

General information

Course objective:

- Understand the basic of instrument and control system engineering.
- Tuning the process applying PID tuning method.
- Be capable of reading and understanding the Process Flow Diagram – PFD, Piping and Instrumentation Diagram (P&ID)
- Understand the important drawings which are commonly used in instrument and control engineering.

What does the C&I engineer do?

In project team:

- Control and instrumentation engineers (C&I engineers) are responsible for designing, developing, commissioning and installing a control system (from controllers to instruments and control valves)

In operation team

- C&I engineers are responsible for maintaining the system operable, modify the control logic as required by Production/ Process engineers. C&I engineers also need to do the routine maintenance, and in case of any failure C&I engineers have to troubleshoot or provide a solution to a problem.

Which systems is C&I engineer responsible for?

- Basic Process Control System (BPCS)/ Process Control System (PCS): Distributed control system (controllers, I/O cards, communication cards, servers, historian servers)
- BPCS instrumentation: Pressure, Temperature, Level, Flow, Analysers (Gas Chromatograph, Oil in Water, Hydrocarbon dewpoint analyser, ect.)
- Control Valves, On/Off Valves, Pressure Relief Valves.
- Emergency Shutdown system (ESD)/ Safety Instrumented System (SIS)
- ESD/SIS control system (controllers, I/O cards, communication cards, historian servers, ect.)
- ESD/SIS instrumentation: Pressure, Temperature, Level.
- Shutdown valve, Blowdown valves
- Fire and Gas system (FGS):
- FGS control system (controllers, I/O cards, communication cards, historian servers, ect.)
- Field fire & gas detectors, PAGA system.
- Package control system such as Hypochlorite system, Instrument air system, HVAC system, compressor package, Gas turbine and Generator control system.
- Telecom system

CONTROL SYSTEM BASICS

We have control system in our company for three main reasons:

- Make money by reducing the size, weight and footprint of process equipment, minimizing the effect of disturbances, reducing downtime, optimizing production, controlling better product quality, reducing energy and raw materials, reducing labor cost (by reduce number of people for process control)
- Reduce risk by eliminating human errors, safety improvement 24/24, lowering the emissions.
- Enhance security: reducing human errors, alarming threats, recording history, integration with security systems.

Instrumentation provides various indications used to operate the process. The process measurement is required for control such as flow, level, temperature and pressure.

1. THE CONTROL LOOP

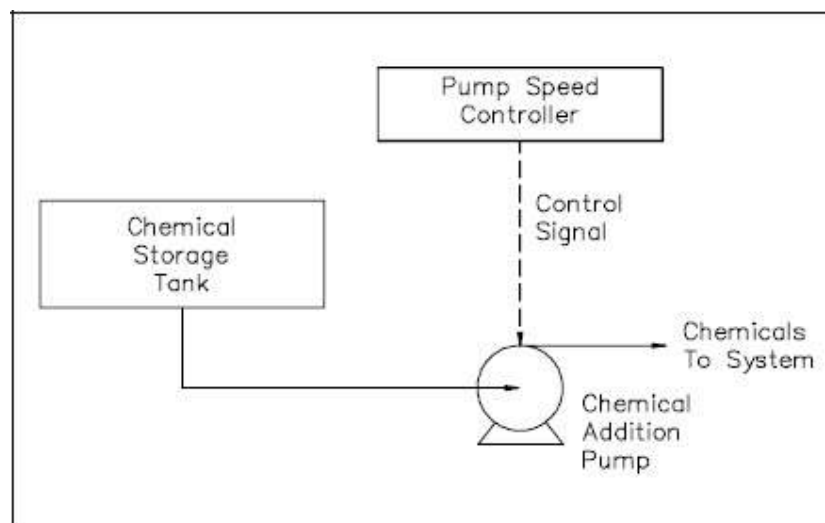
Function of a process control system is to maintain stable operating conditions (flow, temperature, level and pressure) in the process when operating variables such as feed rate, composition, temperature, equipment performance, ect. are changing.

Basic elements of control:

- A process requiring control
- A process measurement
- A controller
- A final control element (control valve, remote on/off valve, shutdown/blown down valve.)

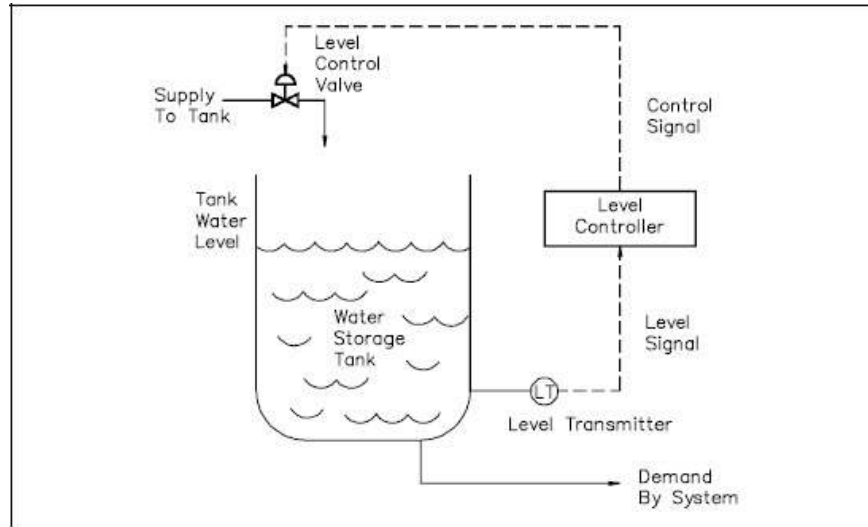
Open loop control

Open control loop is one in which the control action is independent of the output



