Westinghouse Technology Systems Manual

Section 1.3

Instrumentation and Controls

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1.3 INSTRUMENTATION AND CONTROLS

Learning Objectives:

1. Describe the types of sensing instruments used to sense pressure, temperature, and flow.

2. Explain how the properties of pressure, temperature, and flow are converted into electrical outputs.

3. Explain how the following controllers respond to a step change and ramp change in input:

   a. Bistable,
   b. Proportional,
   c. Proportional plus integral, and
   d. Proportional plus derivative.

4. Explain the input and output relationships of the standard logic circuits.

1.3.1 Introduction

This section addresses the detection of process variables and the conversion of these measured values into electrical or pneumatic signals. These signals will then be used for indication and control functions. The basic controllers used in power plant control systems will be discussed including their response to various input signals. In addition, a brief discussion of simple logic circuits will conclude this section.

1.3.2 Pressure Sensing Instruments

Pressure, defined as force per unit area, is one of the measured and controlled properties. Pressure measurements range from the high pressure of the reactor coolant system measured in pounds per square inch (psi) to the vacuum in the main condenser measured in inches of mercury (in. Hg). The devices listed in this section are used for the measurement of system pressure.

1.3.2.1 Bourdon Tube

The simple bourdon tube, shown in Figure 1.3-1, consists of an oval tube rolled into an arc of a circle. One end is open to the process variable to be measured and the other end is closed. The surface area on the outer portion of the arc is larger than the surface area of the inner portion, and when pressure (force per unit area) is applied, the tube tends to straighten out very slightly. If the pressure is removed, the elasticity of the tube causes it to return to its original shape. The pressure of the fluid is converted to a mechanical motion by the bourdon tube. This motion can be converted into an electrical or pneumatic signal, or can drive a pointer on a local indicating gage for measurement of the applied pressure. The helical element, shown in Figure 1.3-2(b), is a variation of the simple bourdon tube. It is similar to the bourdon tube except that it is wound in the form of a spiral containing four or five turns. The helical element amplifies the movement of the closed end of the bourdon tube. The spiral type of measuring element is a second modification (Figure 1.3-2(a)) of the bourdon element. It is a thin-walled tube that has been flattened on opposite sides to produce an approximately elliptical cross section. The tube is then formed into a spiral. When pressure is applied to the open end, the tube tends to uncoil.

1.3.2.2 Bellows Pressure Sensor

The bellows pressure sensor, shown in Figure 1.3-3(a), is made up of a metallic bellows enclosed in a shell, with the shell connected to a pressure source. Pressure acting on the outside of the bellows compresses the bellows and moves its free end against the opposing force of the spring. A rod attached to the bellows transmits this motion to the pressure transmitter.

1.3.2.3 Diaphragm Pressure Sensor

The diaphragm pressure sensor, shown in Figure 1.3-3(b) consists of a metallic diaphragm (rigidly supported at each end), a spring, and a force bar that is connected to the diaphragm. When pressure is applied, the diaphragm moves in opposition to the spring, which causes motion of the force bar. When pressure is removed, the elasticity of the diaphragm and action of the spring return the sensor to its zero pressure condition.

1.3.2.4 Mechanical to Electrical Signal Conversion

In the sensors described above, the application of pressure results in a mechanical signal. Two devices are available for the conversion of this mechanical signal into an electrical signal that can be used in the plant control or protection systems. The use of one device, the force balance transmitter, results in a current (milliampere, ma) output; the use of the other device, the movable core transformer transmitter, results in a voltage output.

Force Balance Transmitter

Force balance refers to the system whereby the free motion of the sensor is limited and actively opposed by some mechanical or electrical means. In Figure 1.3-4 a simplified force balance transmitter is shown. As pressure increases, the diaphragm is moved to the left. This motion, in turn, causes movement of the force bar (the force bar is pivoted at the sealed flexure). The force bar motion causes movement of the reference arm, which closes the gap between the error detector transformer coils and the ferrite disk attached to the reference arm. When the gap of the error detector becomes smaller, the magnetic coupling between the transformer coils increases, increasing the output of the error detector transformer. The output of the error detector is amplified and applied to the force feedback coil. The increased current in the force feedback coil exerts a greater pull on its armature moving the reference arm in the opposite direction, thus restoring the system balance. The amount of current required to maintain the system in balance is proportional to pressure and, therefore, can be used in the indicating and control loops. Two current ranges, 4 to 20 ma or 10 to 50 ma, are generally used for this transmitter's output circuitry.

Movable Core Transmitter

In the movable core transmitter, show in Figure 1.3-5 the pressure sensor's mechanical linkage is connected to the core of a linear variable differential transformer (LVDT). The LVDT consists of a primary coil and two secondary coils. The movement of the core changes the magnetic flux coupling between the primary coil and the secondary coils which, in turn, causes a change in the voltage output of the secondary coils. The secondary coils are connected in series opposition so that the two voltages in the secondary circuit have opposite phases. With the core in the center position of the transformer, the voltage output is zero. This will give a normal voltage range of -10 to 0 to +10 v.

Variable Capacitance Transmitter

Another type of transmitter is being installed at nuclear power plants currently under construction. This type of transmitter is called a variable capacitance transmitter (see Figure 1.3-6) and consists of a set of parallel capacitor plates with a sensing diaphragm placed between the plates. The capacitor is filled with silicon oil. The need for a pressure-sensing element, such as a bellows or bourdon tube, and its mechanical linkage has been eliminated by connecting the process fluid to a separate isolating diaphragm. One side of the isolation diaphragm is in contact with the process stream, while the other side is in contact with the silicon fill oil. When pressure is applied to the isolating diaphragm, the force is transmitted through the silicon oil to the sensing diaphragm causing it to deflect. The deflection of the sensing diaphragm is detected by the capacitor plates. The change in capacitance, because of sensing diaphragm deflection, is converted to a 4-to-20-ma output that is transmitted to the plant protection and/or control systems.

