PID Controller Design

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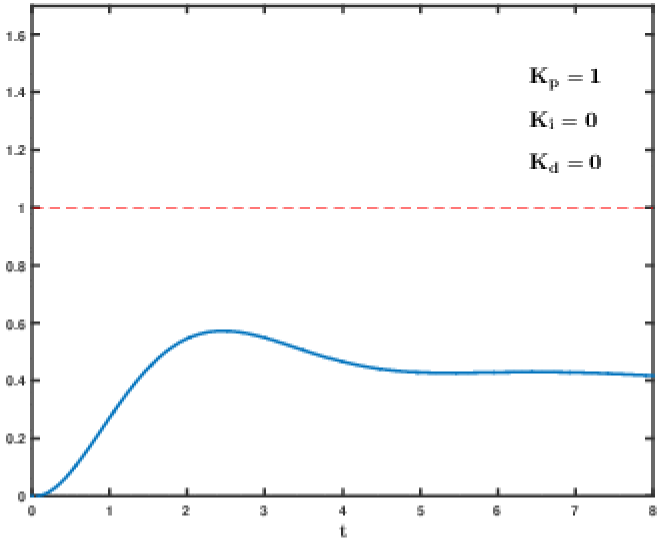
PID controller

➢ Definition

A proportional–integral–derivative controller (PID controller or three term controller) is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modulated control.



➢ Origin:

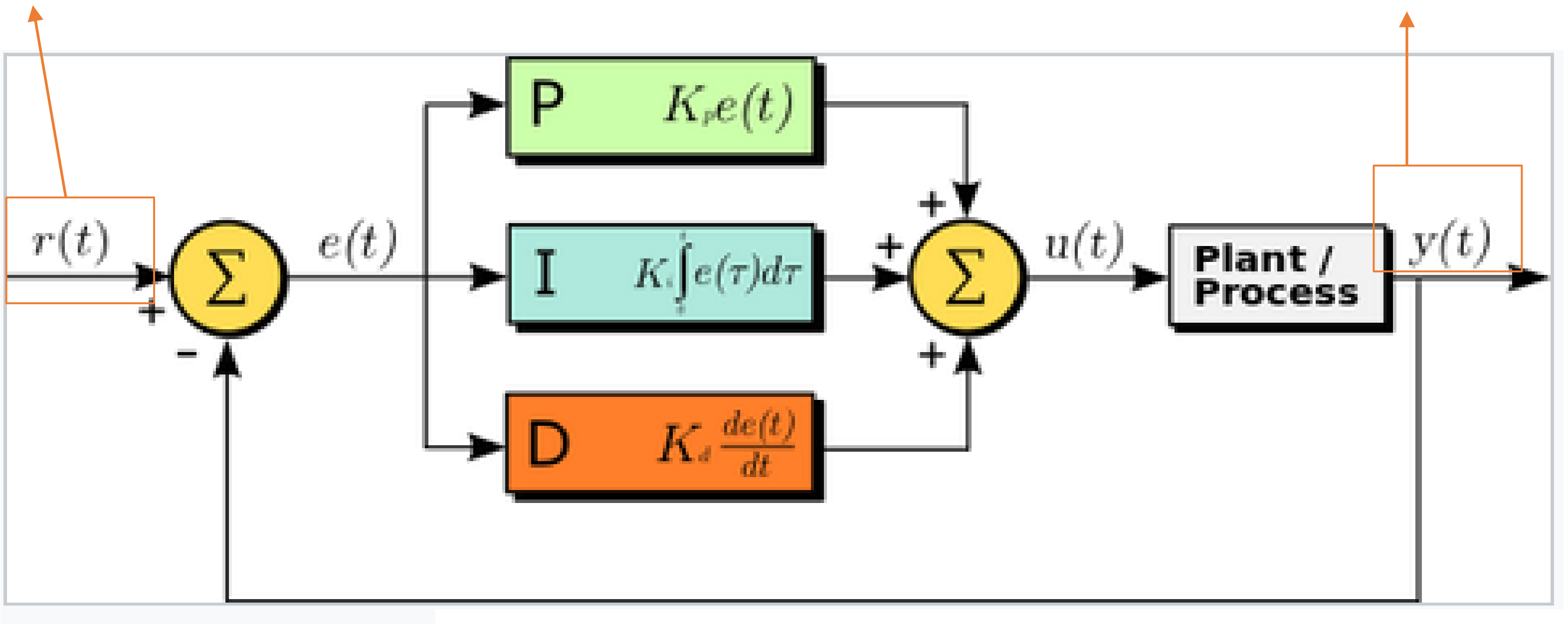
1. PID or three-term control was first developed using theoretical analysis, by Russian American engineer Nicolas Minorsky

