**Compulsory Exercise II**

1. **Controller Tuning**
2. **Tune the controller as a PI controller using the Ziegler-Nichols’ method.**

After removing the derivative and the integral term, the Kp value is slowly increased to give constant oscillation. The constant oscillations were obtained at a Kp value of 26.7.

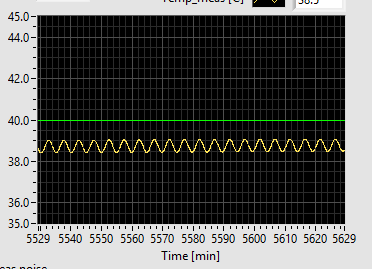


Figure 1. Proportional controller action at Kp = 26.7

From Figure 1 the value of Ku = 26.7 and PI = 5min (300s) are observed.

Therefore, according to Ziegler Nichols tuning the values of the PI controller is as follows

Kp = 0.45\*Ku = 12.1

Ti = 0.85\*PI = 250

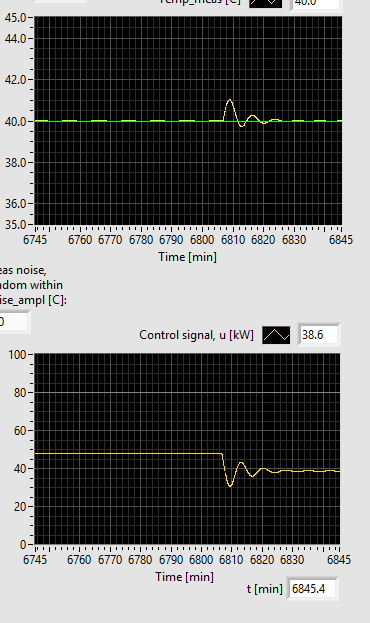
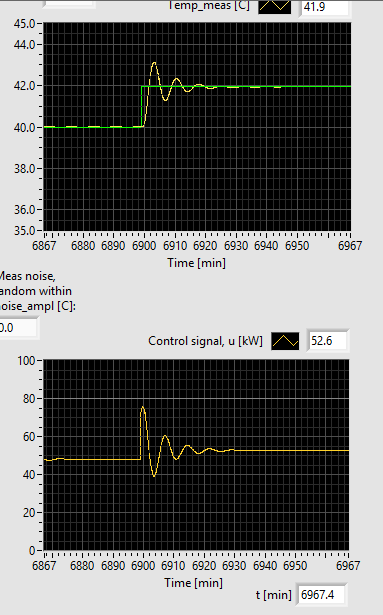
 

Figure 2. Response in step change in disturbance (left) and step change in set-point (right)

For the proportional and integral terms obtained from the Ziegler Nichols, tuning method the Figure 2 shows the result of the step response. The control shows stability for step changes in both disturbance as well as set point.

1. **As in Problem 1a, but use the Relaxed Ziegler-Nichols’ method**

The value of Kp is increased until a satisfactory value of stability is obtained. The Figure 3 represents the value for which a stable response is obtained. This value is obtained at a gain value of 10.

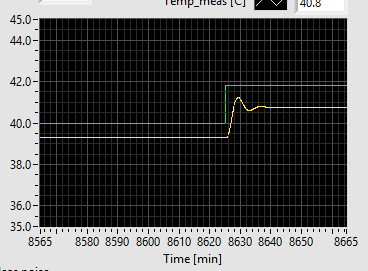


Figure 3. Proportional controller value, which give acceptable stability.

From the figure 3, the value of gain (KPGG) used was 10 and the (Tou) is observed from the figure above to be 4 minutes (240 s). Following the rules presented in the good gain method the following values of Kp and Ti are selected.

Kp = 0.8\*KPGG = 8

Ti = 1.5\* Tou = 360

The responses for the step change in disturbance and the set point and presented in the Figure 4. The stability of the PID controller can be observed in the figure presented. The controller appears to be less aggressive but it presents lesser offshoot and lower fluctuations.

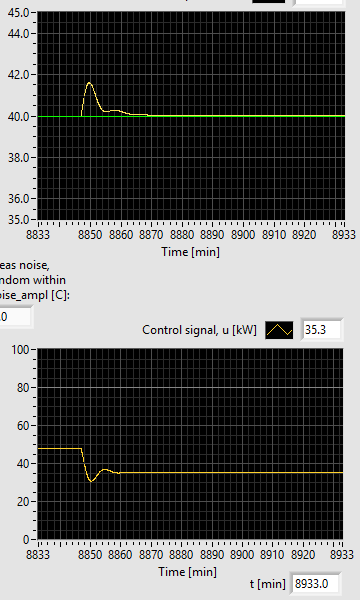
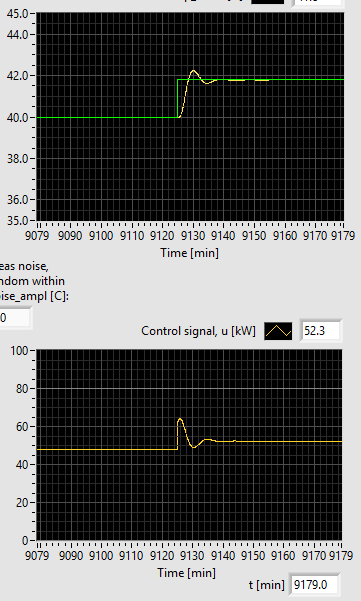
 

