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Guidance on Practice for Control Loop Tuning

GP 30-95

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ENGINEERING TECHNICAL PRACTICES

Foreword

This is the first issue of Engineering Technical Practice (ETP) BP GP 30-95. This Guidance on Practice (GP) is not based on heritage documents from the merged BP companies.

Experience has been drawn from past projects and operations, in both BP facilities and industry worldwide, taking into account lessons learned and good practices.

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1. Scope

This GP provides guidance on control loop tuning, and various methods are illustrated.

2. Symbols and abbreviations

CO	Controller output.
CV	Control variable.
DCS	Distributed control system.
DDE	Dynamic data exchange.
e	Error.
G_p	Process gain.
K_d	Derivative gain.
K_i	Integral gain.
K_p	Proportional gain.
OPC	Object linking and embedded (OLE) for process control.
P	Proportional.
PI	Proportional integral or Process information.
PID	Proportional integral derivative.
PLC	Programmable logic controller.
PV	Process variable.
SP	Setpoint.
STI	Selectable timed interrupt.
T_{au}	Process time constant.
t_d	Process dead time.
T_d	Derivative time.
T_i	Integral time.

3. General

- a. Control loop tuning should be performed for the following benefits:
 1. Increase production by increasing operating efficiency.
 2. Reduce energy costs.



3. Improved product specs.
4. Improve ability to maintain control performance.
5. Decrease Variability.

Typically, proper control loop tuning cuts variability in half. It has been estimated that 80% of process control loops are causing more variability running in Automatic mode than in Manual. If a control loop is running optimally, variability is minimized.

6. Reduce valve maintenance costs, focus maintenance efforts only on problem valves.
 7. Valve movement reduced.
 8. Increased up time.
- b. Control loop tuning should be performed every 6 months. If process conditions change more often it should be performed every 3 months or less as required.
 - c. Control loop tuning should be performed by competent or trained personnel on this practice.
 - d. In a process plant the operator is responsible for the safety of the process and shall be consulted during all operations involving the control system, including controller tuning.
 - e. The PID controller should normally be the first choice for new control loop design.

The PID Controller is a proven industry standard and is well understood. PID is an acronym for Proportional-Integral-Derivative. The PID controller is a feedback controller. Its output, called the controlled variable (CV), is based on the error (e) between the set point (SP), and the measured process variable (PV). The set point may be set by the user or by another controller (as in Cascade Control) or by a process computer (as in supervisory control).

- f. When working with PID loops, make sure the equation being used applies to the specific controller. Manufacturers use many different forms of the PID algorithm. Two common PID forms are shown below:

- a) Independent gains equation:

$$CO = bias + K_p e + K_i \int e dt + K_d \frac{de}{dt} \quad \text{where } e = SP - PV$$

Increasing K_p , K_i , or K_d makes the controller more aggressive.

- b) Dependent gains equation (a.k.a. ISA standard equation):

$$CO = K_p \left(e + \frac{1}{T_i} \int e dt + T_d \frac{de}{dt} \right) \quad \text{where } e = SP - PV$$

Increasing K_p , and T_d makes the controller more aggressive. Increasing T_i makes the controller less aggressive.

- g. PID controllers should be tuned by adjusting K_p (P), K_i or T_i (I), and K_d or T_d (D) to achieve an "optimal" system response. There is no single definition of best tuned that applies to all loops, so no single tuning aid tunes all loops optimally. Process knowledge is always required to determine how fast the loop should be tuned, and what effect or interaction the Controller Output (CO) has on other upstream or downstream processes.

Proportional Gain (or Proportional Band): In either the dependent or independent gains equations shown above, increasing the proportional gain (K_p) makes the controller react more aggressively to deviation from set point. Too much gain and the loop will oscillate and may become unstable. Some controller manufacturers use Proportional Band (PB) instead of gain. PB is usually inversely proportional to the gain, so increasing PB makes this form of the algorithm less aggressive.



Integral Time (or Integral Rate): The integral (sum of the error over time) action drives the error to zero, but also makes the loop less stable. In the dependent gains equation shown above, decreasing the integral time (T_i) makes this form of the PID algorithm more aggressive. The integral time (T_i) is the time it takes the controller to repeat the change in CO due to the proportional gain (K_p). If T_i is too small, the loop may oscillate and become unstable. Conversely, in the independent gains equations shown above, increasing the integral rate (K_i) makes the controller more aggressive. The integral rate is the number of times the controller will repeat the change in CO due to the proportional gain (K_p) per unit time (usually in seconds or minutes). Units for K_i and T_i vary with manufacturers, not based on Independent Gains or Ideal equation.