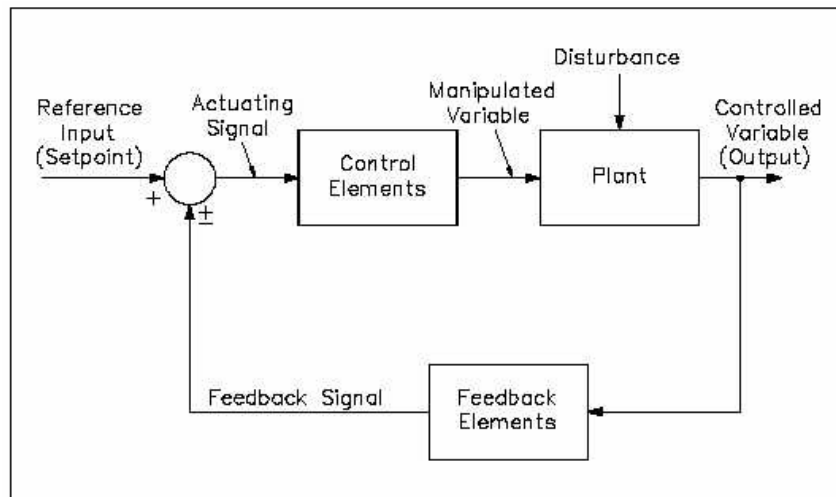
Closed control loop

Closed control loop is one in which control action is dependent on the output

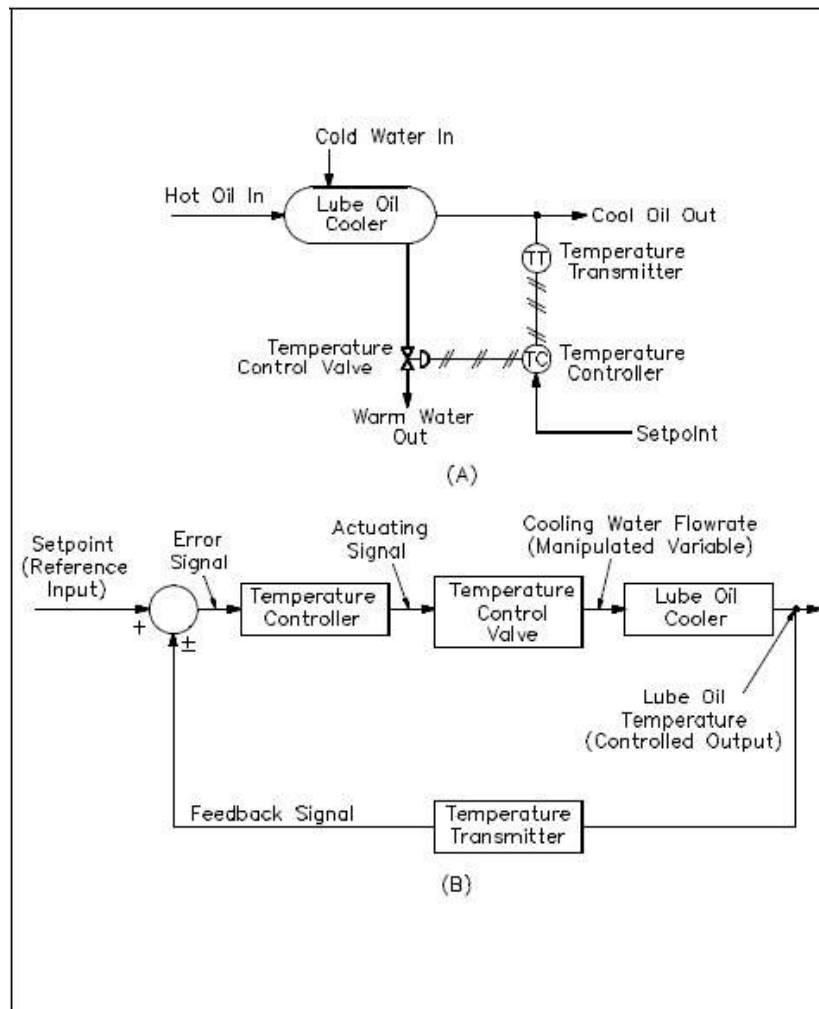


Feedback control loop

Feedback control loop is information in a closed-loop control system about the condition of a process variable. This variable is compared with a desired condition to produce the proper control action on the process. Information is continually "feedback" to the control circuit in response to control action.



Example: Loop Oil cooler and its associated temperature control system



Process time lag:

Process time lag is a term that describes the process delay and retardation, caused by three main factors:

- Capacitance: ability of process to store the energy
- Resistance: opposing the transfer of energy.
- Transportation time: time from one point to another point

Capacitance is the ability of a process to store energy. For example, the walls of the tubes in the lube oil cooler, the cooling water, and the lube oil can store heat energy. This energy-storing property gives the ability to retard change. If the cooling water flow rate is increased, it will take a period of time for more energy to be removed from the lube oil to reduce its temperature.

Resistance is that part of the process that opposes the transfer of energy between capacities. In above example, the walls of the lube oil cooler oppose the transfer of heat from the lube oil inside the tubes to the cooling water outside the tubes.

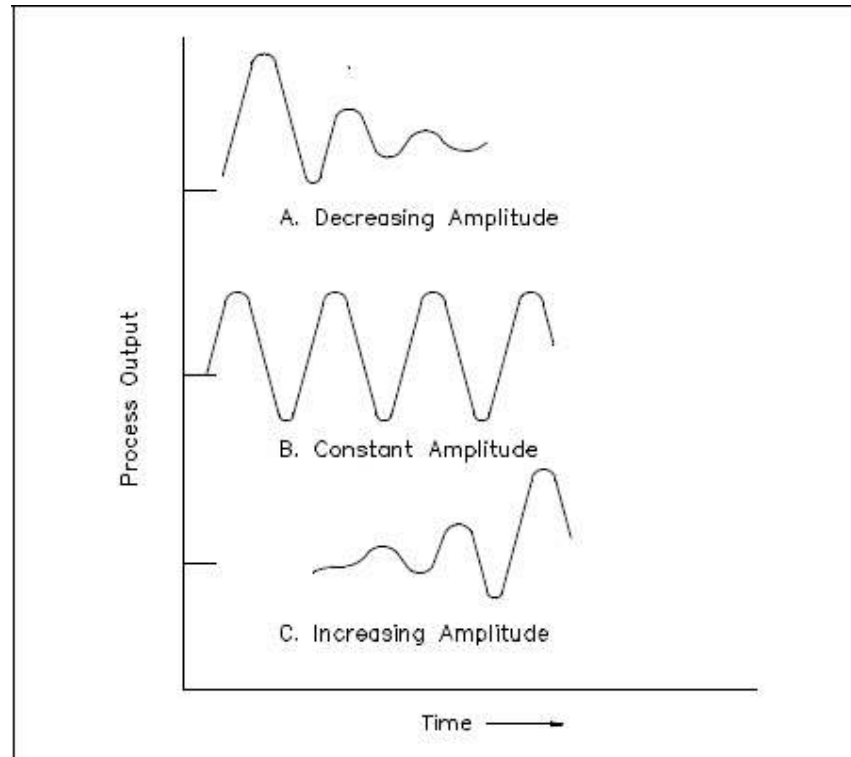
Transportation time is time required to carry a change in a process variable from one point to another in the process. If the temperature of the lube oil is lowered by increasing the cooling water flow rate, some time will elapse before the lube oil travels from the lube oil cooler to the temperature transmitter. If the transmitter is moved farther from the lube oil cooler, the transportation time will increase. This time lag is not just a slowing down or retardation of a change; it is an actual time delay during which no change occurs.