Figure 4. Response in step change in disturbance (left) and step change in set-point (right)

1. **As in Problem 1a, but use the relay-method.**

In this method the simulator is first set in the on/off mode where the control signal fluctuates between the minimum and maximum (0 and 80). The oscillations in the set point is presented in the Figure 5. The period of oscillations is recorded to be 5 minutes (300 s) and the amplitude of oscillation is observed as

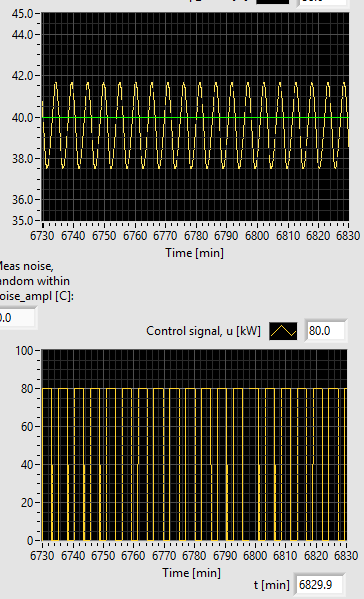


Figure 5. Response of (ON/OFF) relay

= 25.46

Using the same rule as Ziegler Nichols method for PI controller the values of tuning parameters are calculated as follows

Kp = 0.45\*Ku = 11.457

Ti = 0.85\*PI = 255

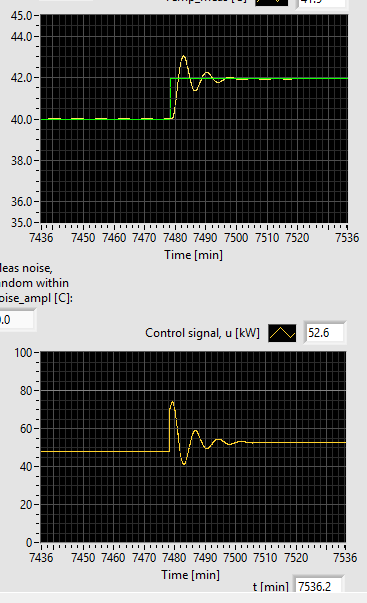
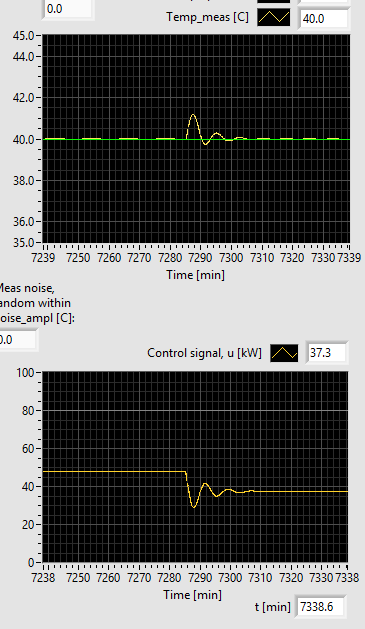
 

Figure 6. Response in step change in disturbance (left) and step change in set-point (right)

A step change is provided in the disturbance variable as well as in the set point. The Figure 6 presents the response of the changes in the measured value and the response of the controller. The plots show that the controller action is stable.

1. **As in Problem 1a, but use the Skogestad method.**

A step change is provided in the control signal and the response of the set point is recorded.

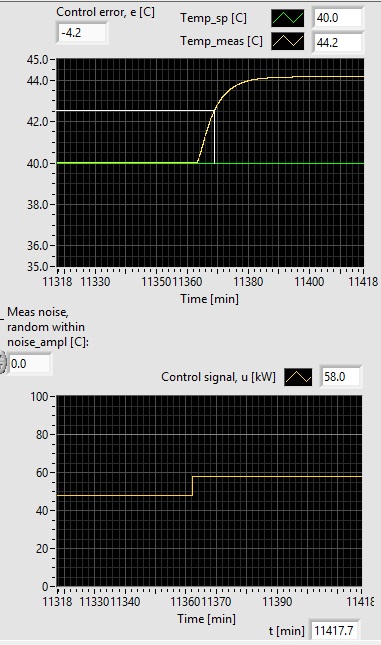


Figure 7. Response of signal for a step change in the control signal.

From the response, curve obtained in Figure 7 it can be observed that the system has a time delay (τ) of 1 minute (60s) and the process time constant (T) is 5 minutes (300s). The slope of the process is Kp is calculated as 0.42.

According to the Skogestad method, the tuning parameters are as follows.

Kp = = = 5.95

Ti = minimum (T, c (Tc+τ)) = minimum (300, 2\*(60+60)) = 240 s.

