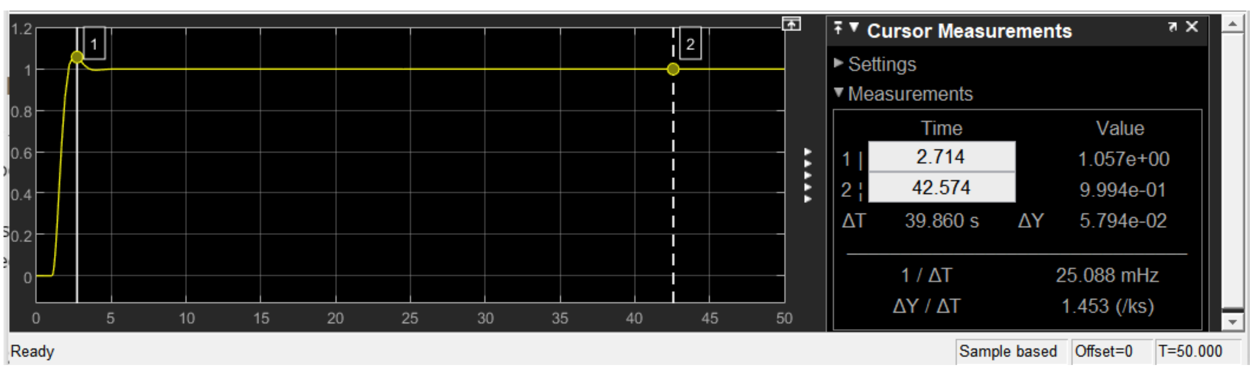
Part 4 :

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.



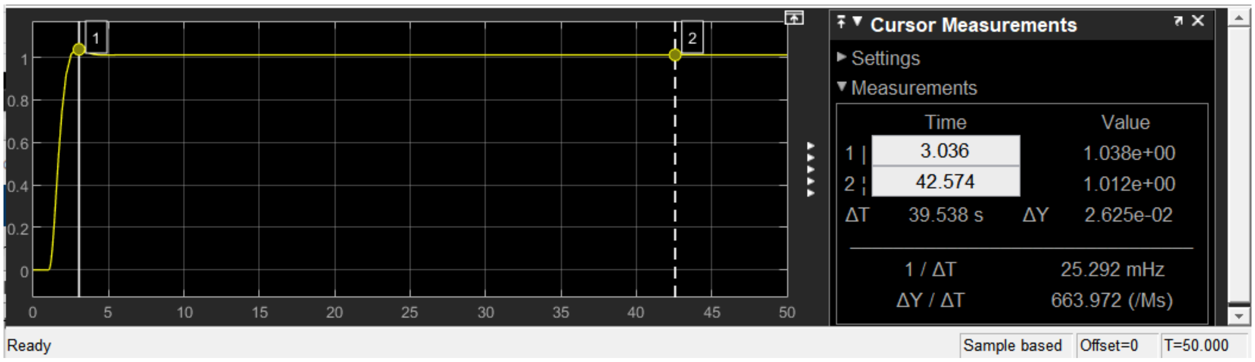
K = 10 KT = 16.98

To get a steady state error less than 0.001 we get value of KT =16.68 when K=10.



K= 11 KT =17.01

Now we try to take K =11. We know that to keep zeta =0.707 we require a peak overshoot of 4.36% but in the above plot we get overshoot greater than 5.7%. In order to decrease the overshoot we increase KT to 17.1 but this leads to steady state error greater than 0.001 (0.006 in above plot).