Control loop stability:

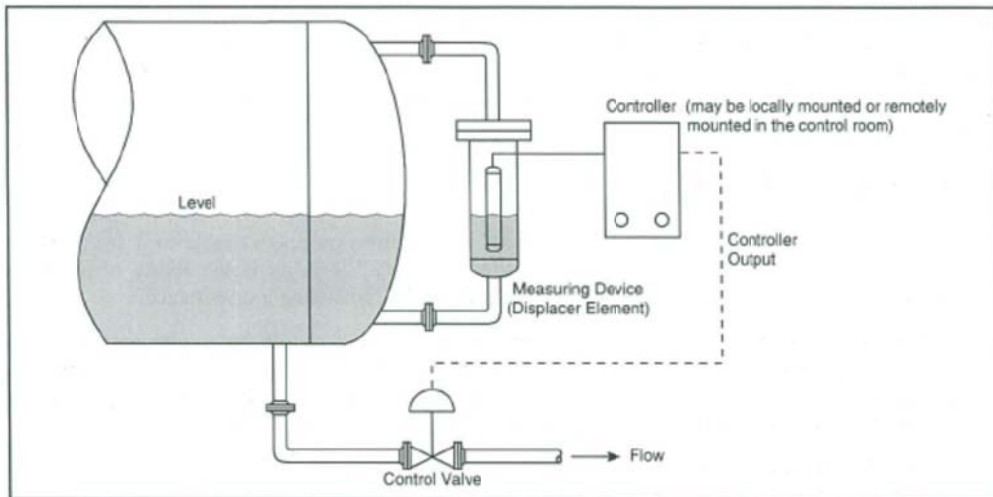
Stable: The amplitude of process variable is decreasing to its desired point (98%) within 4 cycles or less (Figure A)

Conditionally stable: The amplitude of process variable is constant over the period of time. Controlled variable will never reach the desired point.

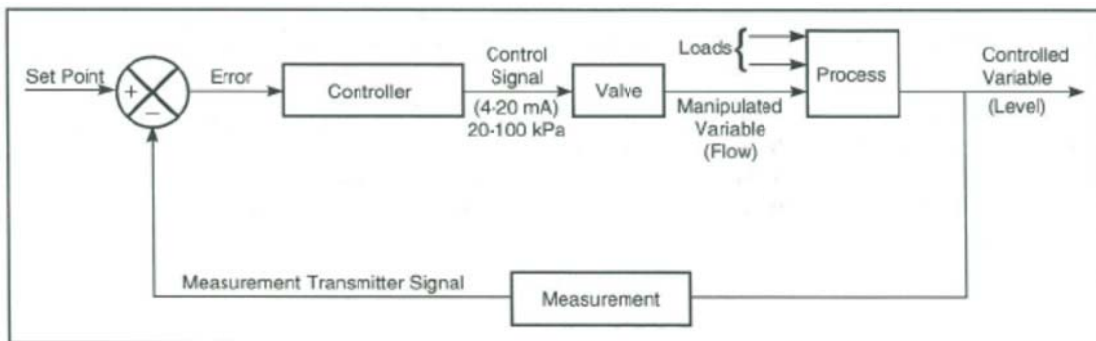
Unstable: the amplitude of process variable is oscillated and increased, consequentially result the out of control process.

**Variables**

Variable is a process condition that can change over time

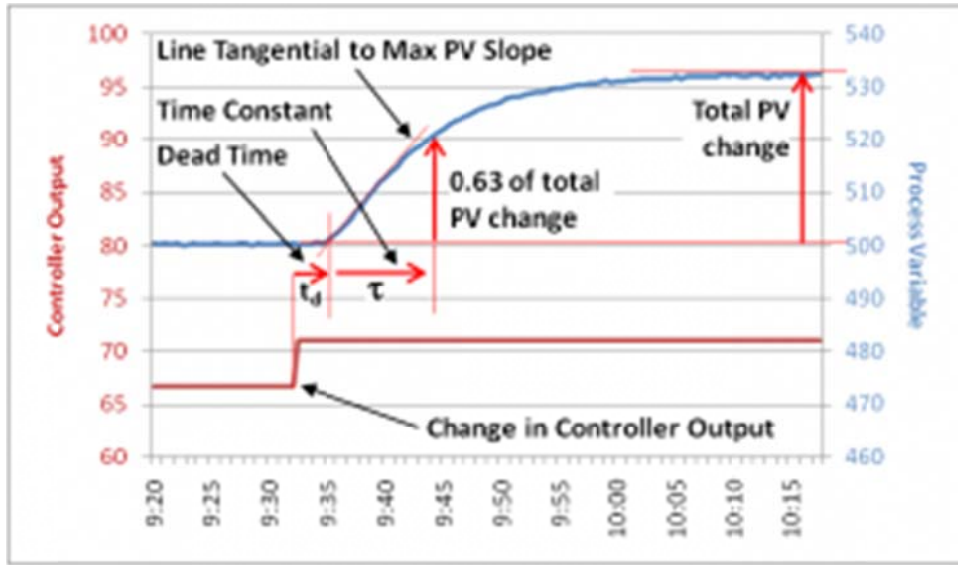


For example, we want to control the level in the tank, this is a level control process. The level will change/ be variable over time because liquid is drained through control valve located at the tank bottom. If we want the level at the specific point, we should manipulate the control valve to maintain the level at setpoint.



