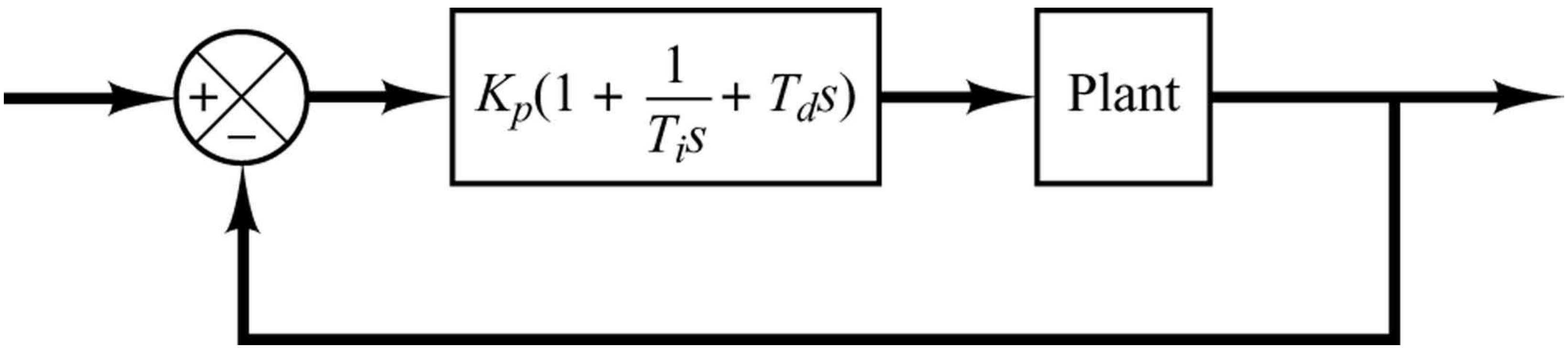
Tuning for PID Controllers

PID Controllers

- PID Controllers are everywhere! Due to its simplicity and excellent, if not optimal, performance in many applications,
- PID controllers are used in more than 95% of closed-loop industrial processes.
- Can be tuned by operators without extensive background in Controls, unlike many other modern controllers (Full State Feedback) that are much more complex but often provide only slight improvement.



$$\frac{U(s)}{E(s)} = G_{PID}(s) = K_P + K_I \frac{1}{s} + K_D s = K_P\left(1 + \frac{1}{T_I s} + T_D s\right)$$

Tuning a PID Controller

- System model is required for techniques we have studied (Root Locus, Bode Plots)
- System models may be determined using system identification techniques, such measuring output for an impulse or step input.
- Traditional control design methods are less appropriate if the system is unknown;
- Most PID controllers are tuned on-site due to machine and process variations. The theoretical calculations for an initial setting of PID parameters can be by-passed using a few tuning rules.

How do the PID parameters affect system dynamics?

4 major characteristics of the closed-loop step response.

1. **Rise Time**: the time it takes for the plant output y to rise beyond 90% of the desired level for the first time.
2. **Overshoot**: how much the the peak level is higher than the steady state, normalized against the steady state.
3. **Settling Time**: the time it takes for the system to converge to its steady state.
4. **Steady-state Error**: the difference between the steady-state output and the desired output.

How do the PID parameters affect system dynamics?

$$U(s) = G_{PID}(s)E(s) = \left(K_P + K_I \frac{1}{s} + K_D s \right) E(s)$$

The effects of increasing each of the controller parameters K_P, K_I and K_D can be summarized as

Response	Rise Time	Overshoot	Settling Time	S-S Error
K_P	Decrease	Increase	NT	Decrease
K_I	Decrease	Increase	Increase	Eliminate
K_D	NT	Decrease	Decrease	NT

NT: No definite trend. Minor change.

How do we use the table?