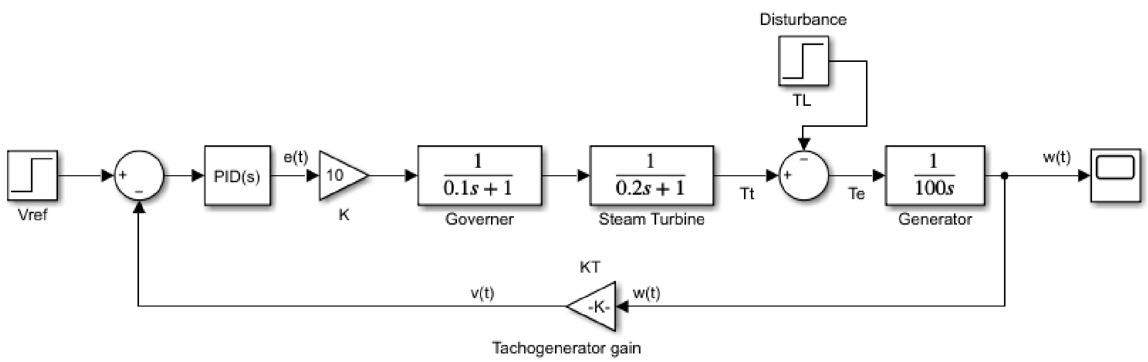
K= 9 KT =16.8

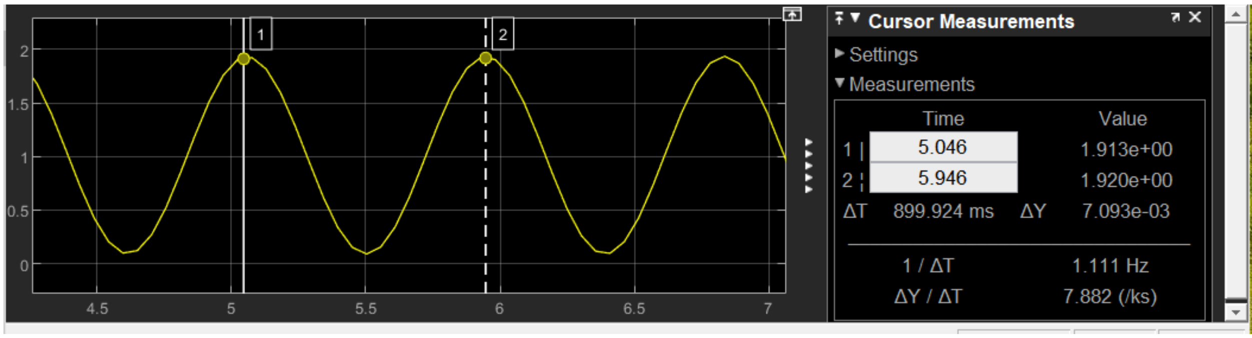
We also try taking K=9. But this gives us an overshoot less than 3.8%. In order to increase the overshoot to 4.36% we decrease the KT to 16.8 but observe that again the steady state error increases more than 0.001(0.012 in above plot).

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).

Part 5:

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:



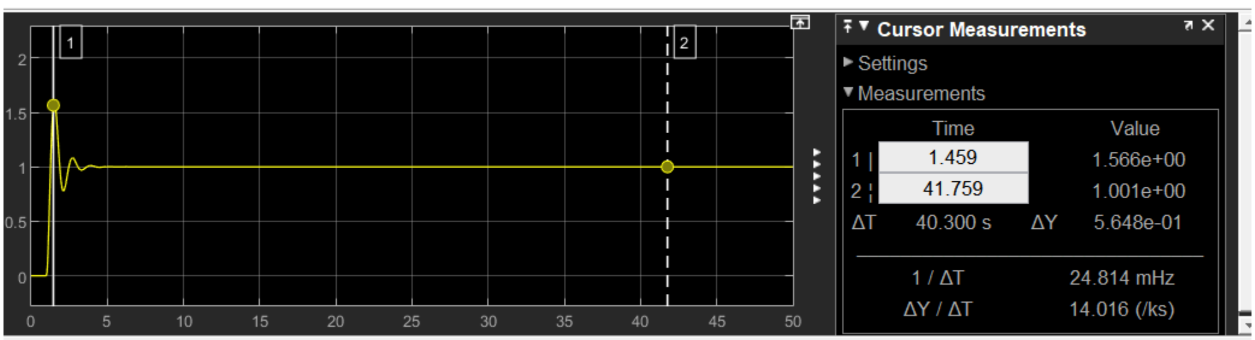


Using continuous cycling method (CL ZN method), to calculate gains we get kcr =8.9 and Pcr = 0.889 sec

Kp = 5.3400

Ki = 11.8799

Kd = 0.6001



Dynamic response for above Kp,Ki and Kd keeping K=10 and KT =16.98. 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 ∈ (16.95,17.04).

We also observe that the peak overshoot has risen to 56%, and the system is no more a second order system so it becomes difficult to comment on zeta.

Conclusions:

1. For K = 10, KT comes out to be ***16.9*** resulting in a damping ratio of 0.7070.

2. For KT as designed in the first step,the value of vref(t) = ***17u(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.
4. We get value of KT =16.68 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. For the given constraints we get a very small range of valid KT $\in$ (16.95,17.04), but also observe that the peak overshoot has risen to 56%, and the system is no more a second order system so it becomes difficult to comment on zeta.