System deadtime

Deadtime defined as the time delay between change in the control signal and the beginning of its effect on the measured value of the controlled variables.

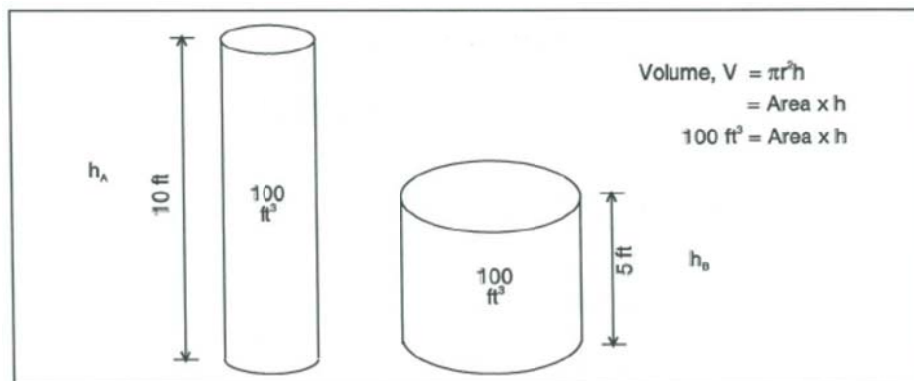


System Capacitance:

Capacitance refers to that portion of the process where energy and/or mass can accumulate. The larger the vessel in relation to the flows, the larger the capacitance and hence the more slowly the controller variables changes for a given change in the manipulated variable. The capacitance of the process tends to reduce disturbances and therefore makes control less difficult.

Process capacitance is measured by Time constant which is calculated from differential equation used to model the process, but approximately is equal to process residence time.

Example: Tank B has larger capacitance than tank A although they are at the same volume.



Understanding the response characteristics of various processes allows control and instrument engineer to design an effective control system including selecting the control method and control valve.

Fluid flow:

- Small capacity

- Negligible deadtime
- RC time constant from 0.1 to 0.5 seconds
- Fast responding process and is therefore subject to noise resulted in instability process

Pressure:

- General large capacity
- Small deadtime
- RC constant is same as flow
- Fast responding process but is somewhat self regulating and large capacity and gas compressibility helps dampen process oscillations making this stable process (low noise/ disturbance)

Liquid level:

- General large capacity
- Small deadtime
- RC time constant is large in atmospheric vessels, and is small in the high-pressure vessels.
- Precise control can be sacrificed for stability. That is, the level can usually oscillate for the sake of maintaining the stable flow.

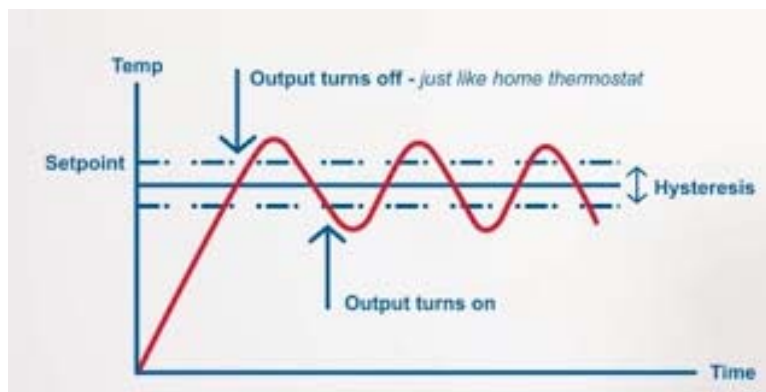
Temperature:

- Large capacity
- Large deadtime
- Long time constant
- Slow to respond to load changes

2. Types of control systems

On/off control

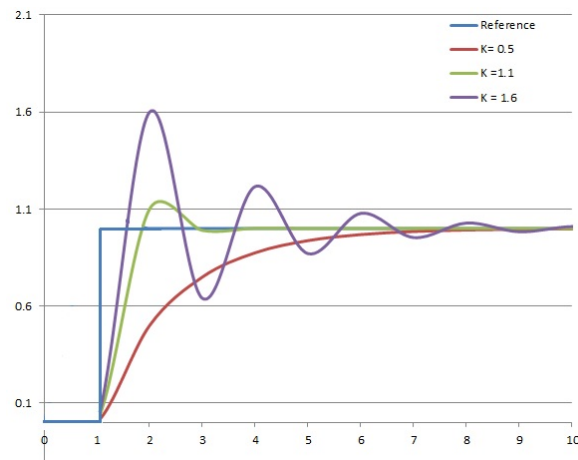
On/off control is simplest of all control modes and easy to understand.



Proportional control

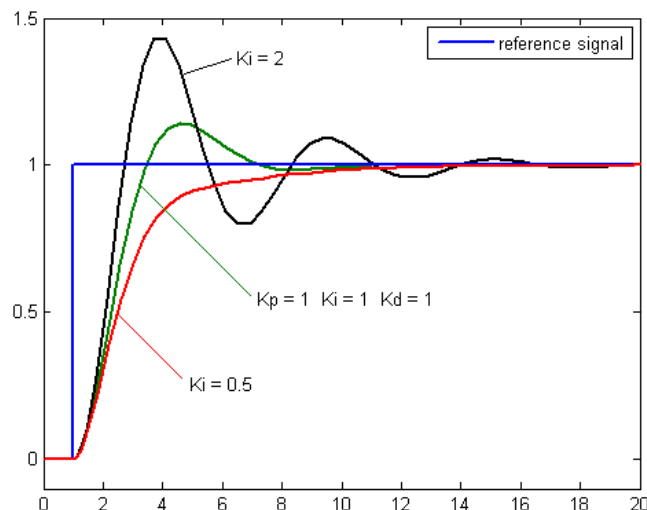
The proportional control mode is in most cases the main driving force in a controller. It changes the controller output in proportion to the error. If the error gets bigger, the control action gets bigger. This makes a lot of sense, since more control action is needed to correct large errors.

The adjustable setting for proportional control is called the Controller Gain (K_c). A higher controller gain will increase the amount of proportional control action for a given error. If the controller gain is set too high the control loop will begin oscillating and become unstable. If the controller gain is set too low, it will not respond adequately to disturbances or set point changes.