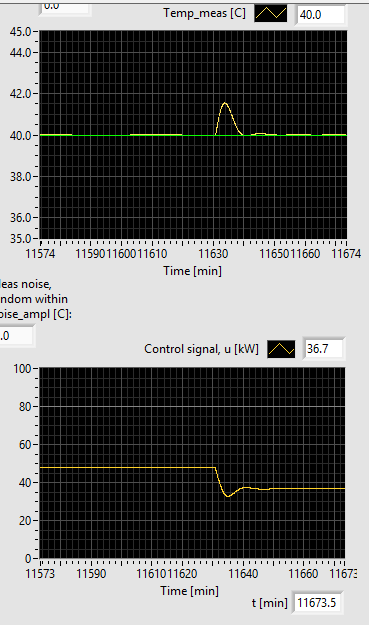
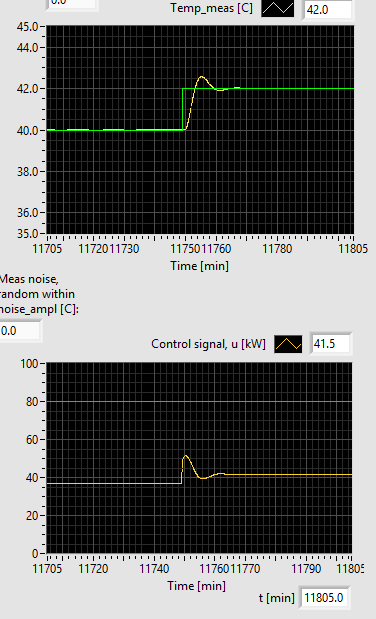
 

Figure 8. Response in step change in disturbance (left) and step change in set-point (right)

From the graphs presented in Fgure 8, it can be observed that the the stability is maintained.

The tuning constants obtained by Skogestad methods have been used in the PID controller and the stability has been checked using step changes in the disturbance as well as set point change. The Figure 8 presents the response of the controller for the step response.

1. **Find the gain margin GM and the phase margin PM of the control system for (1) Ziegler-Nichols’ tuning (cf. Problem 1a) and for (2) Skogestad tuning (1d). Are the values of GM and PM acceptable in each of the two cases?**

* Tuning parameters obtained from Ziegler Nichols method (1a)

The controller signal ‘u’ from the PI controller is multiplied by ΔK and the value is gradually increased. At a value of 1.45 oscillations are observed. The gain margin is calculated as follows

GM = ΔK = 1.45

The process time delay is increased gradually from its initial value of 30, a periodic oscillation can be observed at a value of Δτ = 23. The period of oscillation Pu = 8 minutes (480 s). Therefore, the phase margin can be calculated by the following formulae

PM17.25

* Tuning parameters obtained from Skogestad method (1d)

The same procedure is repeated with the PI controller parameters obtained from the

Skogestad method. The values of ΔK = 2.05 and the value of Δτ = 23.

The values of gain and phase margins are calculated as follows.

GM = ΔK = 2.05

PM32.5

For a stable operating condition the PM and GM range are as follows.

1.7 < GM < 4

30 < PM < 45

The values of PM are GM are within the stability limit for the tuning parameters obtained

from the Skogestad method. But for the tuning parameters obtained from Ziegler Nichols

shows poor stability.

1. **Implementation of a simulator of a control system in Simulink**
2. The simulator with the process model described in the question has been implemented in Simulink. The file is saved by the name ‘**Problem3a.slx’**. A measurement filter is implemented as a matlab function inside the simulink. The PID controller block in simulink is used in the simulink model. The process parameters, PID controller tuning parameters and the measurement filter time constant is mentioned as parameters (and not as numbers) in simulink and the simulator is run using the ‘sim’ command in matlab script saved as a file ‘Problem2.m’.

When the matlab script **Problem2.m** is run it asks for the following choice.

1. – Question 2a
2. – Question 2b
3. – Question 2c
4. – Question 2d

After the simulator is run the values of IAE y (filtered measurement) and u (control signal)

is saved as in the matlab workspace. The plot command is used to plot the date from

workspace.

The simulator is run with the default values of PID block which is a Kp =1 and Ti = 0. The following figure presents the value of y with a proportional controller.