Derivative Time (or Derivative Gain): In either the dependent or independent gains equations shown above, increasing the Derivative Time (T_d) or the Gain (K_d) makes the controller react more aggressively to deviation from set point. Derivative action adds stability to a loop, but may also amplify noise in the measurement, so the PV should be filtered. Derivative should be used on the PV only (D on PV). If K_d or $K_p T_d$ is too small, the loop will be sluggish. If K_d or $K_p T_d$ is too large, the loop will oscillate and may become unstable.

4. Considerations before tuning

- a. Oscillations: Generally, any time a steady state pattern in the PV and CO over time exists, such as oscillation, the loop should be evaluated for tuning or hardware problems.

If the loop is placed in manual and the pattern persists, the cause is likely another loop upstream.

If an upstream oscillation is slower than the downstream loop response time, the downstream loop may be able to dissipate this oscillation. But if the upstream oscillation is faster than the downstream loop response time, no amount of tuning will enable the downstream loop to dissipate the oscillation.

- b. Response Time: If the loop exhibits a response to a load disturbance or setpoint change that is unacceptable (too slow or too fast), the loop should be retuned. No matter how a loop is tuned, the fastest a loop can settle to a new setpoint or recover from a disturbance is about 10 times the process deadtime. If this is not fast enough for process requirements, the process or control strategy shall be redesigned.
- c. Noise and Valve Movement: Excessive noise (generally 2% or greater) causes the controller to move the valve excessively, and indicates a need for a PV filter.
- d. Loop Gain: If the controller output is normally less than 15% or greater than 85% during the steady state operation the valve is oversized or undersized.

Typically, $1 < G_p < 3$. Where $G_p = \frac{\text{Steady state change in PV}}{\text{Steady state change in CO}} = \frac{\Delta PV, \%}{\Delta CO, \%}$

An oversized valve may degrade control. An oversized valve may also be operating on its seat. A cycling process can result from over-sizing since the control loop is always hunting between the valve resolution or it may be either on the seat or just a little off. The solution to an oversize valve is to change the valve trim or replace the valve with an appropriate size.

An undersized valve may pose a safety problem, since it may not have the range to control the process.

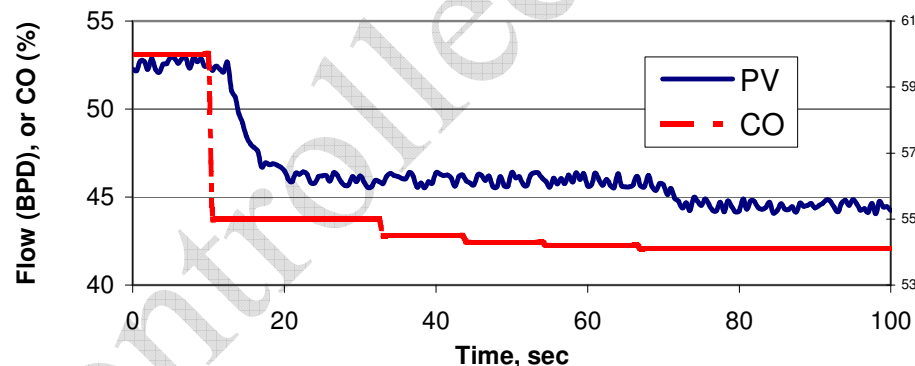
The gain of the loop may also be large if the valve characteristic is incorrect. Maybe the loop gain in this area of the process is too large because the valve is linear and should be equal percentage or vice-versa.



- e. **PV Filtering:** The correct filter on the PV shall be used. For random white noise, a butterworth second order filter is the best choice, but a first order filter works almost as well. For a repeatable disturbance of a known, unchanging period (e.g. mechanical source or wave action), a moving average filter is the best, with a period equal to that of the disturbance period or be a multiple. Filtering adds dead time to a loop when filter time constant is too high. Excessive filtering, while appearing to provide a 'smoother' process, makes the loop less stable. A first order filter value should be no more than $1/5^{\text{th}}$ of the process dead time.
- f. **Valve Stiction:** If a control valve sticks, the loop does not function correctly. This may sometimes be spotted without leaving the control room – in automatic mode a sticky control valve may exhibit a saw tooth pattern on the CO and a square wave pattern on the PV. In manual, the PV may not respond to small changes in the CO. No amount of tuning will remove the square wave – saw tooth oscillation. Options are: accept the cycling, repair the valve, or implement a controller algorithm that stops the integral action within a dead band of the SP.

