Math Supports "Opposite but Equal" if SP Constant

Consider that if the set point (SP) is constant, then:

$$\frac{de(t)}{dt} = \frac{d(\overset{0}{SP} - PV)}{dt} = -\frac{dPV}{dt}$$

That is, as long as SP is constant, then:

deriv on error = **–** deriv on measurement

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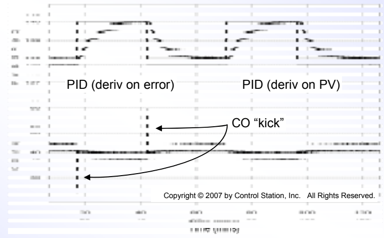
Derivative on PV Does Not "Kick"



- Heat Exchanger under PID control shows CO kick with derivative on e(t)
- Impact of CO kick on PV performance depends on sample time (T) relative to τ_p (fast/small sample time gives little chance for impact)
- But potential for wear on mechanical FCE (e.g., valve) is always a concern

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PID with Derivative on Measurement

- Dependent Ideal Non-Interacting

$$CO = CO_{bias} + Kc \cdot e(t) + \frac{Kc}{\tau_I}\int e(t)dt - Kc \cdot \tau_D \frac{dPV}{dt}$$

- Dependent Interacting Series

$$CO = CO_{bias} + Kc\left(1 + \frac{\tau_D}{\tau_I}\right)e(t) + \frac{Kc}{\tau_I}\int e(t)dt - Kc \cdot \tau_D \frac{dPV}{dt}$$

- Independent

$$CO = CO_{bias} + Kc \cdot e(t) + Ki\int e(t)dt - Kd\frac{dPV}{dt}$$

Because it does not "kick" when the SP changes:

PID with derivative on measurement is preferred in practical applications

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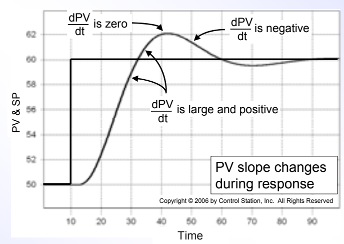
Understanding Derivative Action



- Assuming Kc and τ_D are positive and appropriate size:
  - when dPV/dt (the slope) is positive, the derivative contribution works to decrease CO from its current value
  - when dPV/dt is negative, derivative contribution increases CO

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PID Controllers Work in Harmony

- Proportional term provides a rapid response to controller error
- Integral term eliminates offset but increases the oscillatory or rolling behavior of the PV
- Derivative term works to *decrease oscillations* in the PV because its largest influence is when PV is rapidly changing

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Step 4 - Controller Tuning from Correlations

- Choose performance with, τ_C, the closed loop time constant
  - *aggressive*: τ_C is the larger of $0.1\tau_P$ *or* $0.8\,\theta_P$
  - *moderate*: τ_C is the larger of $1\tau_P$ *or* $8\,\theta_P$
  - *conservative*: τ_C is the larger of $10\tau_P$ *or* $80\,\theta_P$
- The Internal Model Control (IMC) tuning correlations are:

	Kc	τ_I	τ_D
Ideal	$\frac{1}{Kp}\left(\frac{\tau_P + 0.5\theta_P}{\tau_C + 0.5\theta_P}\right)$	$\tau_P + 0.5\theta_P$	$\frac{\tau_P\theta_P}{2\tau_P + \theta_P}$
Interacting	$\frac{1}{Kp}\left(\frac{\tau_P}{\tau_C + 0.5\theta_P}\right)$	τ_P	$0.5\theta_P$

- Independent algorithm tunings can be computed directly from above Kc, τ_I and τ_D

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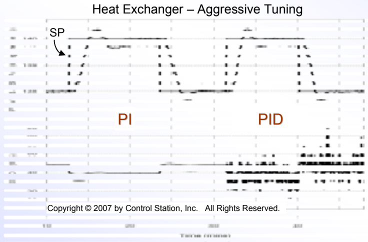
PID Set Point Tracking