The IAE value is obtained as 73.1954

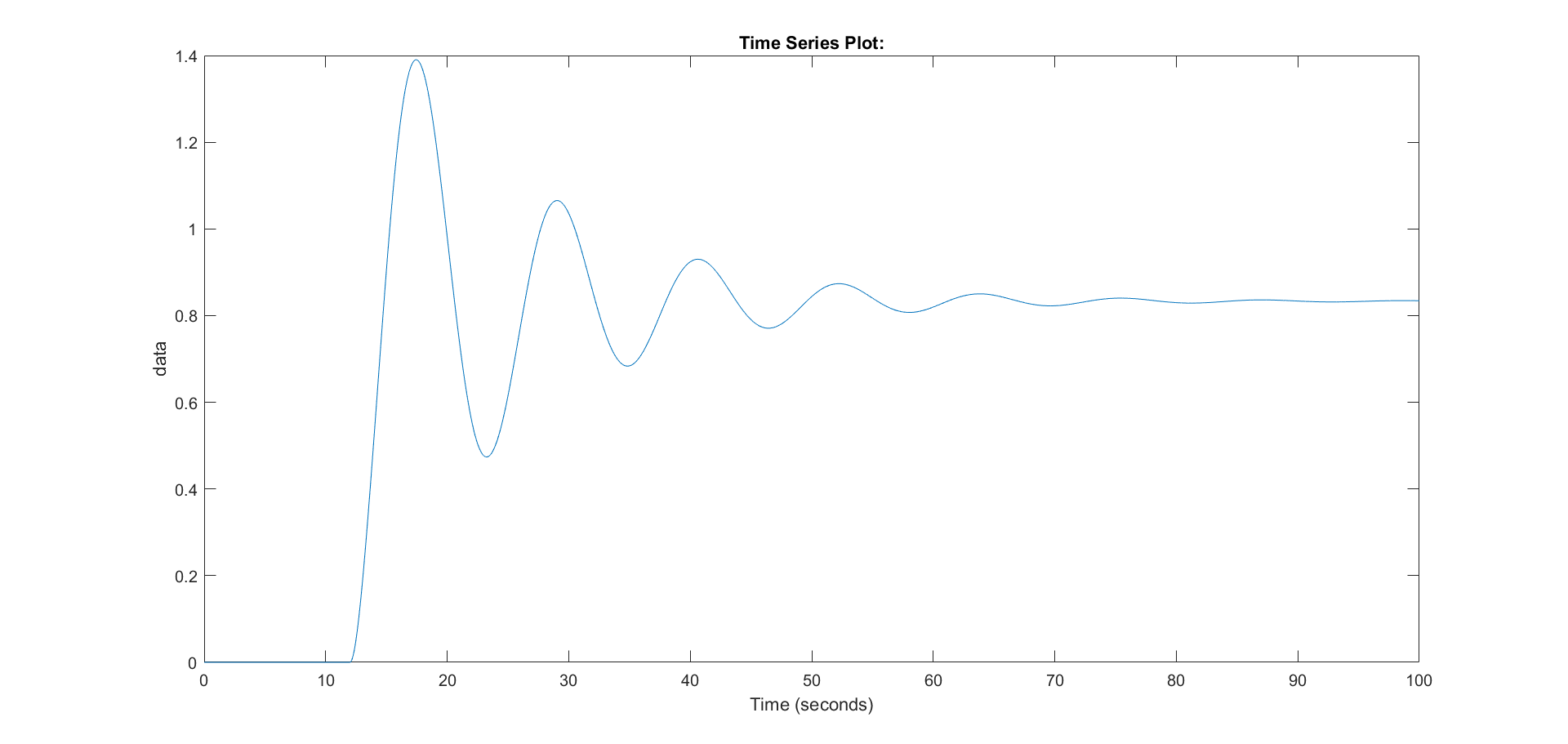


Figure 9. Setpoint tracking for P controller.

The auto-tuner option in simulink is used to obtain the following PID values.

Kp= 0.346

Ti = 0.0443

Td= 0.2567

The simulator is run again with the PID tuning parameters mentioned above and the

following plot is obtained. The IAE obtained from the simulator is also presented.

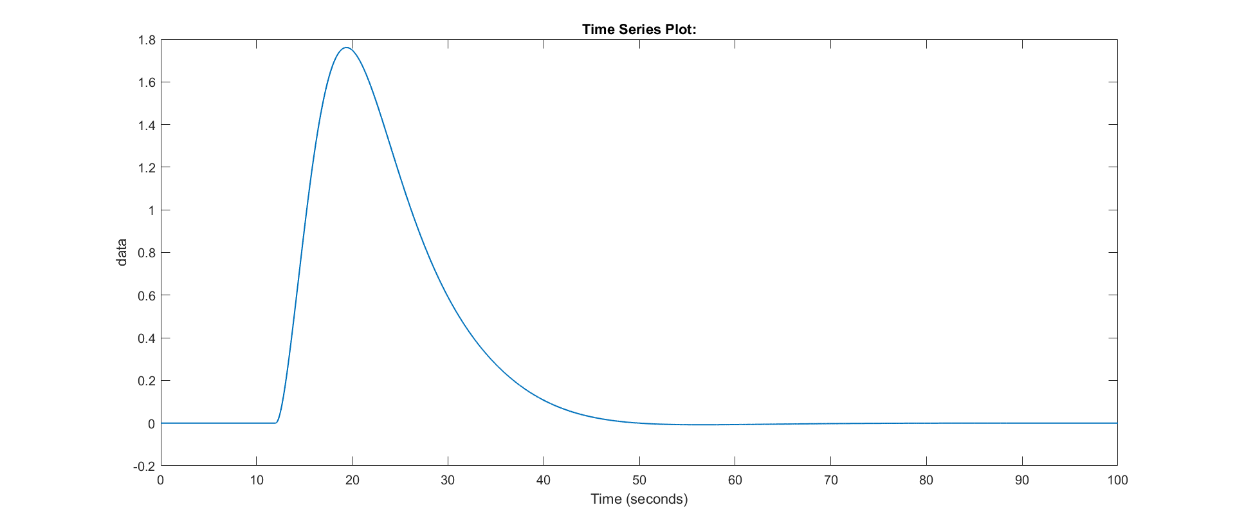


Figure 10. Setpoint tracking for PID controller using auto tuner in SIMULINK.