Integral (Reset) control

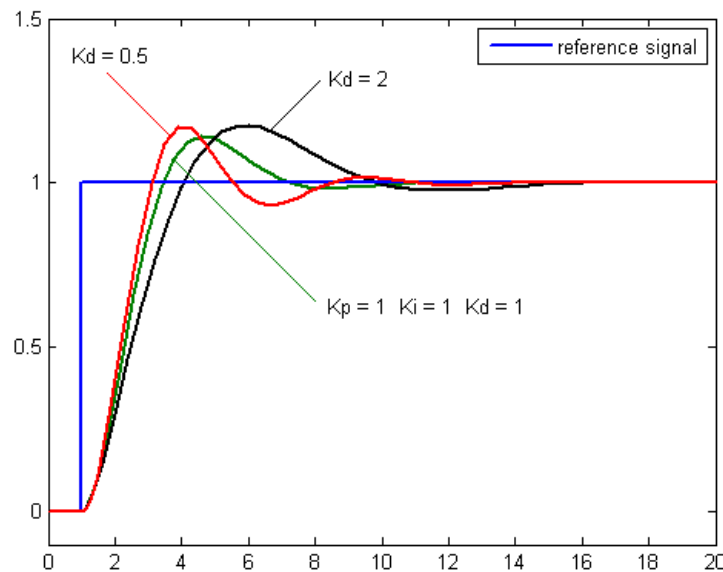
Integral action (reset) is added to the controller to minimize or eliminate the offset. In propositional action, the amount of valve movement is proportional to the error. By contrast, the amount of correction applied with integral action depends both on the magnitude and duration of the error. The prime purpose of reset is, therefore, to prevent offset and keep controlled variable at the control point even as the process load change.



Derivative control

Derivative control can be defined as a crude prediction of the error in future, based on the current slope of the error. Once the derivative mode has predicted the future error, it adds an additional control action equal to $\text{Controller Gain} \times \text{Future Error}$.

For example, if the error changes at a rate of 2% per minute, and the derivative time $T_d = 3$ minutes, the predicted error is 6%. If the Controller Gain, $K_c = 0.2$, then the derivative control mode will add an additional $0.2 \times 6\% = 1.2\%$ to the controller output.



The first point to consider when thinking about using derivative is that a PID control loop will work just fine without the derivative control mode. In fact, the overwhelming majority of control loops in industry use only the proportional and integral control modes. Proportional gives the control loop an immediate response to an error, and the integral mode eliminates the error in the longer term. Hence – no derivative is needed.

On dead-time dominant processes, PID control does not always work better than PI control (it depends on which tuning method you use). If the *time constant (τ)* is equal to or longer than the *dead time (t_d)*, PID control easily outperforms PI control.

PID control in Application

Temperature and Level Loops

Temperature control loops normally have smooth measurements and long time constants. The process variable of a temperature loop tends to move in the same direction for a long time, so its slope can be used for predicting future error. So temperature loops are *ideal candidates for using derivative control* – if needed. Level measurements can be very noisy on boiling liquids or gas separation processes. However, if the level measurement is smooth, level control loops also lend themselves very well to using derivative control (except for surge tanks and averaging level control where you don't need the speed).

Flow Control Loops

Flow control loops tend to have noisy PVs (depending on the flow measurement technology used). They also tend to have short time constants. And they normally act quite fast already, so speed is not an issue. These factors all make flow control loops poor candidates for using derivative control. P+I method is recommended

Pressure Control Loops

Pressure control loops come in two flavors: liquid and gas.

Liquid pressure behaves very much like flow loops, so derivative should not be used, P+I method is recommended.

Gas pressure loops behave more like temperature loops (some even behave like level loops / integrating processes), making them good candidates for using derivative control.

Summary:

Choosing which control mode depends on the application and the process in overall. Here is the control mode versus the application in table:

Control Mode vs Application				
Control Mode	Process Reaction Rate	Load Changes		Application
		Size	Speed	
On-off: Two position with differential gap	Slow	Any	Any	Large capacity temperature and level installations. Storage tanks, hot-water supply tanks, room heating, compression suction scrubber.
Proportional (P)	Slow to moderate	Small	Moderate	Pressure, temperature and level where offset is not objectionable. Kettle reboiler level, drying oven temperature and pressure reducing stations.
Proportional-plus-derivative (rate) P + D	Moderate	Small	Any	Where increased stability with minimum offset and lack of reset wind-up is required. Compressor discharge pressure.
Proportional-plus-integral (reset) P + I	Any	Large	Slow to moderate	Most applications, including flow. Not suitable for batch operations.
Proportional-plus-integral-plus-derivative P+I+D	Any	Large	Fast	Batch control, processes with sudden upset, temperature control.

Typical PID settings

Controller Setting	Likely Minimum	Likely Maximum	Typical Value	Unit of Settings
Flow and Liquid Pressure				
Gain	0.2	1.5	0.5	gain
Integral	0.05	0.5	0.2	minutes
Derivative	0	0	0	minutes
Filter	0	0.2	0.02	minutes
Scan	0.5	2	1	seconds
Inline Temperature				

Gain	0.5	4	1	gain
Integral	0.2	1	0.5	minutes
Derivative	0	0.25	0.1	minutes
Filter	0	0.1	0	minutes
Scan	1	5	2	seconds
Column or Reactor Temperature, Gas Pressure				
Gain	2	10	5	gain
Integral	2	20	5	minutes
Derivative	0	5	1	minutes
Filter	0	0.2	0	minutes
Scan	1	15	10	seconds
Tight Level Control				
Gain	1	10	5	gain
Integral	2	30	10	minutes
Derivative	0	2	1	minutes
Filter	0	0.5	0.2	minutes
Scan	1	5	2	seconds
Surge Tank Level				
Gain	1	4	2	gain
Integral	10	None	60	minutes
Derivative	0	0	0	minutes
Filter	0	1	0	minutes
Scan	5	30	10	seconds
Composition				
Gain	0.1	1	0.5	gain
Integral	10	30	20	minutes
Derivative	2	5	3	minutes
Filter	0	0.5	0	minutes
Scan	10	30	20	seconds