- PID shows decreased oscillations compared to PI performance

Heat Exchanger – Aggressive Tuning

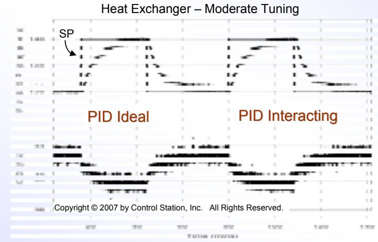


PID has somewhat:
- shorter rise time
- faster settling time
- smaller overshoot

PID Set Point Tracking

- Each PID algorithm performs the same – as long as each is tuned with its proper correlation

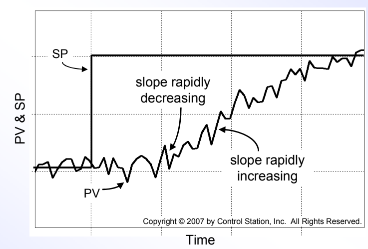
Heat Exchanger – Moderate Tuning



Disadvantages of Derivative

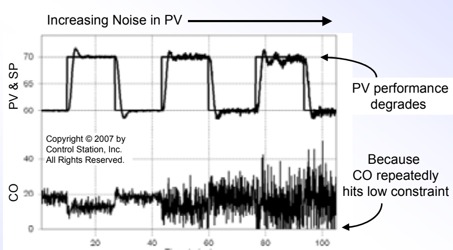
- Measurement Noise is a Problem:
  - Derivative action loses its benefits when there is random error (noise) in the measured PV – a common occurrence
  - The derivative action causes PV measurement noise to be amplified and reflected in the CO signal
  - This is because a noisy PV signal has changing derivatives as the slope switches direction at every sample

Noise Degrades Derivative Action



- Slope (derivative) switches direction every sample
- This produces alternating CO actions (called "chatter") from the PID algorithm
- The CO chatter is amplified based on the size of τ_D

Noise Degrades Derivative Action



- As noise level increases, its impact on CO chatter is apparent
- If CO hits a constraint, lack of "symmetry in randomness" can impact PV

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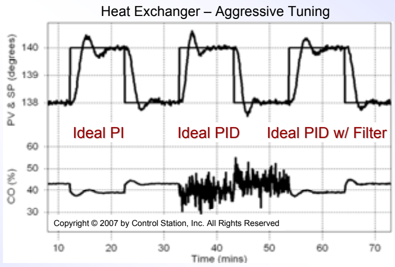
  - *moderate*: τ_C is the larger of $1\tau_P$ *or* $8\,\theta_P$
  - *conservative*: τ_C is the larger of $10\tau_P$ *or* $80\,\theta_P$
- The Internal Model Control (IMC) tuning correlations are:

	Kc	τ_I	τ_D	α
Ideal	$\frac{1}{K_P}\left(\frac{\tau_P+0.5\theta_P}{\tau_C+\theta_P}\right)$	$\tau_P+0.5\theta_P$	$\frac{\tau_P\theta_P}{2\tau_P+\theta_P}$	$\frac{\tau_C(\tau_P+0.5\theta_P)}{\tau_P(\tau_C+\theta_P)}$
Interacting	$\frac{1}{K_P}\left(\frac{\tau_P}{\tau_C+\theta_P}\right)$	τ_P	$0.5\theta_P$	$\frac{\tau_C}{\tau_C+\theta_P}$

Comparing Controller Performance



- IMC tuned ideal algorithm: PI vs PID vs PID w/ CO Filter

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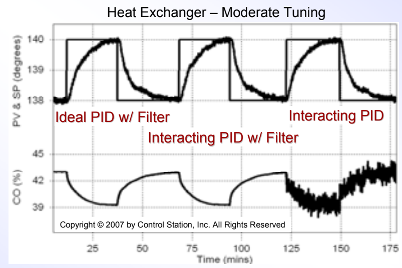
Comparing Controller Performance



- IMC tuned ideal vs interacting algorithm

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