PID Controller Design

- Proportional-Integral-Derivative (PID) controller is a simple, yet versatile, feedback compensator structure

a desired setpoint $\mathrm{SP} = r(t)$

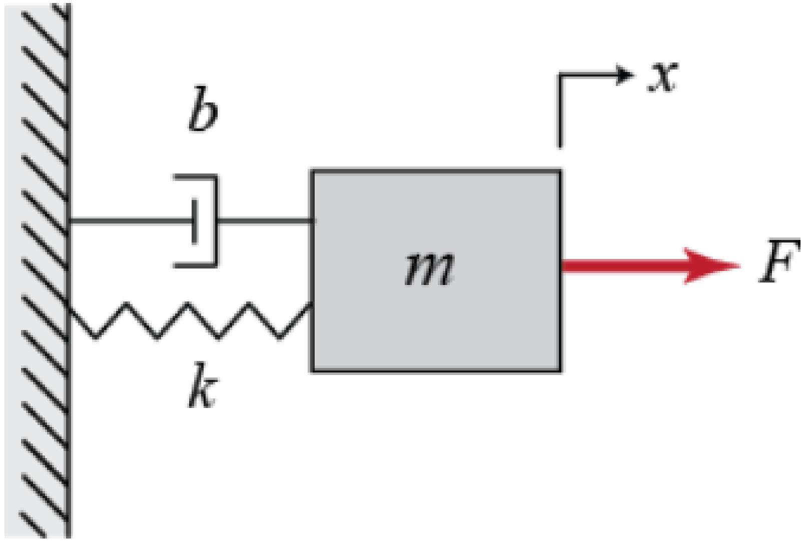
a measured process variable $\mathrm{PV} = y(t)$,



$e(t) = y(t) - r(t)$

The overall control function $u(t) = K_p e(t) + K_i \int_0^t e(t')\,dt' + K_d \frac{de(t)}{dt},$

Example Problem



a simple mass-spring-damper system.

Governing equation $m\ddot{x} + b\dot{x} + kx = F$

Laplace transform of the governing equation

$$ms^2X(s) + bsX(s) + kX(s) = F(s)$$

Transfer function

$$\frac{X(s)}{F(s)} = \frac{1}{ms^2 + bs + k}$$

Let m = 1 kg

b = 10 N s/m

k = 20 N/m

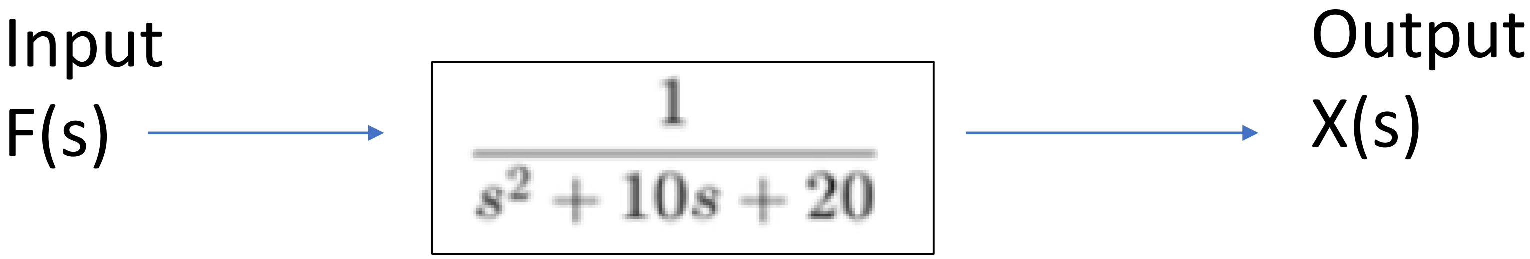
F = 1 N

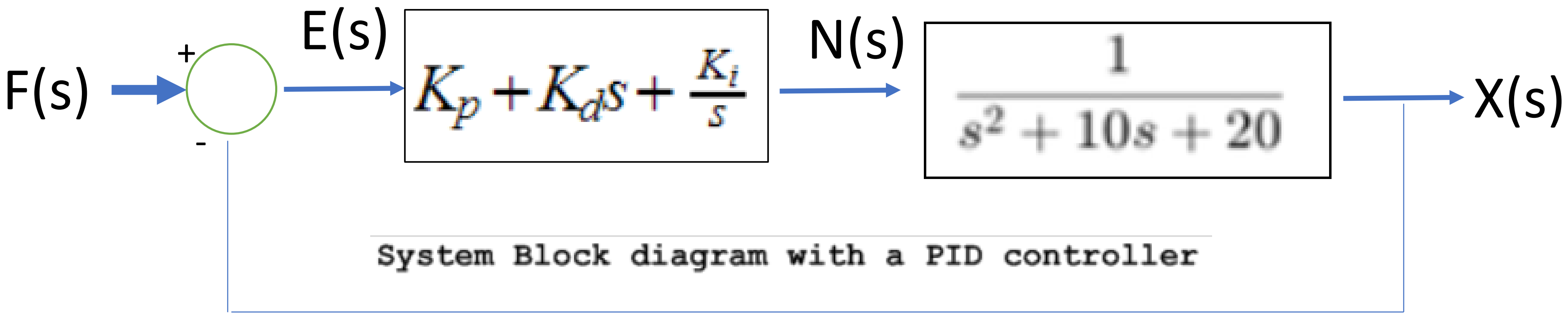
$$\frac{X(s)}{F(s)} = \frac{1}{s^2 + 10s + 20}$$

The goal is to adjust Kp, Ki and Kd to obtain:

- Fast rise time
- Minimal overshoot
- Zero steady-state error

System diagram





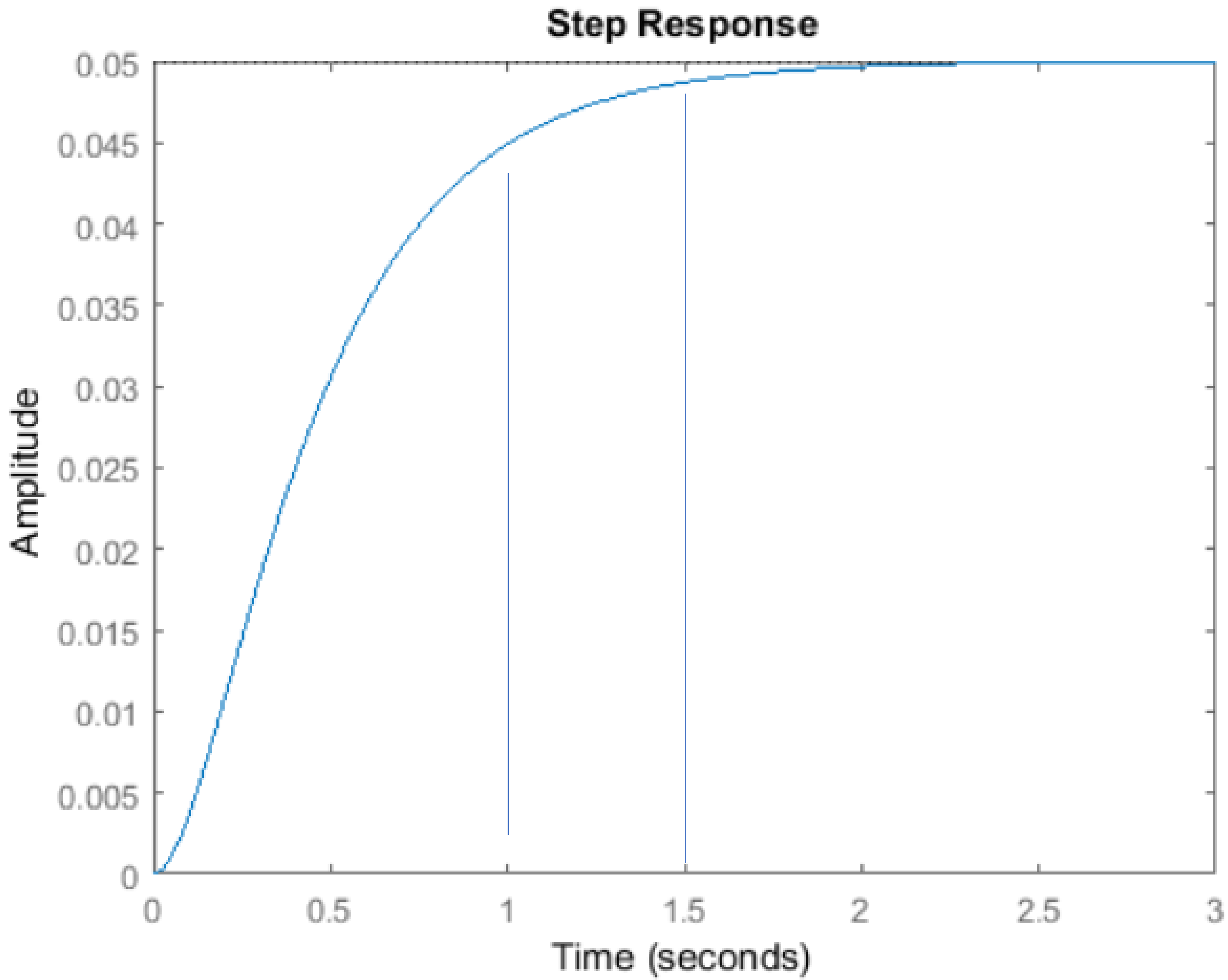
System Block diagram with a PID controller

Transfer function= $\dfrac{K_d s^2 + K_p s + K_i}{s^3 + (10 + K_d)s^2 + (20 + K_p)s + K_i}$

