Process Control and Building Management Systems

EME501

Lec10 Design of PI, PD, PID controllers

INSTRUCTOR

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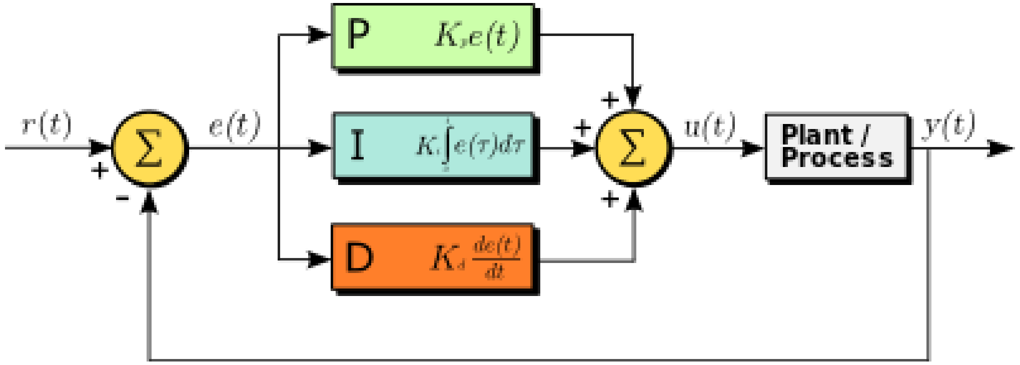
➢ PID controller

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

➢ A PID controller continuously calculates an *error value* e(t) as the difference between a desired setpoint (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted *P*, *I*, and *D* respectively), hence the name.

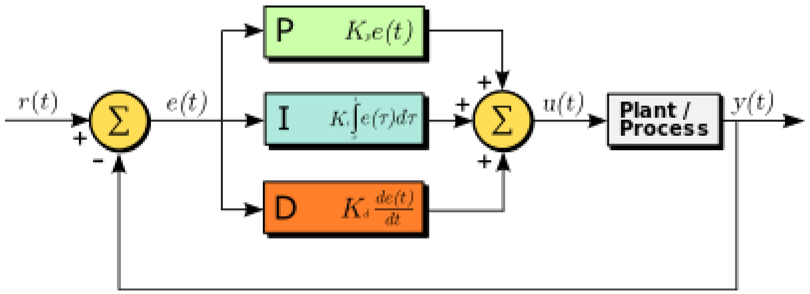


PID controller

- The first theoretical analysis and practical application was in the field of automatic steering systems for ships, developed from the early 1920s onwards.
- It was then used for automatic process control in the manufacturing industry, where it was widely implemented in pneumatic, and then electronic, controllers.
- Today the PID concept is used universally in applications requiring accurate and optimized automatic control.

➢ Fundamental operation

- The distinguishing feature of the PID controller is the ability to use the three control terms of proportional, integral and derivative influence on the controller output to apply accurate and optimal control.



- The block diagram on the PID shows the principles of how these terms are generated and applied. It shows a PID controller, which continuously calculates an error value e(t) as the difference between a desired setpoint SP= and a measured process variable y(t) where e(t)=r(t)-y(t), and applies a correction based on proportional, integral, and derivative terms. The controller attempts to minimize the error over time by adjustment of a control variable u(t), such as the opening of a control valve, to a new value determined by a weighted sum of the control terms.

Tuning

- The balance of these effects is achieved by loop tuning to produce the optimal control function.

- The tuning constants are shown below as "K" and must be derived for each control application, as they depend on the response characteristics of the complete loop external to the controller.

- These are dependent on the behavior of the measuring sensor, the final control element (such as a control valve), any control signal delays and the process itself. Approximate values of constants can usually be initially entered knowing the type of application, but they are normally refined, or tuned, by "bumping" the process in practice by introducing a setpoint change and observing the system response.

➢ Mathematical form

- The overall control function

$$u(t) = K_{\mathrm{p}} e(t) + K_{\mathrm{i}} \int_0^t e(t')\, dt' + K_{\mathrm{d}} \frac{de(t)}{dt}$$

- where K_p, K_i, K_d all non-negative, denote the coefficients for the proportional, integral, and derivative terms respectively (sometimes denoted P, I, and D).

➢ Selective use of control terms

- ➢ Although a PID controller has three control terms, some applications need only one or two terms to provide appropriate control.
- ➢ This is achieved by setting the unused parameters to zero and is called a PI, PD, P or I controller in the absence of the other control actions.
- ➢ PI controllers are fairly common in applications where derivative action would be sensitive to measurement noise, but the integral term is often needed for the system to reach its target value.

