**BASIC CONTROL LOOPS**

**Introduction**
Process control refers to the regulation of a process variable so as to maintain a desired output level. The goal of process control instrumentation is to measure, monitor, and or control a process. For thousands of years, processes were controlled manually by humans with the necessary skills. A person or group of persons observed the process; determined the control actions required, and manipulated the variable or variables necessary to achieve satisfactory product. Due to the subjective nature of this control mechanism, the product quality varied widely and overall efficiency was often poor. Modern production systems use automatic control systems where control is carried out with minimal or without human intervention. Control processes use basic elements that include a sensor (primary element), controller, transmitter, and a final element. Product quality is high and consistent and the overall process efficiency is often near optimum. The role of a process technician in industrial production today is mainly to monitor and maintain automated processes.

**Control System Types**
Control processes use basic elements that include a primary element, controller, transmitter, and a regulator or a final element. Fig.1 and Fig. 2 show these basic elements. There are two basic types of control loops, namely open-loop and closed-loop systems.

**Open-Loop Control System**
Fig. 1 shows an open-loop control system. This system incorporates two control elements consisting of controller and a regulator. The regulator is used in a generic sense, being able to alter the input variable in response to the signal from the controller. Regulator does not mean a specific type of actuator or control valve. An open loop system has no feedback or feed forward mechanism, so the input and output signals are not directly related. Timed controllers can operate the regulator in an open control system. The controllers can operate the regulators at regular intervals, but there is no assurance that the output variable can be maintained at the desired level.

![Open-Loop control diagram](image)

**Fig. 1 Open-Loop control diagram**

![Feedback closed-Loop control diagram](image)

**Fig. 2 Feed back closed-Loop control diagram**
Closed-Loop Control System

Fig. 2 shows a closed-loop control system. This system incorporates all the basic control elements of the primary element (sensor), transmitter, controller and the final control element or regulator. The sensor is used to capture a process variable. The process variable is sent to a transmitter which translates the variable to the controller. The controller examines the information with respect to a desired value and initiates a correction action if required. The controller then communicates to the regulator what action is needed to ensure that the output variable value is matching the desired value. A closed-loop control system has the ability to automatically drive the system so as to eliminate a difference between an output level and the desired level. Therefore there is a high degree of assurance that the output variable can be maintained at the desired level.

Closed-loop control system can be a feedback or a feed forward system. Fig. 2 is a feedback closed-loop system. In this system, the measured process variable is an output variable of the process. This variable value is fed backward and used to initiate a corrective action on a regulator. A feedback closed loop system has a feed-back mechanism that directly relates the input and output signals. The feed-back mechanism monitors the output variable and determines if additional correction is required. In a feedback control system, the regulator may be conceived as behind the sensor. This is not always in a physical sense, though in many situations, the regulator can be physically behind the sensor. Most control loops in the industry are of the feedback type.

The other type of a closed-loop control system is a feed forward. In this system, the measured process variable is an input variable. The measured signal is then used in the same fashion as in a feedback system. In this situation, the regulator may be conceived as being in front of the sensor. This is not always of course in a physical sense, though it could be. Fig. 3 shows a feed forward control system.

![Feed forward control loop](image)

**Fig. 3: Feed forward control loop**

**Loop or Tag Numbers**

Control loops show instruments symbols that are combinations of balloons, lines, letters, and numbers in a shape called a balloon. The letters appear at the top of the balloon and identify the type and function(s) of the instrument. The numbers are located at the bottom of the balloon and identify the loop or tag number for the instrument. An instrument loop groups all instruments monitoring and controlling a process variable into one control unit. The tag number identifies all the instruments in a loop. Equipment may have several loop numbers associated with it if more than one process variable must be controlled for proper functioning. Minimum size of balloon is about 10mm (3/8”). Allow adequate space for symbols and notes. In all cases, diagrams must the neat and legible. Tag numbers should be horizontal. Fig. 4 shows an example of an instrument symbol. The instrument is a flow element and the loop number is 150.

![Instrument symbol](image)

**Fig. 4: Instrument symbol**


Basic Control Loops

Basic control loops are control loops for the common process variables of temperature, pressure, flow, level, and analysis. The main difference in basic control loops is the sensor. This is determined by the variable being measured. Consequently, temperature element (TE), pressure element (PE), temperature element (TE), level element (LE), and analysis element (AE) are specific to process variables of interest.