1.3.3 Flow Sensing Instruments

Selected pressure detection devices may be used to provide a reliable measurement of process flow. To measure flow in this, manner, a differential pressure (ΔP) is created by some type of primary device, such as an orifice plate, a flow nozzle, or a flow venturi. Flow rate measured in this manner is proportional to the square root of the ΔP. The ΔP is sensed and converted from a mechanical movement to an electrical signal for flow measurement.

1.3.3.1 Primary Devices

Orifice Plate

The orifice plate, Figure 1.3-7(a), in its most common form, is merely a circular hole in a thin, flat plate that is clamped between the flanges at a joint in the system piping. The orifice plate is inexpensive and accurate, but as shown in Figure 1.3-7(a) it has poor pressure recovery.

Flow Nozzle

The flow nozzle, Figure 1.3-7(b) provides better pressure recovery (i.e., less pressure loss) than the orifice plate. It consists of a rounded inlet cone and an outlet nozzle.

Flow Venturi

The flow venturi, Figure 1.3-7(c), has the best pressure recovery characteristics and is used in those systems where a high-pressure drop across the primary element is undesirable. The venturi consists of rounded inlet and outlet cones connected by a constricted middle section. As the velocity increases in the constriction, the pressure decreases. A pressure tap is provided in this low-pressure area.

1.3.3.2 Bellows Flow Sensor

The bellows flow sensor (Figure 1.3-8) consists of two bellows: one that senses the high side (inlet) pressure of the primary device and another that senses the low side (outlet) pressure of the primary device. The difference in force exerted by the two bellows is proportional to the differential pressure developed by the primary element. A mechanical connection is made to the force bar of the force balance transmitter or the core of the movable core transformer (Paragraph 1.3.2.4) to convert the differential pressure signal to an electrical signal. Since the flow rate is proportional to the square root of the ΔP, a square root extractor circuit is required to convert the electrical output into flow indication.

1.3.3.3 Diaphragm Flow Sensor

Again, the principle of opposing forces created by the differential pressure across the primary device is used to sense flow with the diaphragm flow sensor (Figure 1.3-9). The displacement of the diaphragm causes motion of the force bar of the force balance transmitter or the core of the movable core transformer (Paragraph 1.3.2.4) and converts the ΔP signal to an electrical signal. A square root extractor is again required. The majority of the flow transmitters in the plant use diaphragm flow sensors.

1.3.3.4 Magnetic Flow Sensors

Unlike the previous flow sensors discussed in this section, the magnetic flow sensor (Figure 1.3-10) does not require a primary element. The magnetic flow transmitter works on the principle that voltage can be generated if relative motion exists between a conductor and a magnetic field. The liquid is used as the conductor. The flow transmitter generates the magnetic field, and the flow of the liquid provides relative motion. Electrodes located in the piping detect the generated voltage.

1.3.4 Level Sensing Instruments

Most measurements of level are based on a pressure measurement of the liquid's hydrostatic head. This hydrostatic head is the weight of the liquid above a reference or datum line. At any point, its force is exerted equally in all directions and is independent of the volume of liquid involved or the shape of the vessel. The measurement of pressure as a result of level head can be translated to level height above the datum line as follows:

$$H = P/\rho$$

where:
H =height of liquid
P = pressure resulting from hydrostatic head
ρ = density of liquid.

Different pressure sensors, both bellows and diaphragm (Paragraphs 1.3.3.2 and 1.3.3.3) are used to sense level. On tanks that are vented, the low side of the differential pressure sensor is open to atmospheric pressure. Pressurized tanks such as the core flood tanks have reference legs that tap into the gas space of the tank; therefore, the level indication is not affected by changes in tank pressure. The pressurizer and steam generators use a filled (wet) reference leg, and level (ΔP) is sensed in accordance with the following equation:

$$\Delta P = H_r\rho_r - H_v\rho_v$$

where :
H_r = height of the reference leg
ρ_r = density of the reference leg
H_v = height of the variable leg
ρ_v = density of the variable leg

The reference legs are kept full by condensate pots that tap into the steam space of both vessels. It should be noted from the above formula that a density change in either the reference or variable leg will affect the ΔP that is seen by the sensor; also when the vessel is full, the ΔP is equal to zero. Both flow and level sensors are referred to as differential pressure cells or transmitters.

1.3.4.1 Variable Capacitance Differential Pressure Transmitters

A detector similar in construction to the variable capacitance pressure detector (Paragraph 1.3.2.5) is used to measure the differential pressure caused by level or flow. As seen in Figure 1.3-11, two isolating diaphragms (one diaphragm for the high-pressure input and one diaphragm for the low-pressure input) are used. The differential pressure exerts a force through the silicon fill oil to change the position of the sensing diaphragm. The change in sensing diaphragm position is detected by the capacitor plates. The change in capacitance is electronically converted to an output with a range of 4 to 20 ma.

1.3.5 Temperature Sensing Instruments

Temperature is one of the most measured and controlled variables in the nuclear plant. Uses of temperature measurements range from inputs into the reactor protection system to measurement and control of the chilled water temperature from the station air conditioning system. Three basic types of temperature detectors are used, the fluid-filled system, the thermocouple, and the resistance temperature detector. Each of these temperature detectors is discussed in the following sections.

1.3.5.1 Fluid-Filled Systems

Fluid-filled temperature sensors are usually gas-filled “pressure” detectors (Figure 1.3-12). When the temperature of a gas changes, its pressure also changes. The pressure change of the gas is sensed by a bourdon-tube-type pressure sensor, in which the bourdon tube is connected to a pointer that travels across a scale calibrated in temperature units. The primary use of these systems is local temperature indication.