IAE = 23.89

1. **Ziegler Nichols tuning method PI.**

The process model and the controller been implemented in Simulink, it can be found in the simulink file by the name ‘Problem3b.slx’. This simulink model can be run by choosing option 2 in the matlab script ‘Problem2.m’.

The simulator is set to proportional mode and the value of the proportionality constant is gradually increased until we obtain steady oscillation. At a Ku value of 1.418 a steady oscillation is obtained as presented in the figure below.

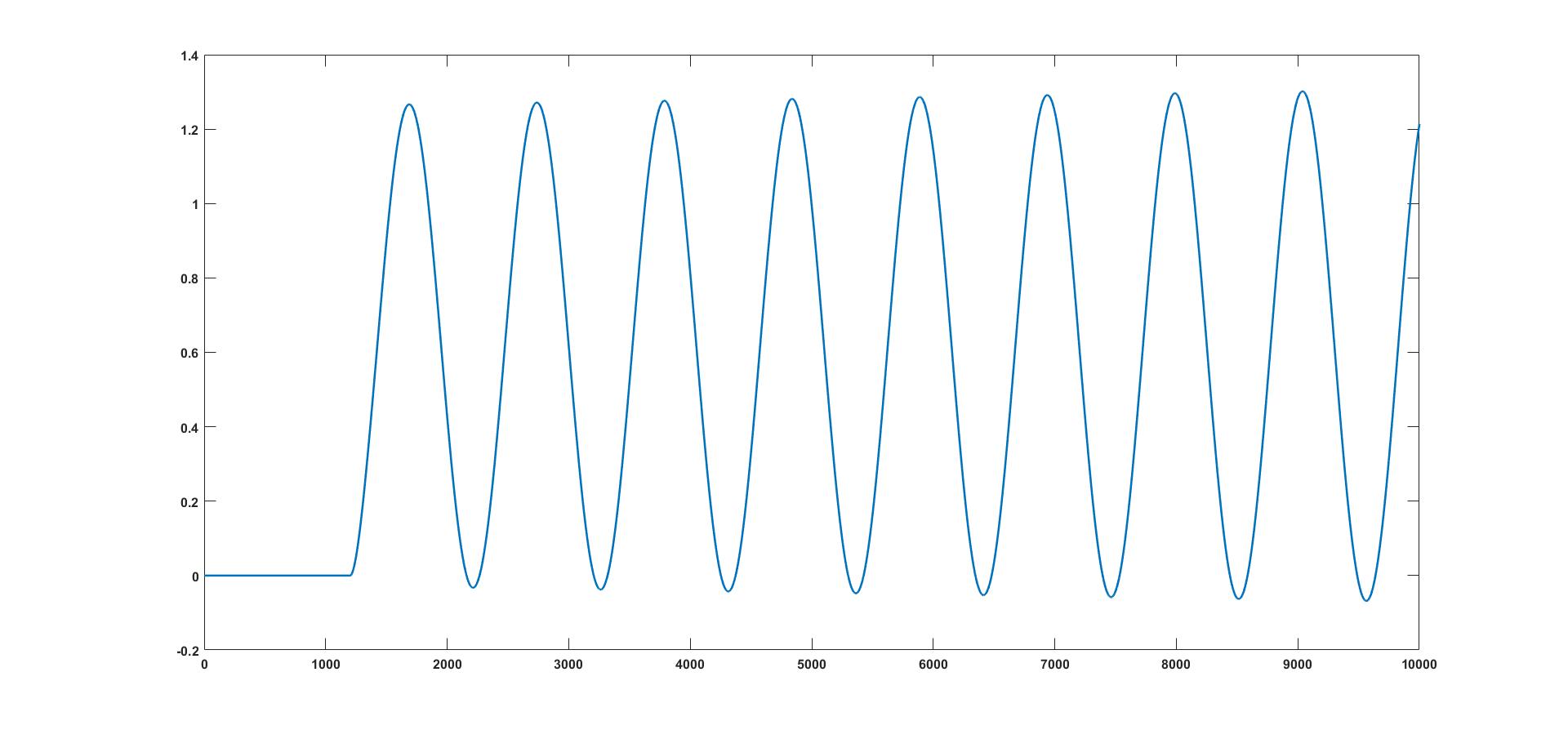


Figure 12. Oscillations at a Ku value at 1.418.

From the figure, the period of oscillations PI has been observed as 11s. Therefore, by the rule for Ziegler Nichols tuning the following value of tuning constants of PI controller has been observed.