In many processes, 0,5% stiction is too much. Stiction guarantees cycling and variability. This problem is much more harmful than the other valve problems, such as Hysteresis.

Figure 1 - Stiction Test

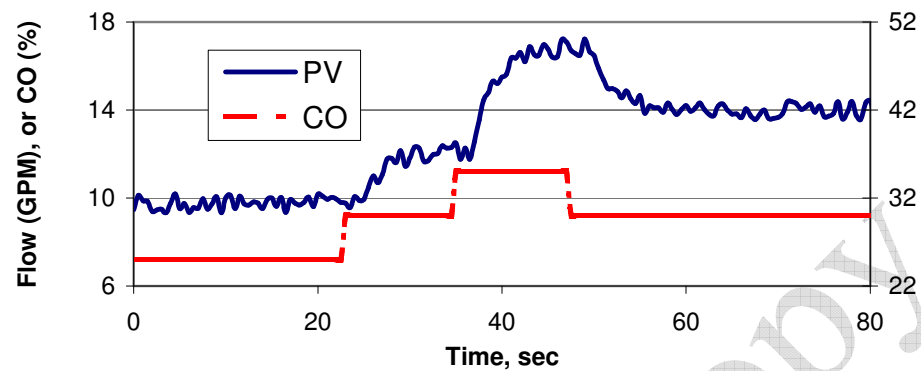


The 1st CO move results in a PV response. Subsequent moves in the same direction, of 0,5%, 0,2%, and 0,1% produce no response. The 4th move of 0,1% produces a response. The stiction is the sum of CO changes that produces no PV response. In this example, the stiction is between 0,8% and 0,9%.

- g. **Valve Hysteresis:** Valves are usually the only mechanical aspect of a loop. Space between connections in mechanical parts leads to hysteresis. This is seen upon a reversal in direction as the parts pass through this space. Hysteresis adds dead time to a loop and makes loop response slower near the setpoint when the loop is settling. Furthermore, Hysteresis induces cycling for an integrating process.



Figure 2 - Hysteresis Test



Hysteresis is seen in a control valve upon reversal of direction. To verify hysteresis, make two CO moves in one direction (up, up, or down, down), then reverse the CO move in the next move. Hysteresis is the difference between the requested CO move and the actual CO move. The latter is obtained from the process gain (Gp) calculated from the 2nd step, and the actual PV movement in the 3rd step. The 1st CO move is done only to take the slack out of the system.

If Hysteresis is more than 1% for valves with positioners or 3% for valves without positioners consider repairing or changing equipment to reduce Hysteresis and improve control. Often, the addition of a valve positioner corrects the problem.

- h. Non Linearity: If the system is operated at different set points, and the ratio of the maximum loop gain to the minimum loop gain is greater than 3 at these different operating points, the loop shall be de-tuned to the worst case (largest gain), or the loop shall be linearised with a valve characteriser (see Section 8.1).
- i. PID Loop Update Time: The correct loop update period shall be used. This is the period that the controller algorithm is executed in a digital system (PLC or DCS). The CO value is calculated at each update time and remains constant until the next update time. A long loop update period adds dead time to a loop and makes the loop less stable. To prevent adding dead time to the process, the loop should be updated no slower than 1/10th of the process dead time. In PLCs, the loop update time shall be programmed according to Section 9.

In practice, many loops, even fast loops such as liquid flow and pressure, are executed a bit slower than this. It is also important that the loop update time be constant. In distributed control systems, this is usually not a concern.

- j. Asymmetric Process: The response to a controller change should be the same whether the CO is increasing or decreasing. If it is not, then the loop is asymmetric. In this case, the loop shall be tuned for the worst case (largest process gain and dead time, the smallest process time constant).

An asymmetric response in liquid flow loops usually indicates a valve problem such as plugged actuator exhaust ports.

5. Tuning with loop analyser software

5.1. General

The intention of this section is to list features available in current loop analyser software to be considered when selecting the optimal tool.

