

Principles of Process Control

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Designed for quick reference and deeper study

1. What Is Process Control?

Aspect	Description
Definition	The use of instrumentation and control strategies to regulate a process so that it operates at a desired setpoint or follows a desired trajectory.
Goal	Maintain product quality, maximize efficiency, ensure safety, and protect equipment.
Typical Industries	Chemical, petrochemical, pharmaceuticals, food & beverage, oil & gas, power generation, water treatment, semiconductor manufacturing.

2. Core Elements of a Control Loop

- Process Variable (PV)** – Measured quantity (temperature, pressure, flow, level, composition, etc.).
- Setpoint (SP)** – Desired value for the PV.
- Controller** – Calculates the corrective action based on the error (SP–PV).
- Final Control Element (FCE)** – Device that implements the corrective action (valve, heater, motor, pump).
- Feedback Path** – Sensor → Controller → FCE → Process → Sensor (closed-loop).
- Feedforward Path** (optional) – Uses measured disturbances to anticipate changes before they affect the PV.

3. Types of Control Strategies

Strategy	Principle	Typical Use
On/Off (Binary) Control	Switches FCE fully on or off based on a deadband around the SP.	Simple heating/cooling, pump start/stop.

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Proportional (P) Control	Output $\propto$ error ($e = SP - PV$).	Reduces steady-state error; may leave residual offset.
Proportional-Integral (PI) Control	Adds integral term to eliminate steady-state error.	Most common for temperature, level, flow.
Proportional-Integral-Derivative (PID) Control	Adds derivative term to anticipate error change.	High-performance processes with fast dynamics.
Cascade Control	Primary loop controls a secondary loop's setpoint.	Temperature control where a flow controller drives the heating rate.
Feedforward Control	Actively compensates for measured disturbances before they affect PV.	Disturbance-prone processes (e.g., inlet composition changes).
Multivariable (MIMO) Control	Simultaneously controls several inter-related PVs.	Complex plants like refineries, pulp-and-paper mills.

4. Fundamentals of PID Tuning

1. Identify Process Dynamics

- Obtain a step response (open-loop) or use a model (first-order plus dead time, FOPDT).

2. Select Tuning Method

- **Ziegler-Nichols** – Fast, aggressive; good for initial settings.
- **Cohen-Coon** – Handles dead time better.
- **Internal Model Control (IMC)** – Provides robustness by explicitly accounting for model error.
- **Auto-tune** – Built-in algorithms in modern DCS/PLC controllers.

3. Tune Parameters

- **K_p (Proportional gain)** – Increases speed, may cause overshoot.
- **T_i (Integral time)** – Reduces steady-state error; too low $\rightarrow$ oscillation.
- **T_d (Derivative time)** – Dampens overshoot; too high amplifies noise.

4. Validate

- Perform setpoint