Kp = 0.45 \* Ku = 0.645

Ti = PI /1.2 = 9.16

Td = 0

The figure below shows the controlling action of PI controller with the tuning parameters

obtained from the Ziegler Nichols tuning method presented above.

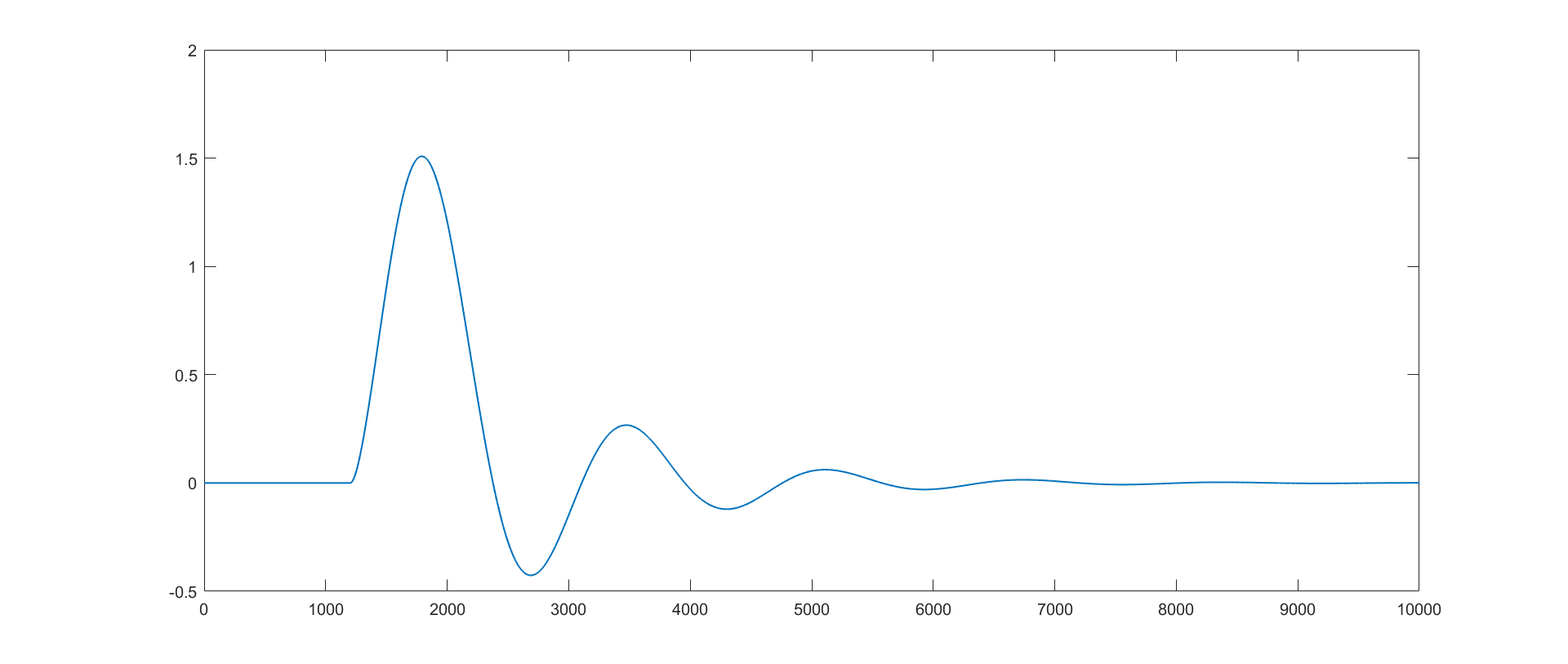


Figure 13. Setpoint tracking of PI controller with Ziegler Nichols tuning parameter.

IAE = 14.7

1. **Ziegler Nichols tuning method PID.**

Using the gain Ku and the oscillations PI obtained in the exercise above, the Ziegler Nichols tuning method for PID controller is calculated as follows.

Kp= 0.6 \* Ku = 0.851

Ti = PI /2 = 5.5

Td= PI /8 = 1.375

A values in simulink model is changed to a PID values from the Ziegler Nichols tuning parameters. The simulator is run again to obtain the IAE.

