1. **Tuning according to specifications Points: /2**

* Realize an open loop system with the following model . Is the open-loop system stable? Show a theoretical and an empirical (practical) proof. (0.1)

PZ plot => poles: -0.1, -0.01 => use simulation time at least 1000 s (time constants: 10, 100)

Step response is stable. Bode diagram here is not good: Bode uses the open loop network to predict the closed-loop stability/behavior.

* Use in closed loop mode with unity feedback. Apply 20 (Celsius) as step reference signal.**\*** (0.2)

Here you can see that the open loop system becomes unstable.

* Design a P controllers that has a 15⸰ of phase margin. Apply 20 (Celsius) as step reference signal.**\*** (0.3)

With a simple gain the system can made stable.

* Vary the gain of the P controller. What do you observe? (0.2)

The higher the gain, the lower the error, the smaller the phase/gain margin >> results in more oscillatory behavior, the longer the settling time and the

* Design a PI controller that has 45⸰ phase margin. Apply 20 (Celsius) as step reference signal.\* (0.5)
* Design a PID controller with 60⸰ phase margin. Apply 20 (Celsius) as step reference signal.\* (0.5)

*\*For each experiment prepare a graph and indicate the measured quantities, be prepared to explain all your findings. Fill out the table below and draw conclusions.*

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Case | Controller | | | Bode diagram | | | Step response | | | |
| K | Ti | Td | Static gain | Phase-margin | Gain-margin | Static gain | Max overshoot/ undershoot | Settling  Time | Static  error |
| closed  loop | - | - | - | 54 dB/501.18 | -195 deg. | -26 dB/0.05 | ∞ | ∞ | ∞ | ∞ |
| P15⸰ | -29.4 dB/ 0.0427 | - | - | 24.6 dB / 16.9 | 15 deg | 3.1 dB /1.4 | 19/20=  0.95 | (32-19)/19\*100 =  68.4% | ≈250 s | 20-19=1 |
| PI45⸰ | -37.9 dB/ 0.0127 | 100 | - | 40 dB/100 (or ∞) | 45 deg | 10.4 dB/ 3.13 | 20/20=1 | (24.4-20)/20\*100=  23.6% | ≈ 68 s | 20-20=0 |
| PID60⸰ | -33.7 dB/ 0.0207 | 100 | 10 | 70 dB/3100 (or ∞) | 60 deg | 8.04 dB / 2.52 | 20/20=1 | (21.1-20)/20\*100 =  5.5% | ≈ 15 s | 20-20=0 |

* Analyze the above obtained results (0.2)

The higher the PM, the lower the settling time, smaller the oscillations.

P: there is a steady-state error, that can be reduced with increasing the gain => stability issues (see above)

PI: no steady-state error but slow

PID: super cool: no steady-state error and fast

1. **ZIEGLER-NICHOLS TUNING 1. Points: /0.5**

* Realize the following system: . Perform the Ziegler-Nichols open loop method. What parameters did you estimate from the process variable? (0.25)

May need to change the time resolution. T=10s, L=5s, Kp=5

* Design a closed-loop PID controller based on the recommendations of Ziegler-Nichols. What parameters did you estimate? (0.25)

K=1.2\*10/5/5=0.48; Ti=10; Td=2.5

1. **ZIEGLER-NICHOLS TUNING 2. Points: /0.5**

* Realize the following system: Perform the Ziegler-Nichols closed loop method. What parameters did you estimate from the process variable? (0.25)

Kcrit=6; Pcrit=4.36s

* Design a closed-loop PID controller based on the recommendations of Ziegler-Nichols. What parameters did you estimate? (0.25)

K=3.6; Ti=2.18; Td=0.545