➢ Controller theory

➢ The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining u(t) as the controller output, the final form of the PID algorithm is

$$u(t) = \mathrm{MV}(t) = K_{\mathrm{p}} e(t) + K_{\mathrm{i}} \int_0^t e(\tau)\, d\tau + K_{\mathrm{d}} \frac{de(t)}{dt}$$

where

K_{p} is the proportional gain, a tuning parameter,

K_{i} is the integral gain, a tuning parameter,

K_{d} is the derivative gain, a tuning parameter,

$e(t) = \mathrm{SP} - \mathrm{PV}(t)$ is the error (SP is the setpoint, and PV(t) is the process variable),

t is the time or instantaneous time (the present),

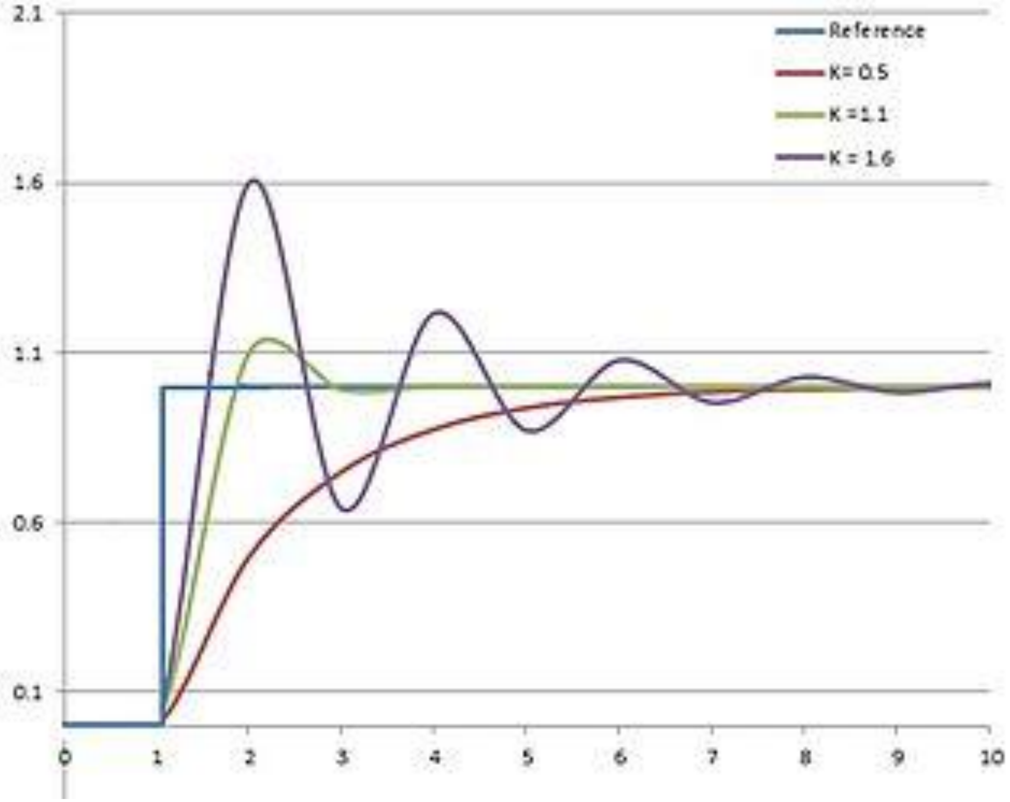
τ is the variable of integration (takes on values from time 0 to the present t).

➢ Proportional term

- ➢ The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant Kp, called the proportional gain constant.

- ➢ The proportional term is given by

$$P_{\mathrm{out}} = K_{\mathrm{p}} e(t).$$



➢ Proportional term

- A high proportional gain results in a large change in the output for a given change in the error.