Open-Loop Step Response

transfer function

$$\frac{X(s)}{F(s)} = \frac{1}{s^2 + 10s + 20}$$



The rise time: 1 s

the settling time: 1.5 s

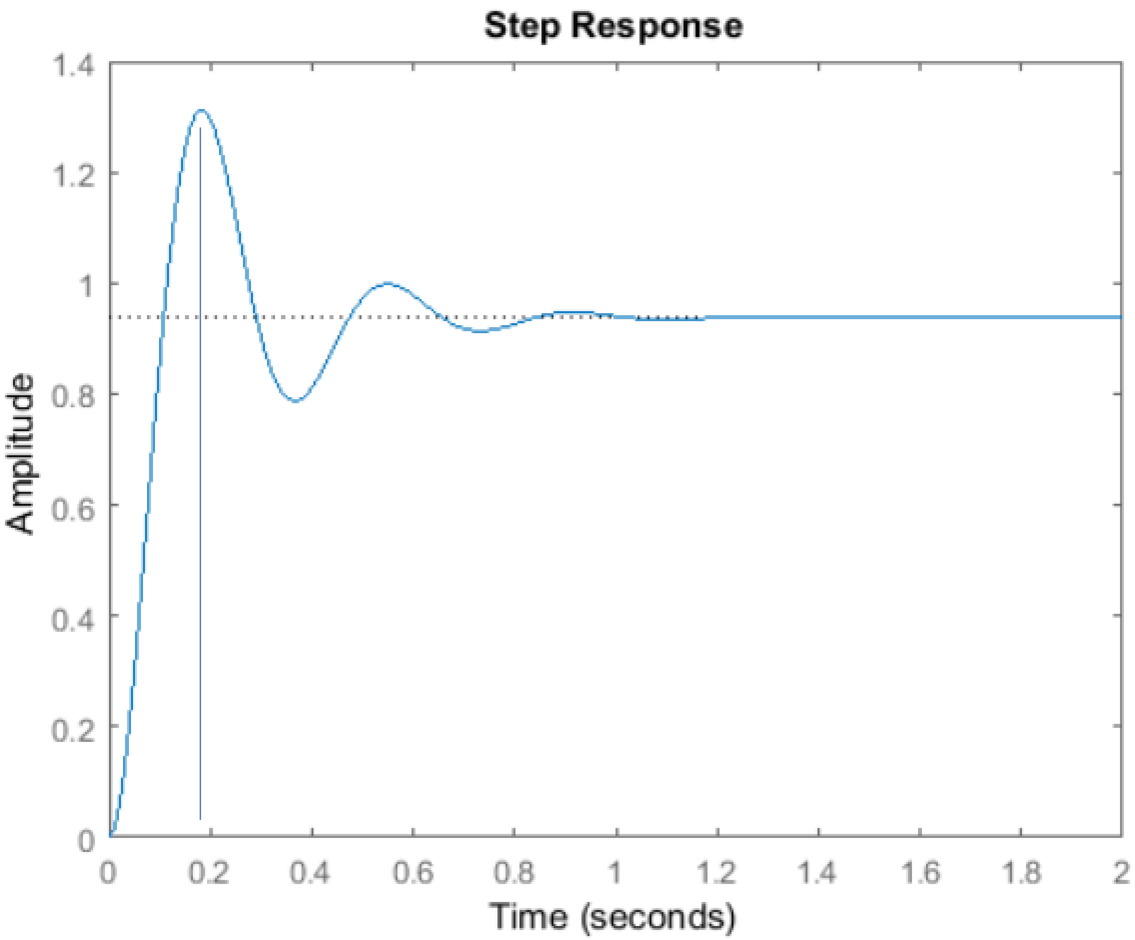
steady-state error: 0.95

Proportional Control: Kp

transfer function

$$T(s) = \frac{X(s)}{R(s)} = \frac{K_p}{s^2 + 10s + (20 + K_p)}$$

Kp = 300;