Exercise: Tuning a control loop by using Matrikon Simulator (trial version)

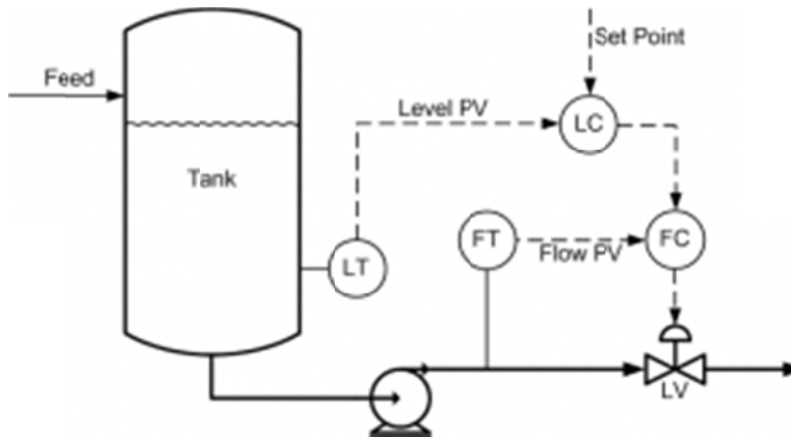
In manual mode:

- Step (pump test) the CO. (up or down)
- Trend PV response and CO
- Compute $G_p(\Delta PV / \Delta CO)$ in %PV/%CO
- Compute t_d (delay time/ dead time)
- Compute τ (time constant - time to 63.2% of total change less deadtime)

3. Control strategy:

Cascade control

In a cascade control arrangement, there are two (or more) controllers of which one controller's output drives the set point of another controller. For example: a level controller driving the set point of a flow controller to keep the level at its set point. The flow controller, in turn, drives a control valve to match the flow with the set point the level controller is requesting.



The controller driving the set point (the level controller in the example above) is called the primary, outer, or master controller. The controller receiving the set point (flow controller in the example) is called the secondary, inner or slave controller.

Cascade control has advantages:

- Loops that correctly employ the cascade architecture respond more effectively to disturbances. This is because the inner loop is both closer to the source of the disturbance and faster than the outer loop. That combination allows the process to correct for upsets more quickly.
- The inner loop helps to correct for nonlinearities such as Stiction that are associated with the control valve.
- A faster inner loop reduces the overall variability experienced by the process. Since the inner loop is able to respond more quickly to disturbances than the outer loop, it reduces the severity of a given disturbance and limits the degree of variability that would otherwise impact the process.

Cascade control has three disadvantages:

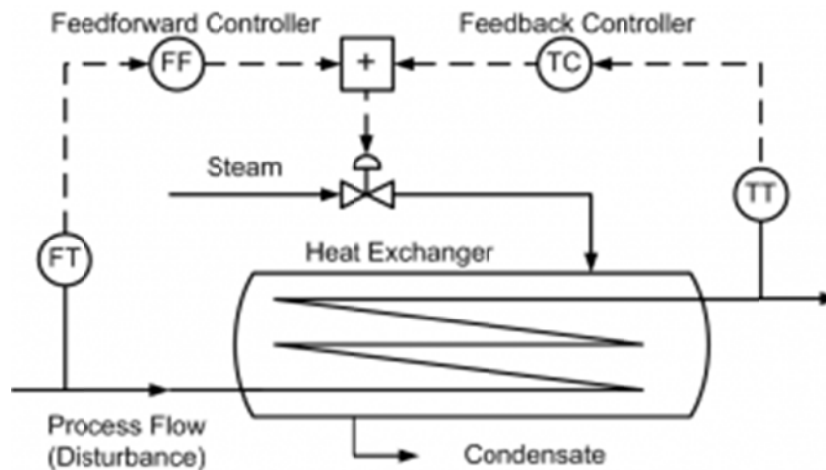
- It requires an additional measurement (usually flow rate) to work.
- There is an additional controller that has to be tuned. And three,
- The control strategy is more complex – for engineers and operators to operate and maintenance

Feedforward

Feedforward control can be used very successfully to improve a control loop's response to disturbances. Feedforward control reacts the moment a disturbance occurs, without having

to wait for a deviation in process variable. If any process control loop is subject to large, measurable disturbances, it can benefit greatly from feedforward control.

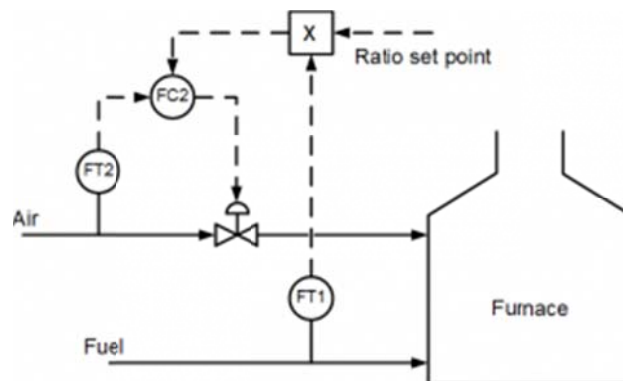
In contrast to feedback control, feedforward control acts the moment a disturbance occurs, without having to wait for a deviation in process variable. This enables a feedforward controller to quickly and directly cancel out the effect of a disturbance. To do this, a feedforward controller produces its control action based on a measurement of the disturbance.



Ratio control

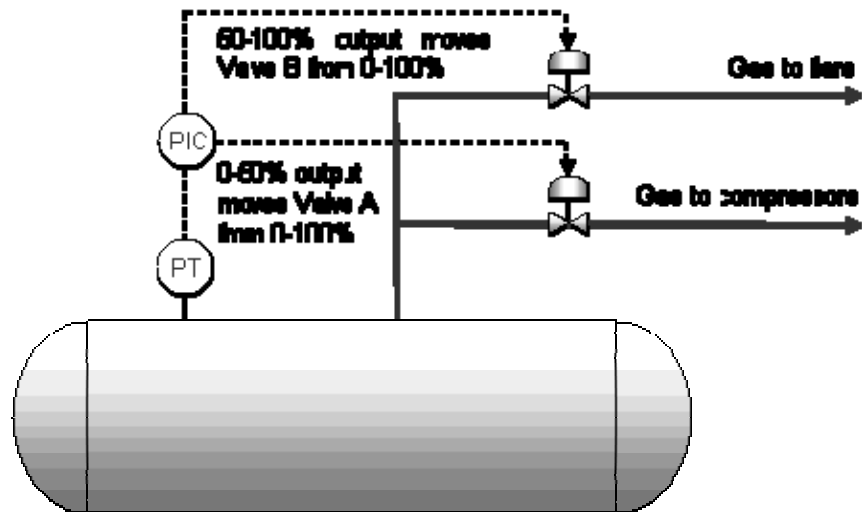
Process design and operations often calls for keeping a certain ratio two or more flow rates. One of the flows in a ratio-control scenario, sometimes called the master flow or wild flow, is set according to an external objective like production rate.

