Appendix
Derivation of BIBO Stability Condition of Linear PID Control System

Suppose a nonlinear process N is controlled by a linear PID controller. In the computerized implementation, the PID controller is discretized by using a zero order holder where s in the transfer function of PID controller is substituted by $\frac{1-z^{-1}}{\Delta t}$ and for a linear PID controller in the series form, we have:

$$\frac{u_k - u_{k-1}}{\Delta t} = \frac{K_c}{T_i}\left(1 + \frac{T_i}{\Delta t} + \frac{T_d}{\Delta t} + \frac{T_i T_d}{\Delta t^2}\right) e_k - \frac{K_c}{T_i}\left(\frac{T_i}{\Delta t} + \frac{T_d}{\Delta t} + \frac{2T_i T_d}{\Delta t^2}\right) e_{k-1} + \frac{K_c T_d}{\Delta t^2} e_{k-2}.$$

Referring to Fig. 6.4, if we define:

$$\begin{cases} e_{1,k} = e_k = r_k - y_k \\ e_{2,k} = u_k \\ u_{1,k} = r_k \\ u_{2,k} = u_{k-1} \\ H_1(e_{1,k}) = \Delta u_k = u_k - u_{k-1} \\ H_2(e_{2,k}) = N(e_{2,k}) = y_k \end{cases}$$

Applying the small gain theorem, we can obtain the following sufficient condition for the BIBO stability of the linear PID controlled system, as:

$$K_c\left(1 + \frac{T_d}{T_i} + \frac{\Delta t}{T_i} + \frac{T_d}{\Delta t}\right) \cdot \|H_2\| < 1$$

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