1.3.5.2 Thermocouples

When two dissimilar metals are welded together and this junction is heated, a voltage is developed at the free ends. The magnitude of the voltage is proportional to the temperature difference between the hot and cold junctions (see Figure 1.3-13) and a function of the types of materials used in thermocouple construction. Because connections must be made to the thermocouple at the cold junction and at the measuring device, all thermoelectric systems consist of three separate thermocouples: the thermocouple proper, the external lead wire, and the reference junction. The voltage developed in the circuit is then a combination of the voltages generated by all three junctions. If the temperature at the reference junction changes, the total voltage of the circuit changes, and the proportionality between the process temperature and measured voltage is destroyed. The temperature of the reference junction must be kept constant, or changes in this temperature may be compensated for by a temperature sensitive resistor. The temperature sensitive resistor will provide a voltage drop in the circuit to compensate for reference junction temperature changes. The incore system uses thermocouples as temperature sensors.

1.3.5.3 Resistance Temperature Detectors

In Figure 1.3-14, a typical bridge circuit is shown. The bridge consists of three known resistances and the resistance temperature detector (RTD). The RTD’s resistance varies with temperature: as temperature increases, the resistance of the RTD also increases. As the resistance of the RTD changes, the voltage difference between points A and B of the bridge circuit changes. This voltage difference is proportional to the temperature that is sensed by the RTD and is used as an input to the indication and control circuits. The RCS hot- and cold-leg temperature detectors are RTDs.

1.3.6 Controllers

In order to control some physical process, (Figure 1.3-18) at least three items must be considered. First, the desired value of the parameter must be chosen. This desired value is called the setpoint for the control system and may be supplied either manually or as a function of a related variable. Second, the actual value of the process must be known. The input of this variable is provided by a detector which senses the value of the process that is to be controlled. Finally, some device must be installed to cause the parameter to achieve its desired value. This device will be controlled by the difference between the setpoint and actual value of the process. The difference between the setpoint and actual value of the parameter is derived in a summing circuit (Σ) and is called an error signal.

The simplest form of controller is a bistable. A bistable turns on or off in response to a control signal. For example a bistable can be used in the control system of a process instrument. In the pressurizer heater control system a bistable controls the operation of the pressurizer heaters in response to pressurizer level. At 17% or less pressurizer level the pressurizer heaters are deenergized. This is in response to the pressurizer level instrument . At 17% level a bistable turns off, preventing operation of the pressurizer heaters in a steam environment. Once pressurizer level is greater than 17% the operator can restore the operation of the pressurizer heaters.

1.3.6.1 Proportional Control

In this paragraph, the basic concepts of a control system are applied to a hypothetical process. It is desired to control the level in a tank (Figure 1.3-19) at a constant value. This tank has an inlet supply of water and a valve installed on the outlet line. A level setpoint of 50% has been chosen and a level transmitter (detector) with the capability of measuring the contents of the tank over the range of 0 to 100% has been installed. The controlled device is the outlet control valve. The following assumptions are made:

1. The inlet flow to the tank can be varied to introduce a disturbance into the system.

2. The outlet flow through the control valve can match inlet flow.

3. The output of the controller will be a value equal to 50% when the tank level is at setpoint, i.e., the error signal is equal to zero.

4. There exists a one to one correspondence between controller output and valve position.

Initial conditions are the tank level at 50% with a given inlet flow equal to outlet flow. Since the tank is at 50% level, the controller output and outlet control valve position are also at 50%, Figure 1.3-19(b). The change in controller output for a change in tank level is represented by the 45° line. Now consider the response of the system if inlet flow is suddenly stopped. First of all, with no inlet flow and the outlet valve positioned at 50%, tank level will drop. As tank level starts to drop, the output of the level transmitter starts to change. In the summing unit (Σ) the change in transmitter output will be sensed resulting in an error signal, Figure 1.3-19(c). The error signal causes a change in controller output which, in turn, causes the outlet valve to start to close. The decrease in tank level will not be terminated until the outlet valve is fully closed and this will occur when the controller output is zero. Unfortunately the output of the controller will equal zero only when the tank is empty. An empty tank falls far short of the goal of controlling tank level at 50%. Conversely, if the level in the tank was at 50% and the inlet flow was increased to its maximum value, then inlet flow would be greater than outlet flow causing tank level to increase.

The increase in tank level is sensed by the level transmitter. The change in the output of the level transmitter is compared with the setpoint in the summing unit (Σ) resulting in an error signal. The error signal causes an increase in the output of the controller resulting in the opening of the outlet control valve. In order to stop the increase in tank level, the outlet valve must be fully open. The outlet valve will be 100% open when the tank is full. Again, the control system will not control the tank level at setpoint. From these two examples, it is evident that the controller will not operate correctly in its present configuration. However, if the output of the controller can be increased by a value that is proportional to the change in the error signal, then the outlet valve will achieve its required position sooner. This will prevent gross oscillations in tank level. Such a controller is called a proportional controller because its output is proportional to the input error signal.

output = (k) (error signal)

where:
k is the proportionality constant.

To illustrate the effect of the proportionality constant, values of k equal to 2 and 5 will be arbitrarily chosen while maintaining a 50% controller output with a zero error signal. As shown in Figure 1.3-19(a) with k equal to 2, if the error signal increases by 25% then the output of the controller will increase to 100%. In the opposite direction a change in the error signal of 25% will result in a controller output of 0%. Formally k is called the “gain” of the controller and is defined as follows:

Gain = Δ output / Δ input

The output of the control system versus tank level for the two different values of gain is shown in Figure 1.3-19(b). The effects of these two values of gain will be examined with perturbations in inlet flow.

Note on Figure 1.3-19(c) that tank level is at 50% (setpoint). At time t=1, the inlet flow is stopped. With output flow greater than inlet flow, tank level begins to decrease. The decrease in tank level will continue until the outlet valve is fully closed. The value of tank level resulting in closure of the outlet valve can be determined from Figure 1.3-19(b). With a gain of 2 the valve will be closed when tank level is 25%. At time t=4, inlet flow is increased from zero to its maximum value. Since inlet flow is greater than outlet flow, tank level will rise. The increase in tank level will stop when outlet and inlet flows are equal. This will occur when the outlet valve is 100% open. Again, the tank level corresponding to the full open valve position can be determined from Figure 1.3-19(b). Since the controller has a gain of 2, the level increase will be stopped at 75%.