The ratio controller manipulates the other flow to maintain the desired ratio between the two flows. The flow controlled by the ratio controller is called the controlled flow. For example, when treating drinking water with chlorine, the water is the wild flow, and the chlorine is the controlled flow.



Split range control

Split-range control has been widely used in industrial processes for controlling pressure, temperature, and flow, and it is normally used to control a two-mode operation.



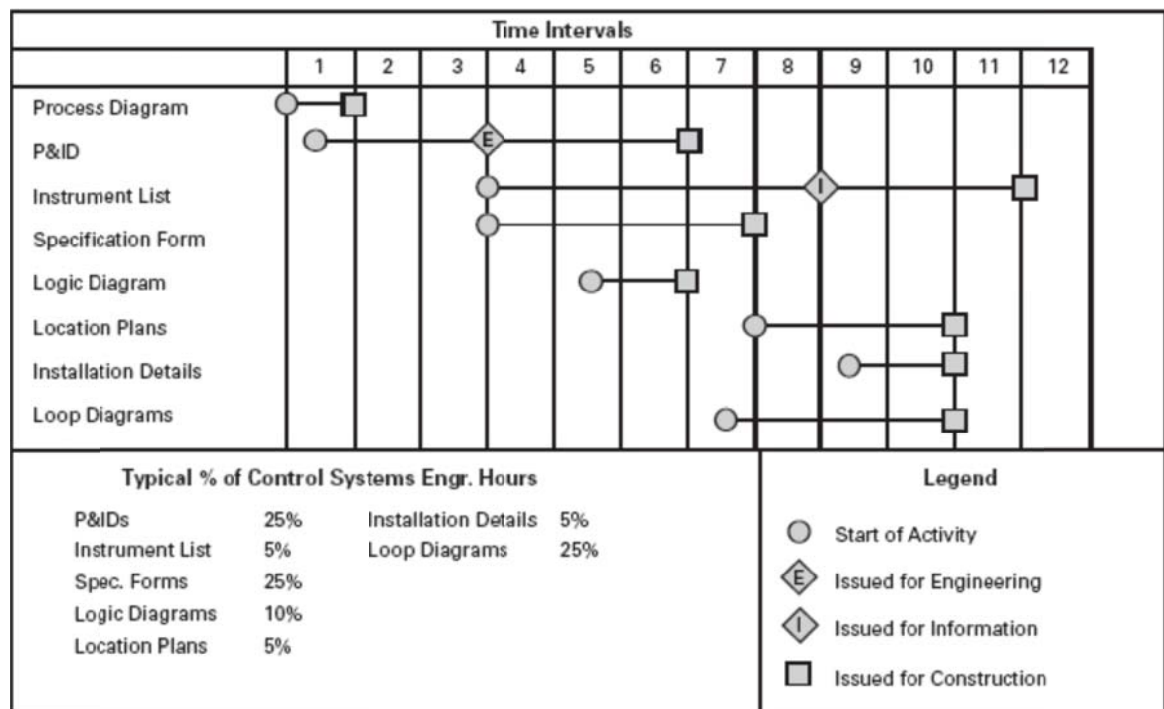
Controller output 0%	Both valves are closed.
Controller output 25%	Valve A is 50% open and Valve B still closed.
Controller output 50%	Valve A is fully open and Valve B closed.
Controller output 75%	Valve A is fully open and Valve B 50% open.
Controller output 100%	Both valves are fully open.

C&I ENGINEERING DOCUMENTATION

There are several documents that C&I engineers have to use in daily work as the following:

- Process Flow Diagrams (PFD)
- Piping and Instrument Diagrams (P&ID)
- Loop Numbering
- Instrument Lists
- Instrument datasheets
- Specification Forms
- Logic Diagrams
- Location Plans (Instrument Location Drawings)
- Installation Details
- Loop Diagrams
- Interconnection Drawings
- Control Narratives
- Standards and Regulations
- Operating Instructions

Below image illustrates a possible sequence for document development. Information from one document is used to develop succeeding documents.



Process Flow Diagram (PFD)

Drawing that shows the general process flow between major pieces of equipment of a plant and the expected operating conditions at the target production rate.

Piping and Instrument Diagrams (P&ID)

Drawing that shows the instrumentation and piping details for plant equipment.

Instrument Lists

The Instrument List (or instrument index) is an alphanumeric listing of all tag-marked components.

Each tag mark will reference the relevant drawings and documents for that device.

Specification and Instrument datasheet

The documents that specify specific requirements in selecting, design the control system and the field instrument based on international or local standards. The requirements of selecting a device should meet the international standard and local standards.

Datasheet is a form which provides details of process information, and specific requirement for procurement of an instrument. Datasheet provides very comprehensive information.

Location Plans (Instrument Location Drawings)

Plans show the location and elevation of control components on plan drawings of a plant.

Installation Details (Hook up drawing)

Installation Details define the requirements to correctly install the tag-marked devices. The Installation Details show process connections, pneumatic tubing, or conduit connections, insulation requirements, and support methods.

Loop Diagrams

Loop diagram shows information of the wiring for one instrument from field to control room. Loop diagram is commonly used by Instrument engineers as it help them to carry out loop check.

Reference of International and Local Standards.