Typical steps for designing a PID controller are

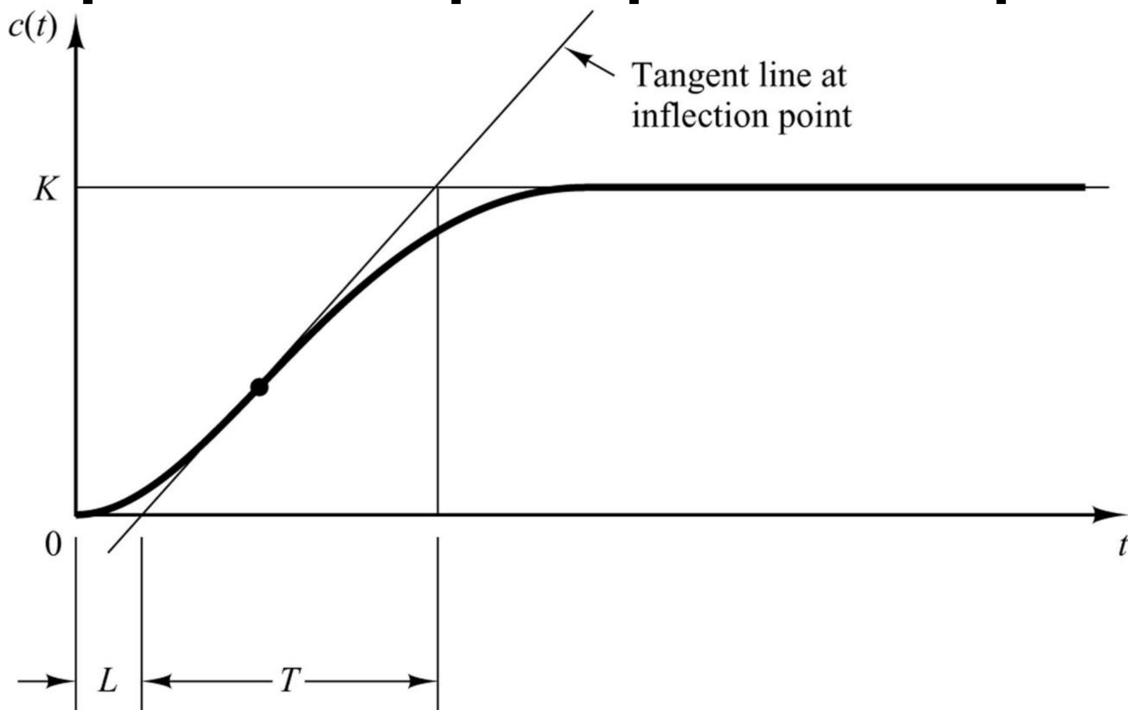
1. Determine what characteristics of the system needs to be improved.
2. Use K_P to decrease the rise time.
3. Use K_D to reduce the overshoot and settling time.
4. Use K_I to eliminate the steady-state error.

This works in many cases, but what would be a good starting point? What if the first parameters we choose are totally crappy? Can we find a good set of initial parameters easily and quickly?

The Ziegler-Nichols tuning rule to the rescue

Ziegler and Nichols conducted numerous experiments and proposed rules for determining values of K_P, K_I and K_D based on the transient step response of a plant.
They proposed more than one methods, but we will limit ourselves to what's known as the first method of Ziegler-Nichols in this tutorial. It applies to plants with neither integrators nor dominant complex-conjugate poles, whose unit-step response resemble an S-shaped curve with no overshoot. This S-shaped curve is called the reaction curve.

Ziegler–Nichols Tuning 1st Method S-shaped Step Input Response Curve



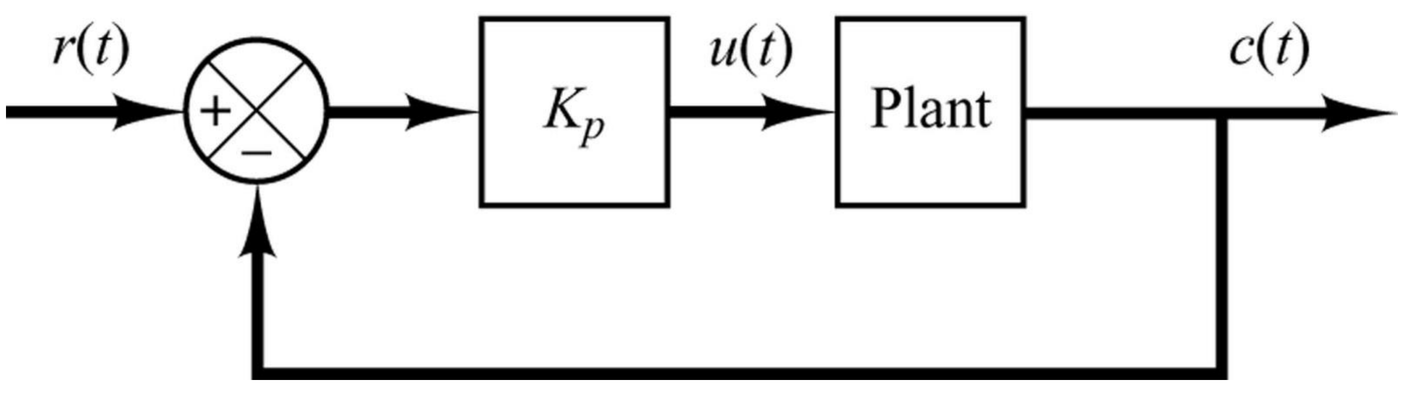
- The S-shaped reaction curve can be characterized by two constants, delay time *L* and time constant *T*, which are determined by drawing a tangent line at the inflection point of the curve and finding the intersections of the tangent line with the time axis and the steady-state level line.

