Tuning for PID Controllers

EGR 386
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 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

<table>
<thead>
<tr>
<th>Response</th>
<th>Rise Time</th>
<th>Overshoot</th>
<th>Settling Time</th>
<th>S-S Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_P )</td>
<td>Decrease</td>
<td>Increase</td>
<td>NT</td>
<td>Decrease</td>
</tr>
<tr>
<td>( K_I )</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
<td>Eliminate</td>
</tr>
<tr>
<td>( K_D )</td>
<td>NT</td>
<td>Decrease</td>
<td>Decrease</td>
<td>NT</td>
</tr>
</tbody>
</table>

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.
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)

<table>
<thead>
<tr>
<th>Type of Controller</th>
<th>$K_p$</th>
<th>$T_i$</th>
<th>$T_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>$\frac{T}{L}$</td>
<td>$\infty$</td>
<td>0</td>
</tr>
<tr>
<td>PI</td>
<td>$0.9 \frac{T}{L}$</td>
<td>$\frac{L}{0.3}$</td>
<td>0</td>
</tr>
<tr>
<td>PID</td>
<td>$1.2 \frac{T}{L}$</td>
<td>$2L$</td>
<td>$0.5L$</td>
</tr>
</tbody>
</table>
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

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<th>$T_i$</th>
<th>$T_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>$0.5K_{cr}$</td>
<td>$\infty$</td>
<td>0</td>
</tr>
<tr>
<td>PI</td>
<td>$0.45K_{cr}$</td>
<td>$\frac{1}{1.2}P_{cr}$</td>
<td>0</td>
</tr>
<tr>
<td>PID</td>
<td>$0.6K_{cr}$</td>
<td>$0.5P_{cr}$</td>
<td>$0.125P_{cr}$</td>
</tr>
</tbody>
</table>
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

This concludes the instruction part of our tutorial. We learned two things about PID controllers.

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.