the rise time: 0.18

the settling time: 0.8 s

steady-state error: 0.05

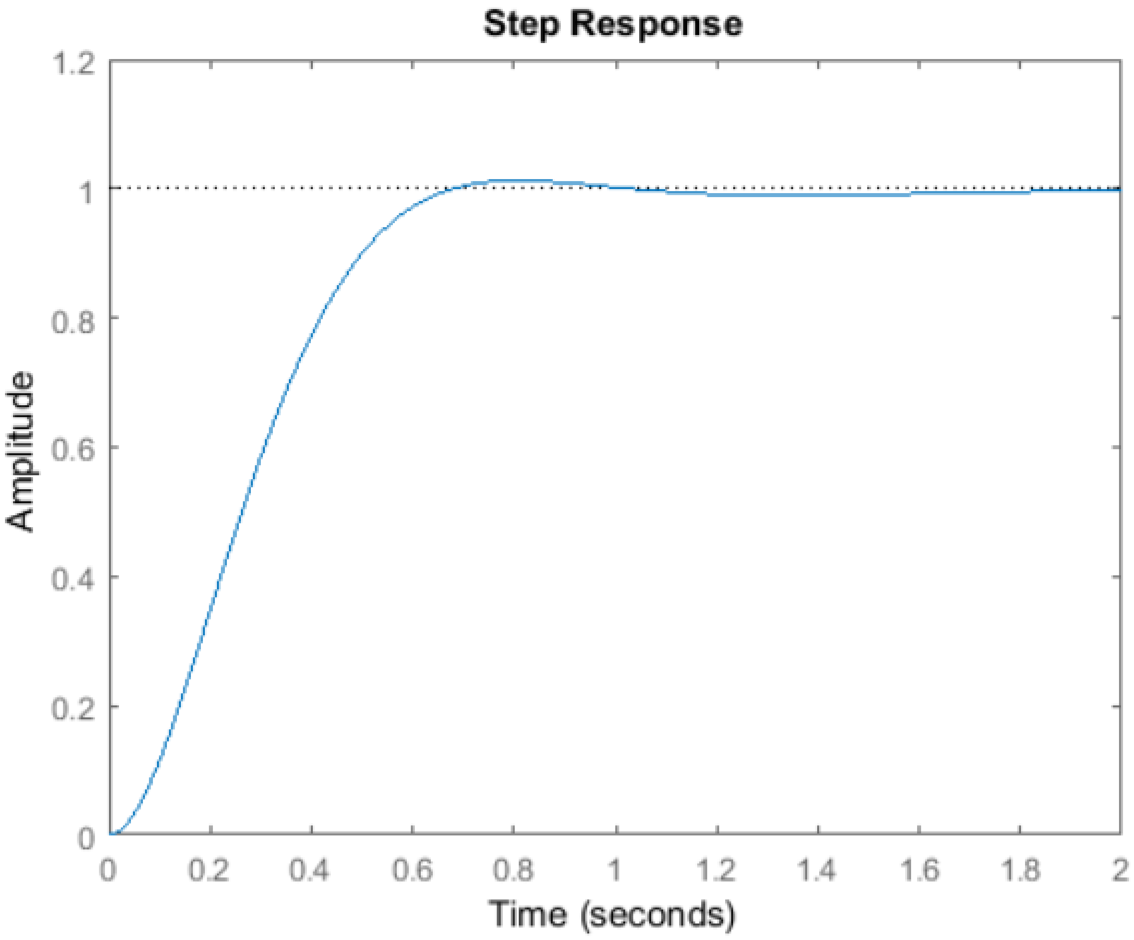
Proportional-Integral Control: Kp， Ki

transfer function

$$T(s) = \frac{X(s)}{R(s)} = \frac{K_p s + K_i}{s^3 + 10s^2 + (20 + K_p)s + K_i}$$

Kp = 30;

Ki = 70;



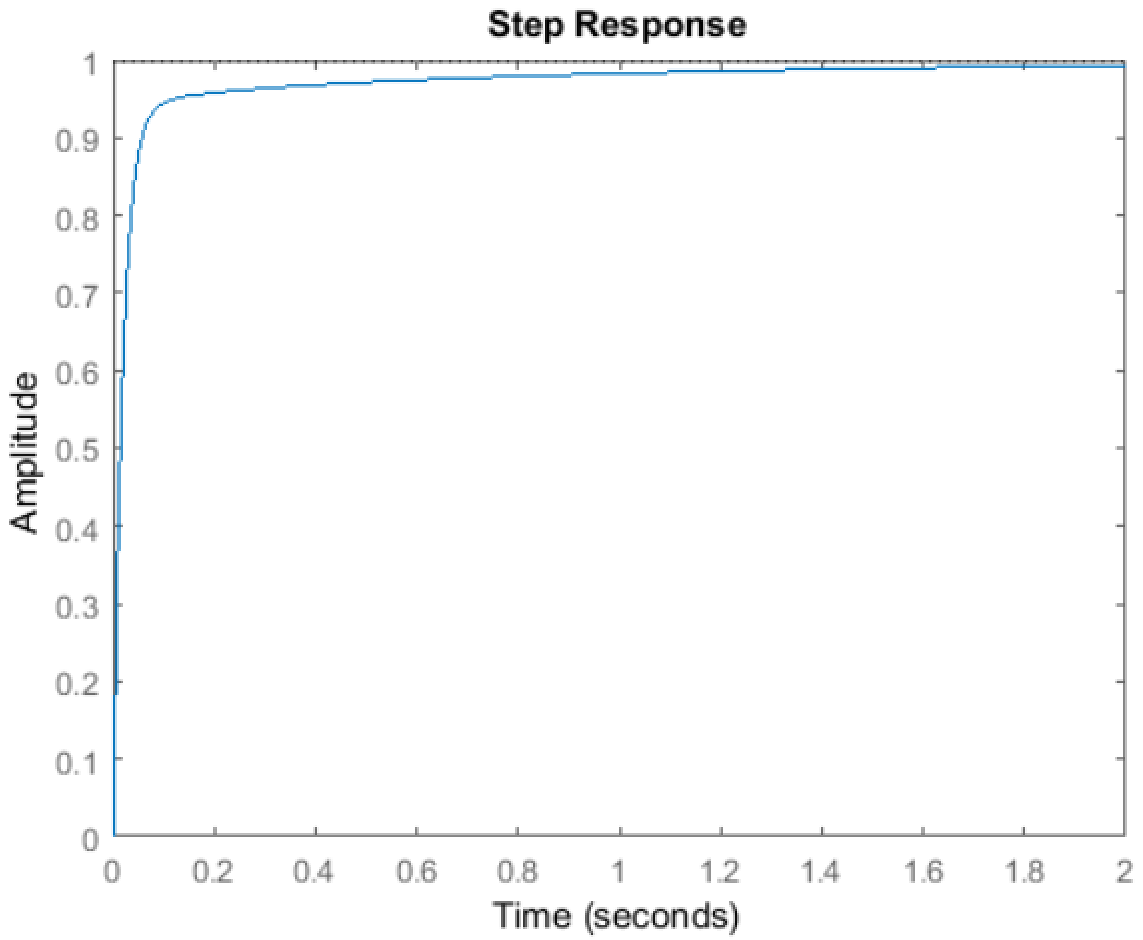
the integral controller reduces the rise time, increases the overshoot, and eliminated the steady-state error

Proportional-Integral-Derivative Control: Kp, Ki, Kd

transfer function

$$T(s) = \frac{X(s)}{R(s)} = \frac{K_d s^2 + K_p s + K_i}{s^3 + (10 + K_d)s^2 + (20 + K_p)s + K_i}$$

Kp = 350;
Ki = 300;
Kd = 50;

