Rate Predictive Process Control

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Background

Process control is the control of chemical processes for quality and safety.

Since the 1980s Model Predictive Control (MPC) technology has been widely used for industrial process control.

The use of MPC is widely published, however there are certain disadvantages.
Background (cont.)

MPC is based on detailed process models and error-minimization. Mr. Kern’s work concluded that these assumptions are actually root causes behind MPC’s limitations Specifically:

1. Process models change frequently requiring retuning
2. In industry process stability is more important than error-minimization
RPC and XMC

Mr. Kern developed rate predictive control (RPC) algorithm to address the limitations of MPC.

RPC adjusts the controller output based on a preset move rate, the ongoing rate of change of the controlled variable, and a future predicted value based on process response time.

RPC is perhaps industry’s first and only inherently adaptive process control algorithm.

Mr. Kern also developed a model-less method of multivariable control (XMC), which utilizes the RPC method internally on a matrix control basis.
Goals

Determine the control theory behind RPC

Test the theoretical performance of RPC

Compare the theoretical performance of RPC to the operational performance of RPC
Procedure

Simulate RPC in Excel and Simulink

Determine overall control loop and transfer functions

Simulate RPC in MATLAB using control loop and transfer functions
Transfer Functions

\[ G_c = \frac{1}{s} \]

\[ G_p = \frac{1}{\tau_1 s + 1} \]

\[ G_{tds} = e^{-tds} \]

\[ G_{RPC} = \theta s + 1 \]

In Control Theory, transfer functions are used to understand the limitations of the controller.

\( \tau_1 \) = Process response time

\( td \) = Time delay

\( \theta \) = Predicted response time
Transfer Functions (cont.)

Standard feedback control finds error through the following equation:

\[ Y_{sp} - Y = E \]

RPC finds error through the following equation:

\[ Y_{sp} - G_{RPC}Y = E_{predicted} \]
Overall Transfer Function

From the overall control loop given previously the following overall transfer function is defined:

\[
\frac{Y}{Y_{sp}} = \frac{K_3 K_2 G_c K_1 G_p}{1 + K_3 K_2 G_c K_1 G_p G_1}
\]
Open Loop Transfer Function

Based on the overall transfer function the open loop transfer function is given as:

\[ G_{OL} = K_3 K_2 G_c K_1 G_p G_1 \]

By substituting the transfer functions in the overall transfer function can be simplified to give:

\[ G_{OL} = K_3 K_2 K_1 e^{-t_d s} \frac{\theta s + 1}{s(\tau_1 s + 1)} \]
“Proof” of Transfer Functions

Conditions:
- First-order Process
- $t_d = 0$
- $\theta = 10$
- $\tau_1 = 10$
- $\frac{1}{K_3} = 10$
“Proof” of Transfer Functions (cont.)

Conditions:
- First-order Process
- \( t_d = 5 \)
- \( \theta = 15 \)
- \( \tau_1 = 10 \)
- \( \frac{1}{K_3} = 15 \)
Stability without Time Delay

For a first order system when $\theta = \tau_1$ without time delay, the open loop transfer function simplifies to give the following:

$$G_{OL} = \frac{K_1 K_2 K_3}{s}$$
Stability without Time Delay (cont.)

Conditions:
- First-order Process
- $t_d = 0$
- $\theta = \tau_1$

Phase under these conditions
-135 degree line
Stability without Time Delay (cont.)

For a first order system where $\theta \neq \tau_1$ and there is no time delay, the open loop transfer function is simplified to give:

$$G_{OL} = K_3 K_2 K_1 \frac{\theta s + 1}{s(\tau_1 s + 1)}$$
Stability without Time Delay (cont.)

Conditions:
- First-order Process
- $t_d = 0$
- $\theta = 5$
- $\tau_1 = 10$

Phase under these conditions

-135 degree line
Conditions:
- First-order Process
- $\tau_d = 0$
- $\theta = 10$
- $\tau_1 = 5$

Phase under these conditions

-90 degree line
Stability with Time Delay

For a first order function with a time delay when $\theta = \tau_1$, the open loop transfer functions simplifies to the given equation:

$$G_{OL} = \frac{K_1K_2K_3}{s} e^{-tds}$$
Stability with Time Delay (cont.)

Conditions:
- First-order Process
- $t_d = 5$
- $\theta = \tau_1$

Phase under these conditions:
- $K_1 K_2 K_3 = 3$

Point of Instability:
- $-180^\circ$ degree line
Stability with Time Delay (cont.)

Conditions:
- First-order Process
- $t_d = 5$
- $\theta = \tau_1$
- $K_1K_2K_3 = 0.0667$
Stability with Time Delay (cont.)

Conditions:

- First-order Process
- $t_d = 5$
- $\theta = \tau_1$
- $K_1K_2K_3 = 10$
Stability Constraints with Time Delay

Conditions:
- **First-order Process**
- \( \theta = \tau_1 \)
- **First-order Process**
- \( \theta = 5 \)
- \( \tau_1 = 10 \)
- **First-order Process**
- \( \theta = 10 \)
- \( \tau_1 = 5 \)
Maximum Allowable Constants with Respect to Time Delay

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Operational Issues

Mr. Kern set operational guidelines for defining $K_3$ and $\theta$ shown below:

$$\theta \geq t_d + \tau_1$$

$$K_3 \leq \frac{1}{K_1 K_2 \theta}$$
Operational Issues (cont.)

Conditions:
- First-order Process
- $t_d = 5$
- $\theta = 15$
- $\tau_1 = 10$
- $\frac{1}{K_3} = 15$

MV = Manipulated Variable

Target

Y

MV

Time (min)
Operational Issues (cont.)

Conditions:
- First-order Process
- $t_d = 5$
- $\theta = 15$
- $\tau_1 = 10$
- $\frac{1}{K_3} = 10$
Operational Issues (cont.)

Conditions:
- First-order Process
- $t_d = 5$
- $\theta = 15$
- $\tau_1 = 10$
- $\frac{1}{K_3} = 1$
Operational Issues (cont.)

Conditions:
• First-order Process
• $t_d = 5$
• $\theta = 10$
• $\tau_1 = 10$
• $\frac{1}{K_3} = 15$
Operational Issues (cont.)

Conditions:
- First-order Process
- \( t_d = 5 \)
- \( \theta = 1 \)
- \( \tau_1 = 10 \)
- \( \frac{1}{K_3} = 15 \)
Conclusions

This analysis confirms the overall control loop and transfer functions determined previously for RPC.

For a first order process without time delay, RPC is inherently stable, even for errors in prediction time versus actual process response time.

For a first order process with time delay, RPC is stable within a range of constants.

Mr. Kern’s published guidelines for “operational stability” (no overshoot for either the Y or MV) are much more conservative than conventional process control stability criteria (no increasing oscillations).
Questions?