Temperature Control Loop

Fig. 5 shows a temperature control loop. Temperature measurements are taken in furnaces, reactors, boilers, heat exchangers, etc. or from the exiting charge from the equipment. Thermocouples and RTDs are the common temperature sensors (TEs). The TEs are linked to TTs that send signals to the other instruments.

Pressure Control Loop

Fig. 6 shows a pressure control loop. Pressure measurements are taken in pumps, compressors, furnaces, reactors, boilers, heat exchangers, etc. or from the connecting piping to or from the equipment. Pressure sensors (PEs) are typically expansion-type pressure gauges such as the bourdon gauge. The PEs are linked to PTs that send signals to the other instruments.

Flow Control Loop

Fig. 7 shows a flow control loop. Flow control loops start at the flow element (FE). This may be an orifice, venturi, nutating, etc. meter. The orifice meter is the most common flow meter. The FEs are linked to FTs that send signals to the other instruments.

Level Control Loop

Fig. 8 shows a level control loop. Level control loops start at the level element (LE). This may be a DP cell or other level sensor. LEs are linked to LTs that send signals to the other instruments.

Analysis Control Loop
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Fig. 9 shows an analysis control loop. The analysis control loops start at the analysis element (AE). This may be able to sense the pH, PPM (parts per millions), concentration, etc of a process variable. For instance, cooling towers require close monitoring of pH and PPM. AEs are linked to ATs that send signals to the other instruments.

Cascaded Control Loop
Cascaded control loops use controllers from at least two control loops. One of the controller acts as the primary controller while other is the secondary controller. Typically, the output of the primary controller is fed into the second control loop. Fig. 10 shows a cascaded control loop. The primary control loop is a temperature control loop while secondary control loop is a flow control loop.

Fig. 9: Analysis control loop

Fig. 10: Cascaded control loop

Fig. 11 shows the two basic types of control loops, namely feedback and feed forward loops.

Fig. 11: Control loop types
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Fig. 12 shows some instruments in a pipe run. Several instruments may be mounted on a pipe branch. Instruments shown include flow valves, pressure valves and gauges, thermometers, level indicators, etc.

Fig. 12: Pipe run instrumentation
**Process Instrument Types**

An instrument is a device that can measure, display, monitor, and or control a process variable. These include measurement or sensing instruments, display devices, controllers, transmitters, and valves. A measuring instrument determines the size of a process variable. Fig. 1 shows a process control loop with basic instruments. Sensors and transmitters are the common measuring instruments in piping systems. According to their functions, instruments may be classified as sensors, transducers, transmitters, controllers, regulators, recorders, alarms, and indicators.

**Transducer**

A transducer is a device that converts one form of energy to another. Transducers are used extensively in control systems and are often integral part of sensors and transmitters. Common transducers are pneumatic-current (P/I) or current-pneumatic (I/P) and voltage-pressure (E/P) transducers.

**Transmitter**

Transmitters are devices that condition a measured process variable into a standard signal range. Common control signals are pressure, voltage, and current. The standard pressure range is 3 – 15 psig; the standard voltage range is 1 - 5 V DC; and the standard range of current is 4 – 20 mA DC. Transmitters sometimes function as transducers and send signals to the controllers, recorders, indicators, and alarms.

**Controller**

The controller uses the control or error signal to drive the final control element. It is the brain or decision maker in a control loop. It incorporates a comparator, a device that compares the output value with the reference value and generates an error signal. The error signal may be a voltage signal, electrical current, air pressure, etc. The error signal may be amplified before being applied to the final element. Controllers have built-in algorithms that determine the corrective action required by the final control element. Controllers send signals to final control elements.

**Regulator**

The regulator is also called the final control element. It uses the control signal from the controller to regulate the control variable so as to minimize or eliminate the error signal. Examples of final elements are control valves, variable-speed drives, relays, pumps, and dampers.

**Indicator**

An indicator is a device that displays the current value of a process variable. The display may be on a scale in analog or digital form. Digital display is gradually replacing analog display. Sometimes indicators are integrated with sensors, transducers, recorders, and controllers. Indicators normally receive input from transmitters or sensors.

**Alarm**

An alarm is a device that produces a signal such as light or sound when a process variable value is out of permissible range. Alarms normally receive input from transmitters, sensors, or controllers.

**Recorder**

A recorder is a device that records the current value of a process variable. The record could be on paper, on computer screens, and electronic storage devices. Recorders normally receive input from transmitters or sensors.