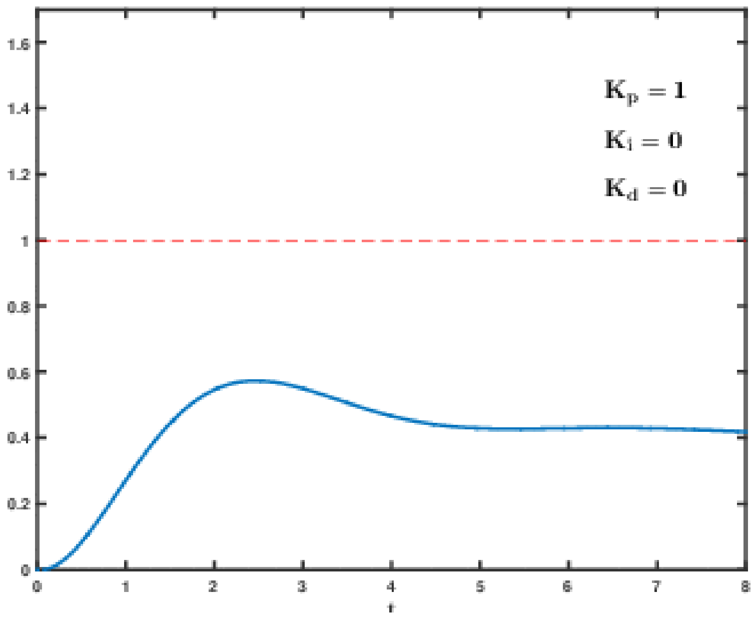


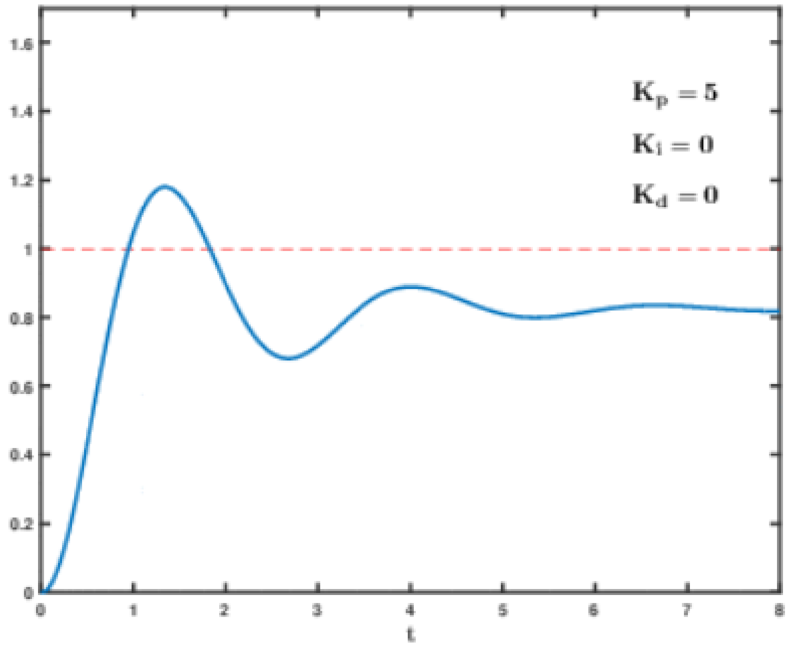
Now, we have designed a closed-loop system with no overshoot, fast rise time, and no steady-state error.

How are the PID parameters (Kp, Ki, Kd) tuned

Manual tuning

1. Set Ki and Kd values to zero. Increase the Kp to approximately half of that value for a "quarter amplitude decay" type response.