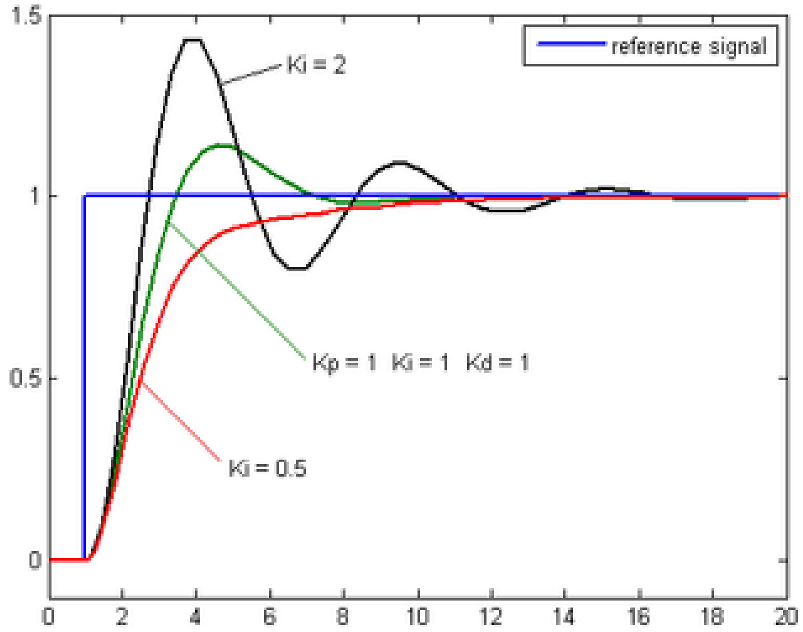
- If the proportional gain is too high, the system can become unstable.

- In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances.

- Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change

➢ Integral term

- The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain (Ki) and added to the controller output.



- The integral term is given by

$$I_{\mathrm{out}} = K_{\mathrm{i}} \int_0^t e(\tau)\, d\tau.$$

➢ Integral term

- The integral term accelerates the movement of the process towards setpoint and eliminates the residual steady-state error that occurs with a pure proportional controller.

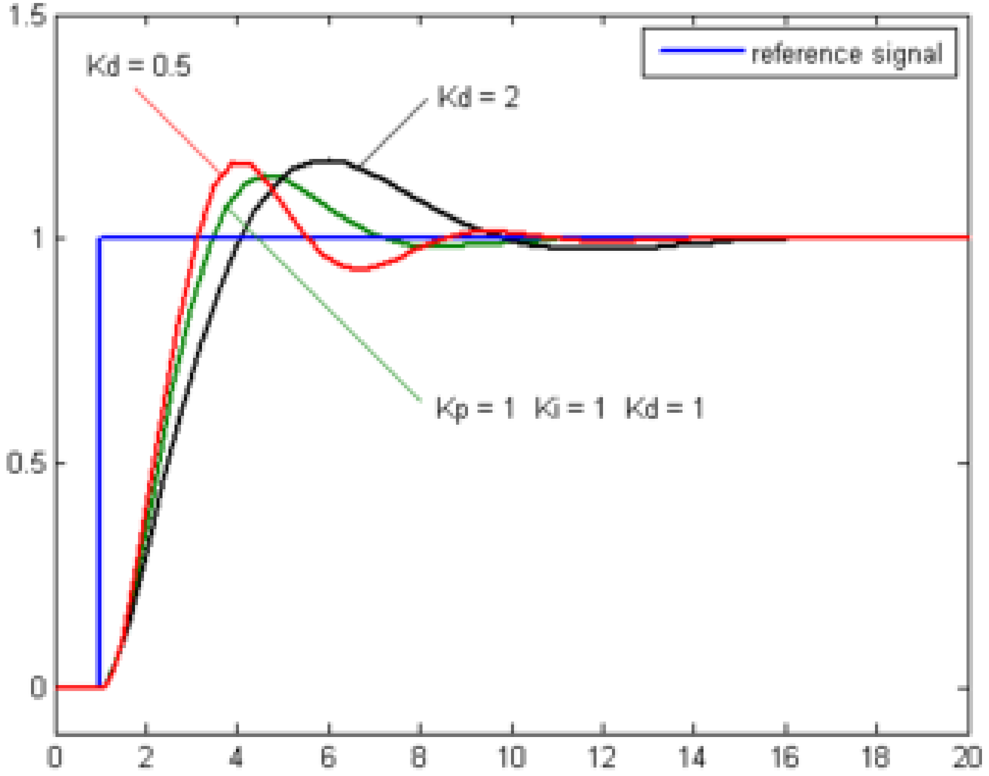
- However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the setpoint value

➢ Derivative term

- The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain Kd. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, Kd.

- The derivative term is given by

$$D_{\mathrm{out}} = K_{\mathrm{d}} \frac{de(t)}{dt}$$



Derivative term

- Derivative action predicts system behavior and thus improves settling time and stability of the system.

- An ideal derivative is not causal, so that implementations of PID controllers include an additional low-pass filtering for the derivative term to limit the high-frequency gain and noise.

- Derivative action is seldom used in practice though – by one estimate in only 25% of deployed controllers– because of its variable impact on system stability in real-world applications.


Thank you