ANSI (American National Standards Institute)

ANSI MC96.1	Temperature Measurement Thermocouples
ASME PTC 19.3 TW-2010	Thermowell Stress Calculation

AGA (American Gas Association)

AGA Report 3	Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids
AGA Report 9	Measurement of Gas by Multi-path Ultrasonic Meters

API (American Petroleum Institute)

RP 14C	Analysis, Design, Installation and Testing of Basic Surface Safety Systems on Offshore Production Platforms
PR 14G	Recommended Practice for Fire Prevention and Control on Open Type Offshore Production Platforms
PR 14J	Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities
MPMS 12.2	Manual of Petroleum Measurement Standards, Chapter 12, Section 2, Calculation of Liquid Petroleum Quantities Measured By Turbine or Displacement Meters
MPMS 14.3	Manual of Petroleum Measurement Standards, Chapter 14, Section 3, Orifice Metering of Natural Gas and other Related Hydrocarbon Fluids (AGA Report No. 3; ANSI/API 2530)
RP 505	Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, and Zone 2
RP 520	Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries, Parts I and II
RP 521	Guide for Pressure-Relieving and Depressurizing Systems
RP 526	Flanged Steel Pressure Relief Valves
RP 527	Seat Tightness of Pressure Relief Valves
RP 551	Process Measurement Instrumentation
RP 552	Transmission Systems

RP 554	Process Instrumentation and Control
RP 555	Process Analyzers
RP 574	Inspection Practices for Piping System Components
STD 598	Valve Inspection and Testing
STD 607	Fire Test for Soft-Seated Quarter-Turn Valves
STD 2000	Venting Atmospheric and Low-Pressure Storage Tanks, Non-Refrigerated and Refrigerated
API-1101	Measurement of Petroleum Liquid Hydrocarbons by Positive Displacement Meter
API-2531	Manual of Petroleum Measurement Standards, Mechanical Displacement Meter Provers

ASME (American Society of Mechanical Engineers)

ASME Section VIII	ASME Boiler and Pressure Vessel Code, Section VIII Pressure Vessels, Division I - Rules for Construction of Pressure Vessel
ASME B1.13M	Metric Screw Threads: M Profile

CFR (Code of Federal Register)

Section 30, 250, Subpart H	Production Safety Systems
----------------------------	---------------------------

IEC (International Electrotechnical Commission)

IEC 60028	International Standard of Resistance for Copper
IEC 60079-0~20	Electrical Apparatus for Explosive Gas Atmospheres
IEC 60085	Electrical Insulation - Thermal Evaluation & Designation
IEC 60092	Offshore & Marine Cables
IEC 60189	Low-frequency cables and wires with PVC insulation and PVC sheath
IEC 60227	PVC Insulated Cables of Rated Voltages up to and Including 450/750V
IEC 60228	Conductors of Insulated Cables
IEC 60331	Characteristics of Fire Resistant Cables
IEC 60332	Characteristics of Flame Retardant Cables
IEC 60344	Guide to the Calculation of DC Resistance of Plain and Coated Copper for Low Frequency Cables and Wires

IEC 60529	Classification of degree of protection provided by enclosure
IEC 60754	Test on Gases Evolved During Combustion of Materials from Cables
IEC 60811	Common Test Methods for Insulating and Sheathing Materials of Electric and Optical Cables
IEC 60885	Electrical Test Methods for Electric Cables
IEC 60751	Industrial Platinum Resistance Thermometer Sensors
IEC 60446	Basic and safety principles for man-machine interface, marking and identification – Identification of conductors by colors or alphanumeric
IEC 61000	Electromagnetic Compatibility-Testing and Measurement
IEC 61034	Measurement of Smoke Density of Cables Burning Under Defined Conditions
IEC 61131-3	Programmable Controllers - Programming Languages
IEC 61508	Functional safety of Electrical/ Electronic Programmable Electronic Safety-related Systems
IEC 61511	Safety Instrumented Systems for the Process Industry Sector
IEC 61892	Mobile and fixed offshore units – Electrical installations
IEC 61892-4	Mobile and fixed offshore units - Electrical installations - Part 4: Cables
IEC 61892-7	Mobile and fixed offshore units - electrical installations - hazardous areas
IEC 62061	Safety of Machinery- Functional Safety of safety related electrical, electronic and programmable electronic control systems
IEC 62444	Cable Glands for Electrical Installations

ISA (International Society for Measurement and Control)

RP3.2	Flange Mounted Sharp Orifice Plates for Flow Measurement
ANSI/ISA-5.1	Instrumentation Symbols and Identification
ANSI/ISA-5.2	Binary Logic Diagrams for Process Operations
ISA-5.3	Graphic Symbols for Distributed Control/Shared Display

	Instrumentation, Logic and Computer Systems
ANSI/ISA-5.4	Instrument Loop Diagrams
ANSI/ISA-7.0.01	Quality Standard for Instrument Air
ANSI/ISA-18.1	Annunciator Sequence and Specifications
ISA-20	Specification Forms for Process Measurement and Control Instruments, Primary Elements and Control Valves
ISA-RP31.1	Specification, Installation, and Calibration of Turbine Flowmeters
ISA-RP60.6	Nameplates, Labels and Tags for Control Centres
ISA-RP60.8	Electrical Guide for Control Centres
ISA-RP60.9	Piping Guide for Control Centres
ANSI/ISA-75.11	Inherent Flow Characteristics and Rangeability of Control Valves
ANSI/ISA-84.01	Application of Safety Instrumented Systems for the Process Industries
NACE (National Association of Corrosion Engineers)	
MR0175-2000	Sulphide Stress Cracking Resistant-Metallic Materials for Oilfield Equipment
NFPA (National Fire Protection Association)	
NFPA 70	National Electrical Code (NEC)
NFPA 72	National Fire Alarm and Signaling code
NFPA 496	Purged and Pressurized Enclosures for Electrical Equipment
ISO (International Organization for Standardization)	
ISO 3864	Safety Colour and Safety Sign
SOLAS	
SOLAS	International Convention for Safety Of Life at Sea
Vietnamese Standards	
TCVN 6171: 2005	Fixed Offshore Platforms: Technical Supervision and Classification
TCVN 6767-2: 2000	Fixed Offshore Platforms, Part 2: Fire Protection, Detection and Extinction

TCVN 6767-3: 2000	Fixed Offshore Platforms, Part 3: Machinery and Process Systems
TCVN 6767-4: 2000	Fixed Offshore Platforms, Part 4: Electrical Installations