Now, using a gain of 5 for the same conditions as described above with the previous gain of 2. At time t=1, with the tank level at 50% (setpoint), the inlet flow is stopped.

With output flow greater than inlet flow, tank level begins to decrease. The decrease in tank level will continue until the outlet valve is fully closed. The value of tank level resulting in closure of the outlet valve can be determined from Figure 1.3-19(c). With a gain of 5 the valve will be closed when tank level is 40%. When k is equal to 5, changes in the error signal of -10% to +10% correspond to controller output of 0% and 100% respectively. With a gain of 5, the increase in tank level will be terminated at 60%.

It should be noted that tank level is not controlled at setpoint in either case. This is a characteristic of a proportional controller. A proportional controller will not control at setpoint because a change in the error signal is required to cause a change in the output of the controller. Although the proportional controller will not control at setpoint, it will control within a band around the setpoint. This leads to the definition of the proportional band (PB). The proportional band of a controller is the change in input required to cause a 100% change in the output. The proportional band is the reciprocal of gain as illustrated on Figure 1.3-19(c) and the following:

Table 1.3-1
Gain and Proportional Band

Gain	Proportional Band (in %)
0.5	200%
1.0	100%
2.0	50%
5.0	20%

At a glance it would appear that increasing the gain would cause the controller to control closer to setpoint. While this is true, limitations on gain do exist. Equipment or process time delays must be taken into consideration when choosing values of gain.

1.3.6.2 Proportional Plus Integral Control

In order to eliminate the proportional controller's offset between the actual value of the parameter and the process setpoint, integral control action is added to the control system (see Figure 1.3-20). The integral action eliminates the offset by integrating the proportional band and adding this signal to the controller output. Prior to examining the operation of integral action, two terms need to be defined. The first term is "reset rate" and is defined as the number of times the magnitude of the change in controller output caused by the proportional band deviation will be added to the controller output per unit time. Reset rate is expressed in repeats per minute (RPM). The other term is "reset time" and is defined as the time required to repeat the magnitude of the change caused by the proportional band action. Reset rate and reset time are reciprocal terms. To illustrate this, assume a controller has a proportional band of 200% (gain = 0.5) and a reset rate of 2 RPM. If a step change of 20% occurs in the process variable, the magnitude of the change in the controller output due to proportional band action is 10%. A reset rate of 2 RPM will cause a change of an additional 20% every minute the error exists. A reset rate of 2 RPM corresponds to a reset time of 0.5 minutes; therefore, the output of the controller will be changed an additional 10% every 30 seconds.

For review, the actions of the control system in response to a step change from 50% to 70% with a gain of 0.5 and a reset rate of 1 RPM are as follows:

1. The controller output due to proportional controller action will increase from 50% to 60% (20% Δ input x 0.5 gain = 10%).

2. The change of 10% due to proportional action will cause a change of 10% every minute for a 1 RPM reset rate.

3. The output of the integral action will be combined with the output of the proportional controller to cause a greater opening of the tank outlet control valve for each percent level error.

4. A greater opening of the control valve will increase the outlet flow from the tank. If outlet flow is increased, then tank level will decrease.

5. As the level decreases, the output of the controller will decrease closing down on the outlet control valve. This action will continue until the setpoint of 50% is reached.

Now use the same initial conditions as above, with the exception that the reset rate is changed to 2 RPM. The actions of the control system in response to a step change from 50% to 70%, with a gain of 0.5 and a reset rate of 2 RPM, are as follows:

1. The controller output due to proportional controller action will increase from 50% to 60% (20% Δ input x 0.5 gain = 10%).

2. The change of 10% due to proportional action will cause a change of 20% every minute for a 2 RPM reset rate.

3. The output of the integral action will be combined with the output of the proportional controller to cause a greater opening of the tank outlet control valve for each percent level error.

4. A greater opening of the control valve will increase the outlet flow from the tank. If outlet flow is increased, then tank level will decrease.

5. As the level decreases, the output of the controller will decrease closing down on the outlet control valve. This action will continue until the setpoint of 50% is reached.

The addition of integral action to the controller will achieve the desired result of having the control system control at setpoint because controller output will continue to change as long as an offset between the actual value of the parameter and its setpoint exists. As the value of the controller changes, the controlled device will be modulated. This action will restore the parameter to setpoint.

1.3.6.3 Proportional Plus Derivative Control

The installation of derivative action into the control scheme gives the system the ability to start action based upon the rate of change of the control systems input. This is sometimes referred to as an anticipatory circuit. A derivative controller “anticipates” the change in the process variable by the addition of a signal that is proportional to the rate of change of the input signal. The change in controller output due to derivative action is called “rate gain” and is defined as the multiplication of the change in proportional action due to a step change in the process parameter. A step change is used here as a reference condition.

As an example, if a step change of 10% causes a proportional controller’s output to change by 5% (200% proportional band), then the addition of derivative action with a rate gain of 5 would cause an additional increase in the controllers output of 25%. Figure 1.3-21 illustrates the effects of adding derivative action to the control system. Inlet flow to the tank is adjusted to give a rate of increase in level of 10% per minute It will be assumed that the increase in controller output does not decrease the rate of level increase (no feedback). As tank level begins to increase at a rate of 10% per minute, the output of the controller due to proportional action begins to increase at 5% per minute (gain times the change in input). The rate of change of level is constant; therefore, the output of the derivative circuit will increase from 0% to 10% (rate gain of 2 times the 5% change in output due to proportional band action) and remain constant.

The increase in controller output positions the level control valve to a greater opening per percent level error restoring tank level to setpoint sooner. A comparison of the proportional control output graph, and the proportional plus derivative graph, shows that the time required to reach a particular controller output is decreased by the addition of derivative action. This reduction in time is called “rate time” and is defined as the decrease in time it would take the controller output to reach the same value that would be obtained by only proportional action when the process parameter is changing from setpoint at a constant rate.