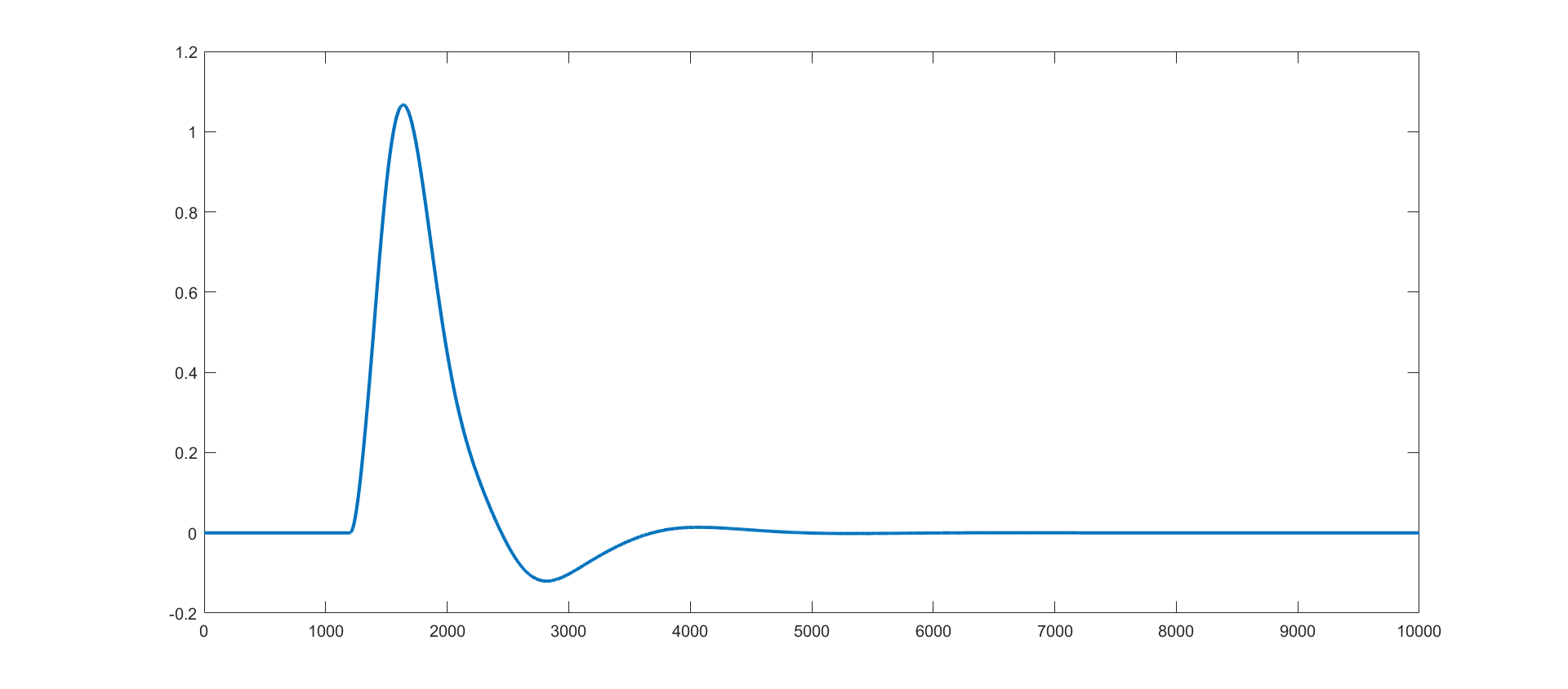


Figure 14. Setpoint tracking of PI controller with Ziegler Nichols tuning parameter.

IAE = 7.168

**d. Problem of using PID controller**

Comparing the values of IAE obtained from PI and PID controller it has been observed that the PID has lower IAE compared to PI controller.

IAE\_PI = 16.3

IAE\_PID = 8.4

However, in case of a real online sensor, measurement noise is always an issue. The measurement noise is included in the simulator by adding a random Gaussian noise (mean = 0; variance = 0.1) into the online measurement. The simulator is run with a PI and PID controller (this is done by choosing option 4 in the file Problem4.m) and the response of set point tracking and the control signal are presented below.