Ziegler–Nichols Tuning Rule Based on Step Response of Plant (First Method)

Type of Controller	K_p	T_i	T_d
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	$2L$	$0.5L$

Ziegler–Nichols Tuning, Second Method

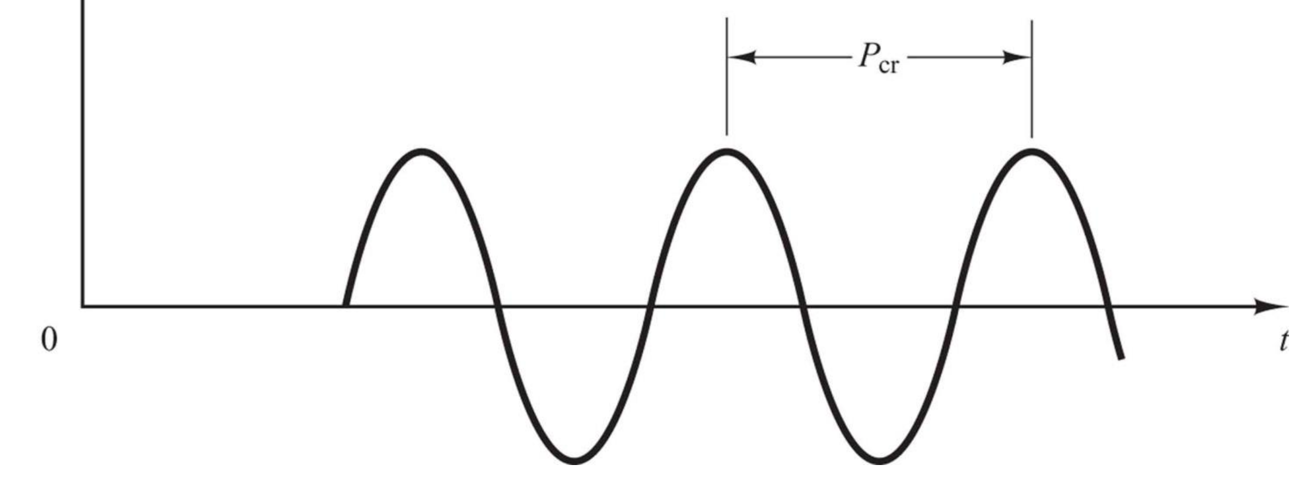
- Start with Closed-loop system with a proportional controller.
- Begin with a low value of gain, K_P
- Potential of this method to go unstable or cause damage.



Ziegler–Nichols Tuning, Second Method

- Begin with a low/zero value of gain K_P
- Increase until a steady-state oscillation occurs, note this gain as K_{cr}

Sustained oscillation with period P_{cr}. (P_{cr} is measured in sec.)



Ziegler–Nichols Tuning, Second Method

- Gain estimator chart

Type of Controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

Ziegler-Nichols Tuning Method

- Ziegler-Nichols tuning method to determine an **initial/estimated** set of working PID parameters for an unknown system
- Usually included with industrial process controllers and motor controllers as part of the set-up utilities
  - Some controllers have additional autotune routines.

Ziegler-Nichols Tuning Method

- These parameters will typically give you a response with an overshoot on the order of 25% with a good settling time.
- We may then start fine-tuning the controller using the basic rules that relate each parameter to the response characteristics, as noted earlier.

Summary

Two things to take away from this review of Ziegler-Nichols tuning:

1. Relationships between K_P, K_I and K_D and important response characteristics, of which these three are most useful:
   - Use K_P to decrease the rise time.
   - Use K_D to reduce the overshoot and settling time.
   - Use K_I to eliminate the steady-state error.
2. The Ziegler-Nichols tuning rule (reaction curve method) for good initial estimate of parameters.