Figure 1.3-21 shows a transient involving a step change in tank level. The step change causes an increased controller output due to proportional plus derivative action. After the step change has occurred, the rate of change of level deviation is zero. This causes the derivative signal to be reduced to zero over a given period of time.

The time required for the output to decay by 63.2% of the signal due to the action of the derivative portion of the controller is called the “time constant.” The output of the controller is an exponential function and will change by 63.2% of the controller’s maximum value in one time constant. The output of the derivative portion of the controller will equal zero after 5 time constants. If the deviation between setpoint and the process parameter, as shown in Figure 1.3-21 is increasing, the portion of the controller output due to derivative action will reach its steady state value in five time constants.

1.3.6.4 Proportional Plus Integral Plus Derivative (PID) Controllers

The proportional plus integral plus derivative (PID) controller is the most sophisticated controller used in the power plant and can be used to summarize the previous types of controllers. The proportional component of the PID provides an output that is proportional to its input. The input signal to the controller is the error that results from the comparison of the actual value of the parameter and its desired value (setpoint).

The proportionality constant is called gain. Since a change in the input is required to cause a repositioning of the controlled device, an inherent offset would exist. The addition of the integral portion of the PID controller eliminates the offset of the proportional action. The integral portion of the controller accomplishes this function by adding the integral of the proportional deviation to the output of the controller. This increase in controller output changes the status of the controlled device and causes the process parameter to achieve the desired value. Finally, the derivative action adds an anticipatory feature to the controller. This anticipatory feature is performed by adding a signal to the controller output that is proportional to the rate of change (the derivative) of the proportional band deviation. Response of the PID controller to various input signals without feedback is shown on Figure 1.3-23.

1.3.7 Logic Diagrams

The concept of logic diagrams was introduced to provide complete system information to personnel in an easily interpreted format. These diagrams, through the use of standard symbols, explain specific system or component control, protection and operational capabilities without requiring detailed research of complex electrical or mechanical system diagrams. With the use of a few standard symbols and a basic knowledge of the system's functions and capabilities, a large quantity of useful information may be obtained. To illustrate the concept of logic diagrams and their component parts, the basic symbols will be introduced and briefly discussed and an example given of their application.

The symbols to be discussed will not be all inclusive; however, those discussed are the most common. In every case of logic diagram usage by a vendor, architect engineer, or utility, an explanation sheet of symbols is included.

1.3.7.1 "OR" Logic

The "OR" logic is represented in Figure 1.3-26(a). This logic symbolizes an input and an output function. In the "OR" logic flow, any input signal is considered to be passed through to produce an output. The loss of all inputs will cause a loss of the output.

1.3.7.2 "AND" Logic

The "AND" logic is represented in Figure 1.3-26(b). Multiple input functions are required to produce an output function. In the "AND" logic, all input functions or a specified number of the input functions must be present to produce an output.

1.3.7.3 "NOT" Logic

The "NOT" logic represented in Figure 1.3-26(c) illustrates a function that will produce an output with no input signal. Likewise, with an input signal present, no output is produced.

1.3.7.4 Retentive Memory

This logic function in Figure 1.3-26(d) will either produce an output or not produce an output depending on its last energized input. If the last input signal received is the input aligned with the output, an output signal is allowed to pass. If the last input signal received is not aligned with the output, the output signal will be terminated.

1.3.8 Electrical Relay

Figure 1.3-27 illustrates the physical layout of a relay and the electrical circuit representations. There are two types of auxiliary contacts used in relays. The "A" contacts are shut when the main relay contacts are shut, and open when the main relay contacts are open. The "B" contacts are open when the main relay contacts are shut and shut when the main relay contacts are open. These "A" and "B" contacts are used as part of the instrumentation and control circuits for the system controlled by the relay.