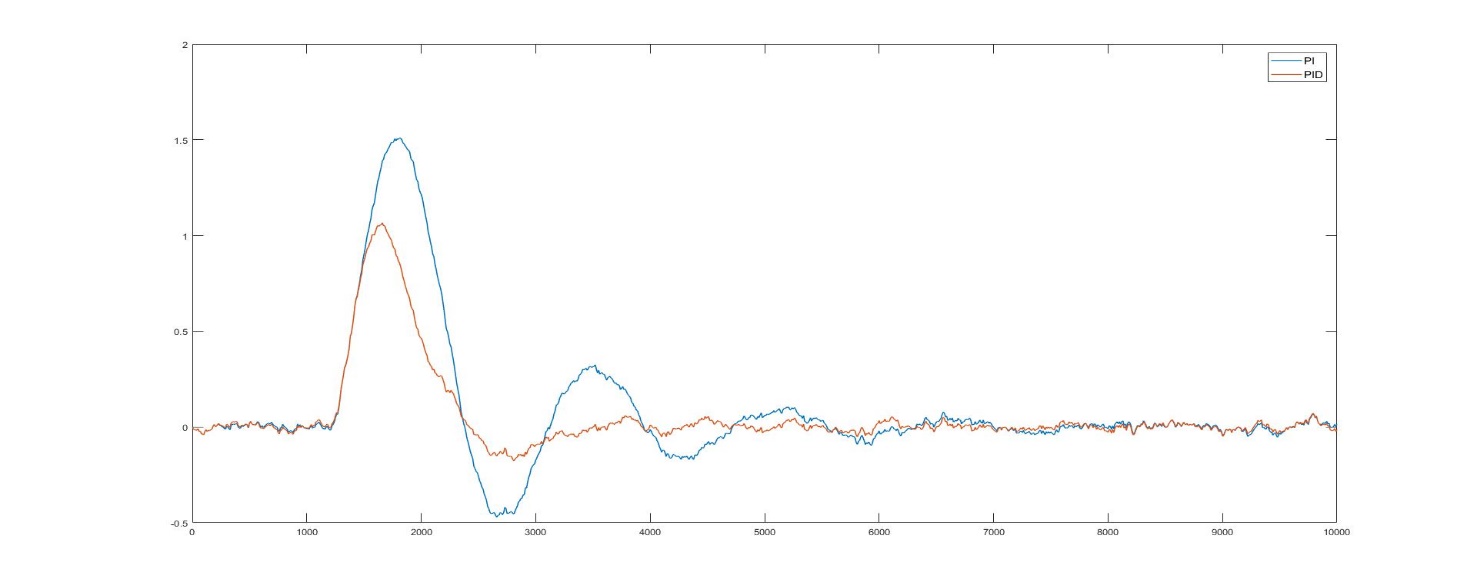


Figure 15. Setpoint tracking PI vs PID controller.

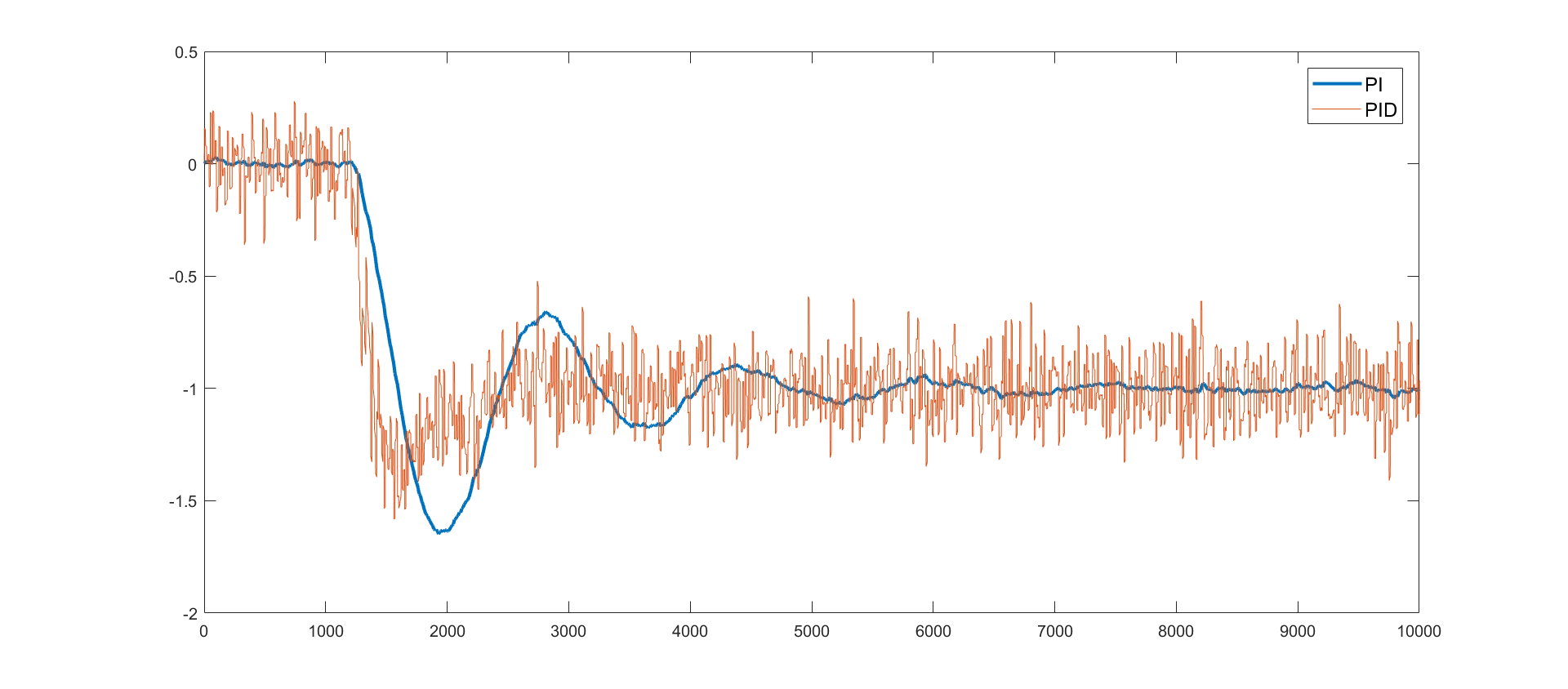


Figure 15. Control signal PI vs PID controller.

From the figure above it can be observed that the PI controller has less fluctuations, whereas the PID controller has much higher fluctuation in the control signal. Such high fluctuations in the control signal could easily damage the pumps, frequency drive or the actuator. Therefore, it can be considered to be more practical to use a PI controller rather than a PID controller.

And with the system which we are using that has a time constant and a time delay, in case there is a change in one of these process parameters the PID controller has higher chances of going into the instability region, where as a PI control often shows a much more stable performance.