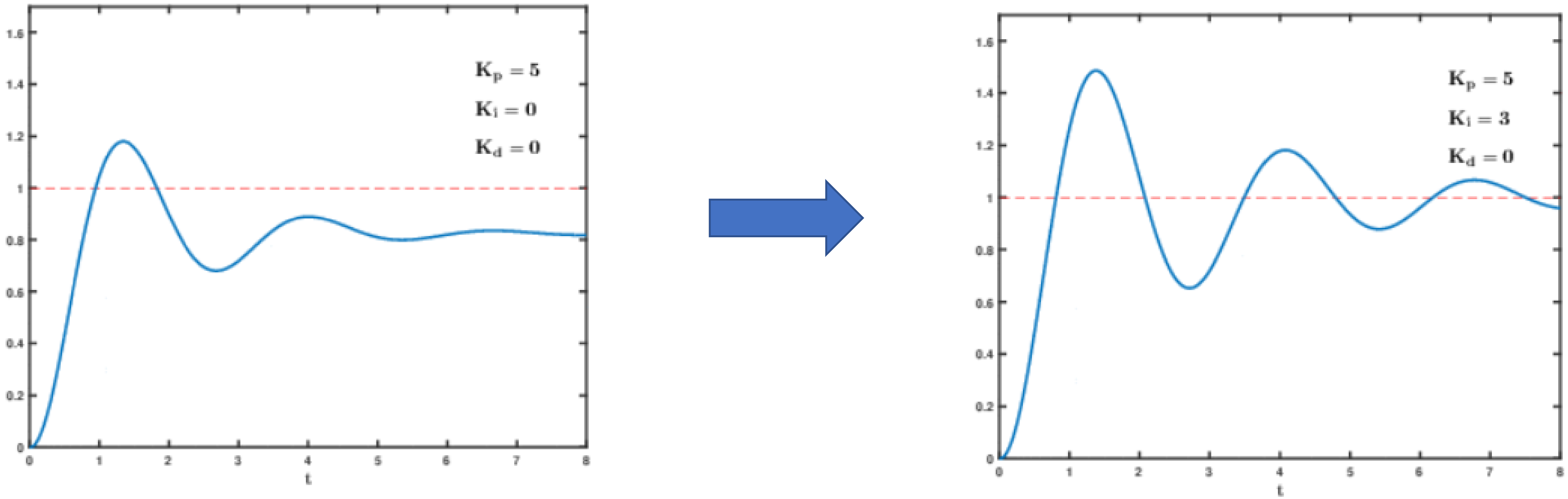




How are the PID parameters (Kp, Ki, Kd) tuned

Manual tuning

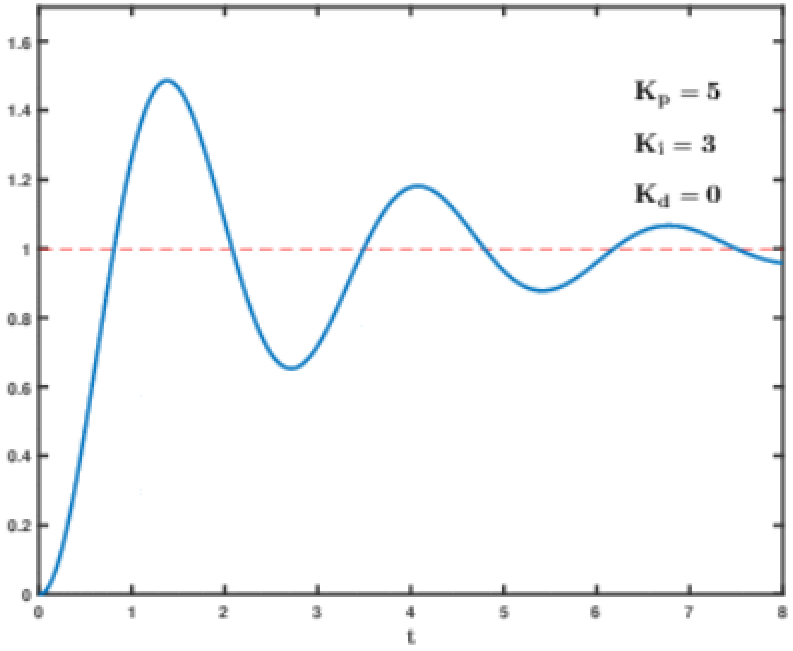
2. increase Ki until any offset is corrected in sufficient time for the process. Make the steady-state error to be zero.