0199-1

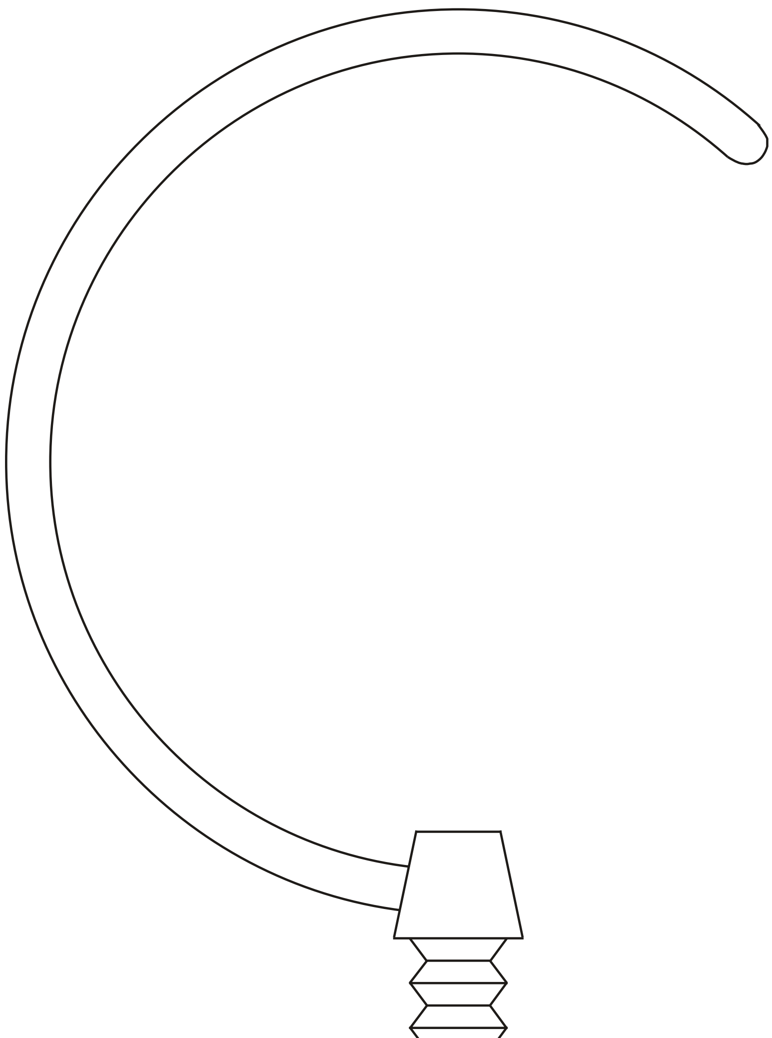
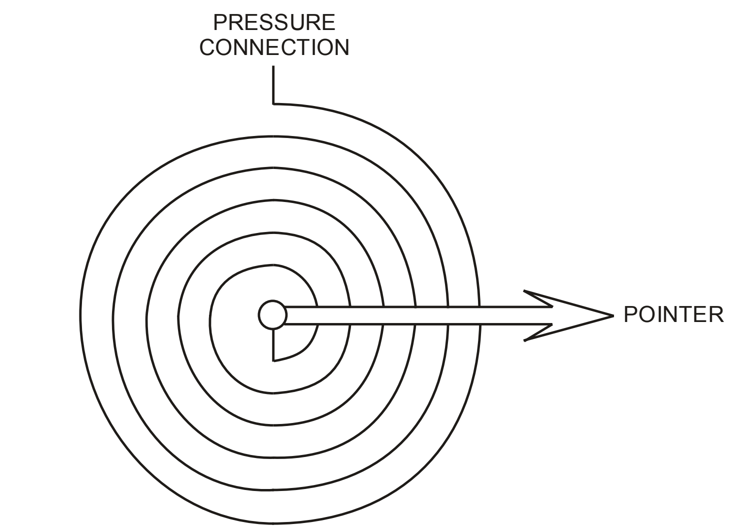
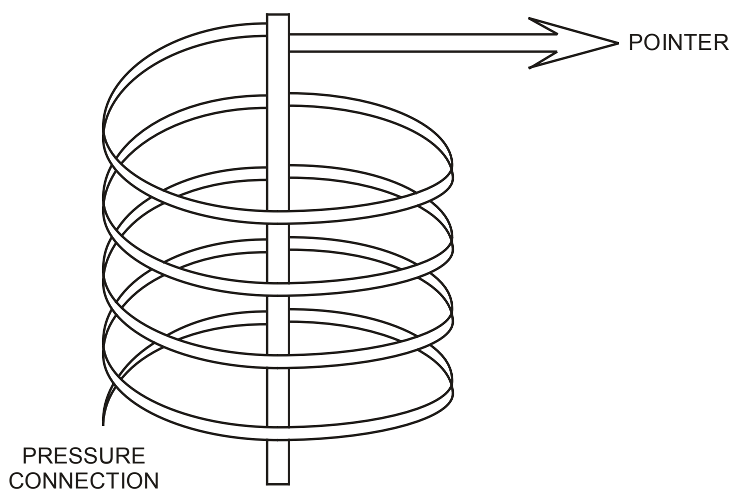


Figure 1.3-1 Simple Bourdon Tube



(a) Spiral pressure detector



(b) Helical pressure detector

Figure 1.3-2 Wound Pressure Detectors

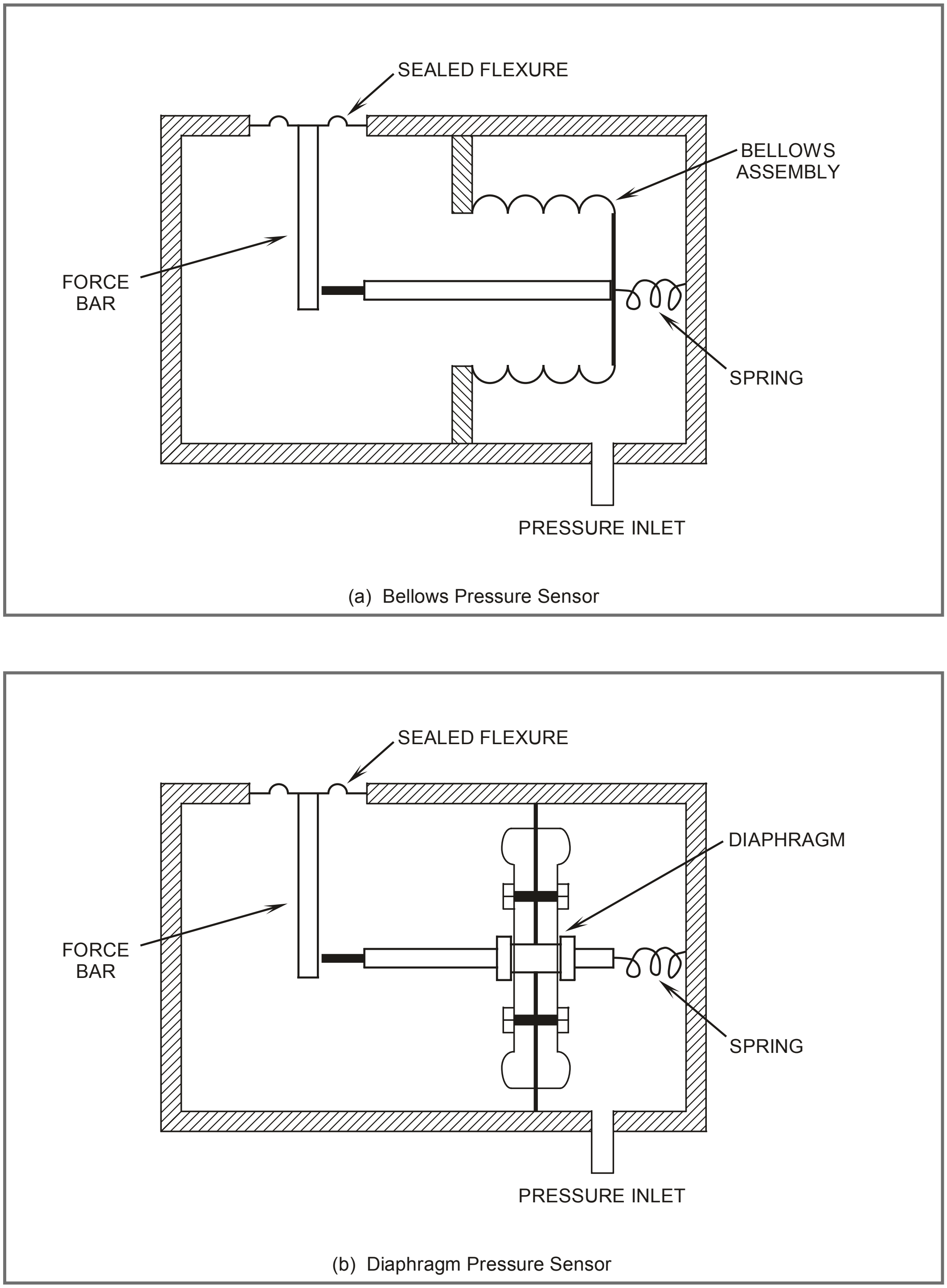


Figure 1.3-3 Sealed Pressure Detectors

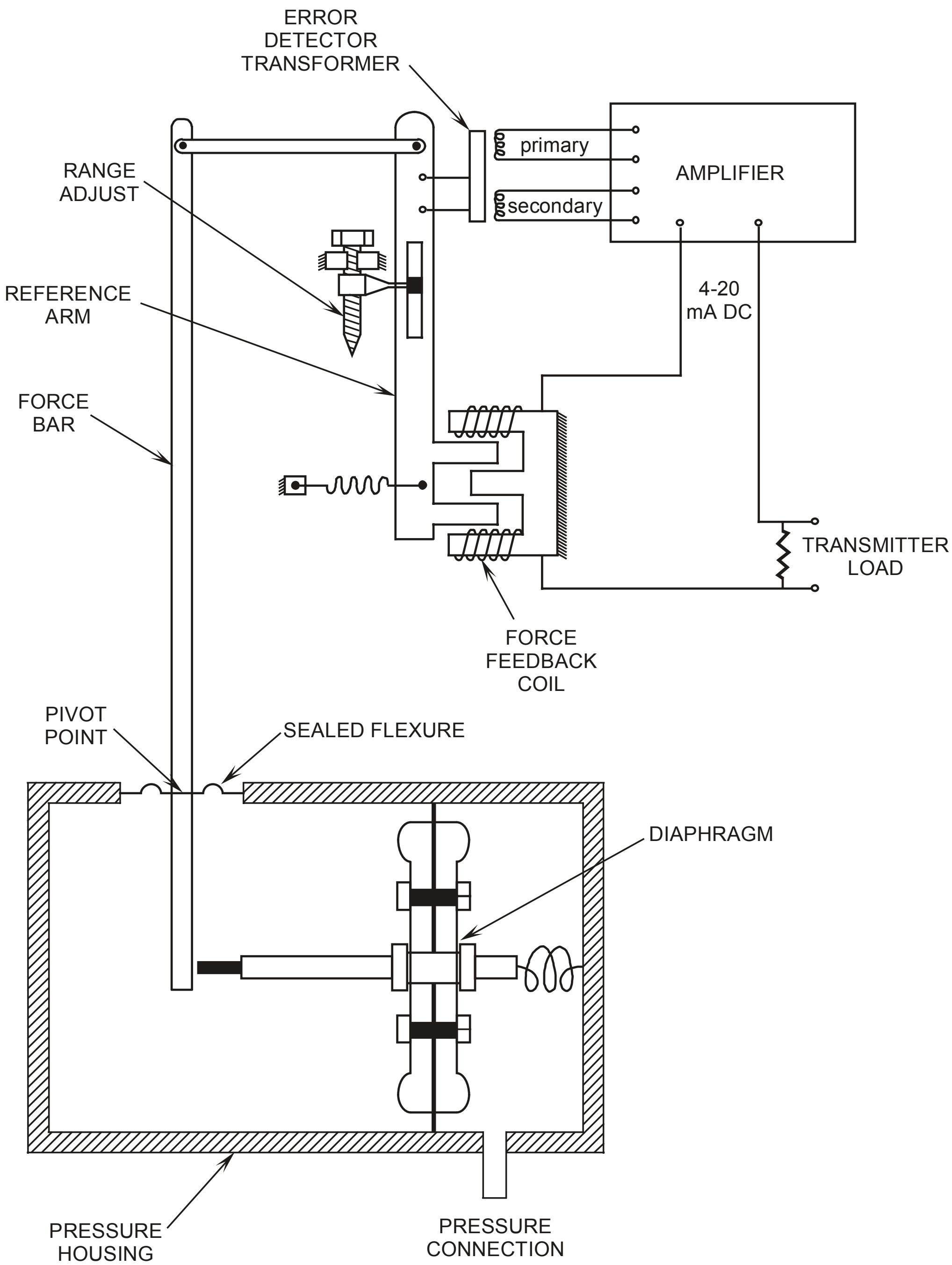
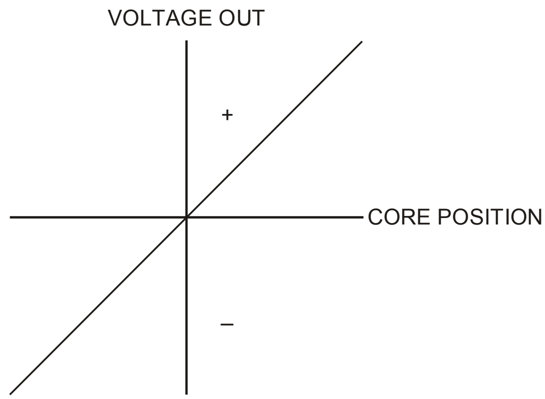