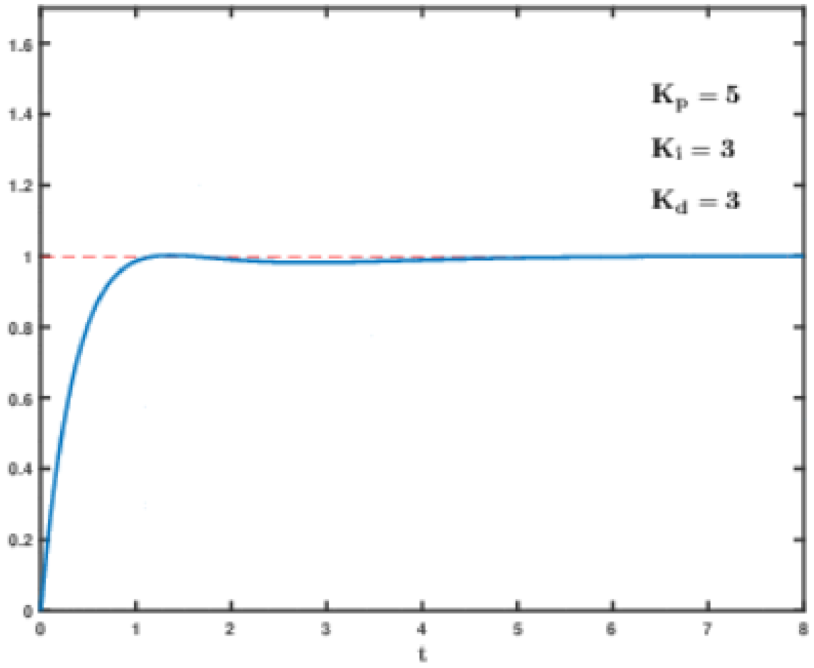


How are the PID parameters (Kp, Ki, Kd) tuned

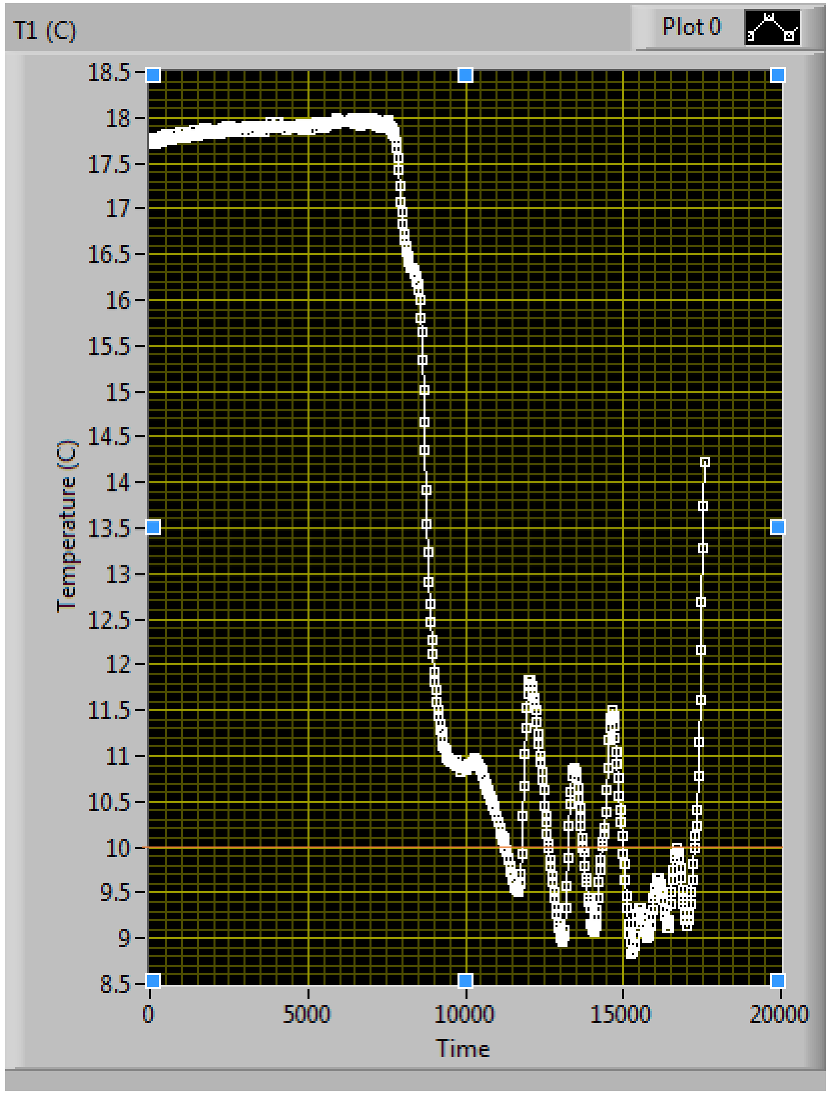
Manual tuning

3. Finally, increase Kd, if required, until the loop is acceptably quick to reach its reference after a load disturbance.

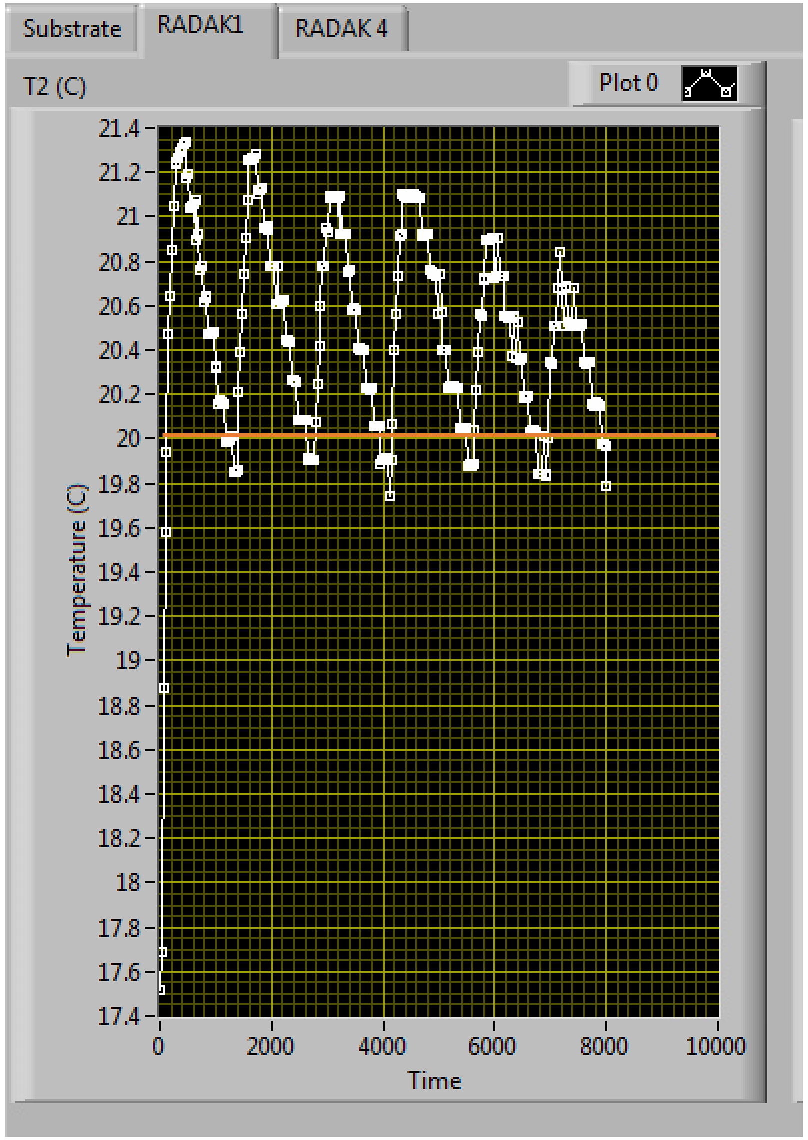




In our cases



Substrate Temperature: 10±2 °C



Source Temperature: 20 (+1.8 ~ -0.2 °C)

Reference

- Nasser M. Abbasi. Determination of PID controller parameters from step response specifications. http://www.12000.org/my_notes/PID_ode/index.pdf
- Introduction: PID Controller Design. http://ctms.engin.umich.edu/CTMS/index.php?example=Introduction&section=ControlPID
- https://en.wikipedia.org/wiki/PID_controller

Thank you!
Any questions?