Figure 1.3-4 Force Balance Transmitters



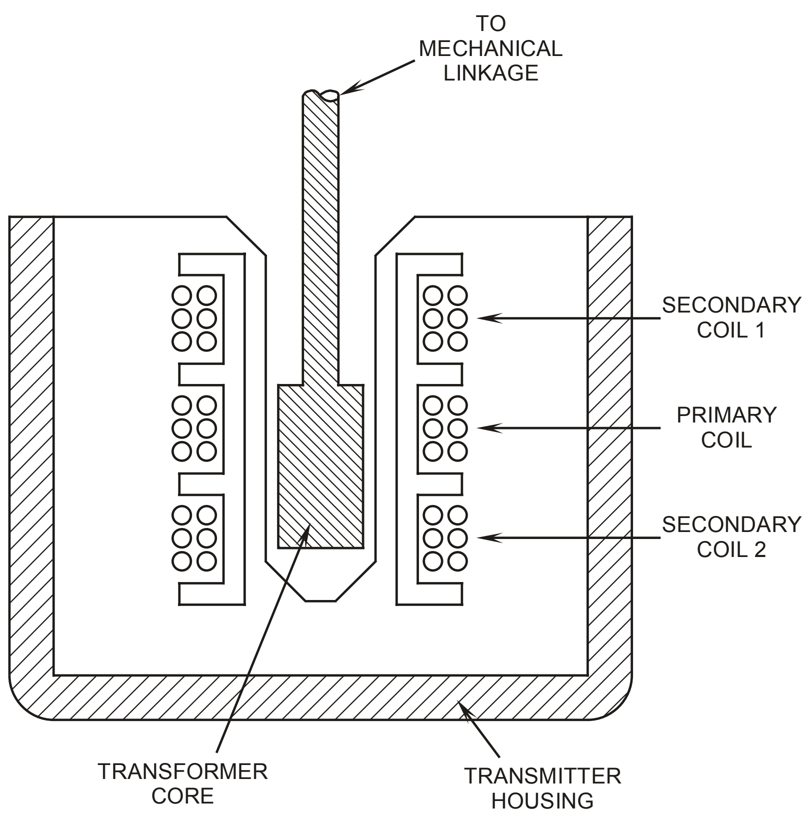


Figure 1.3-5   Movable Core Transmitters

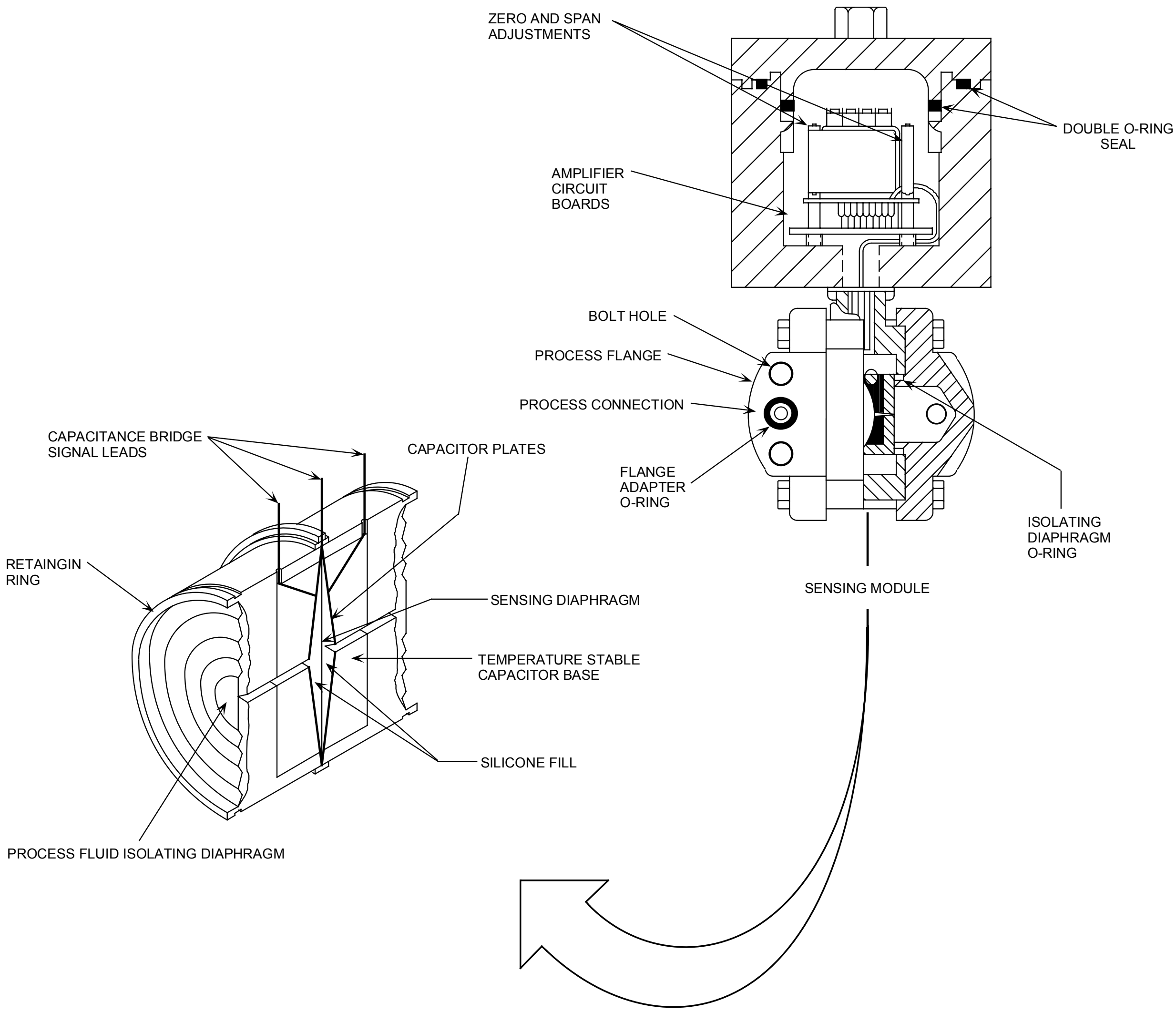


Figure 1.3-6 Variable Capacitance Transmitters

0199-1

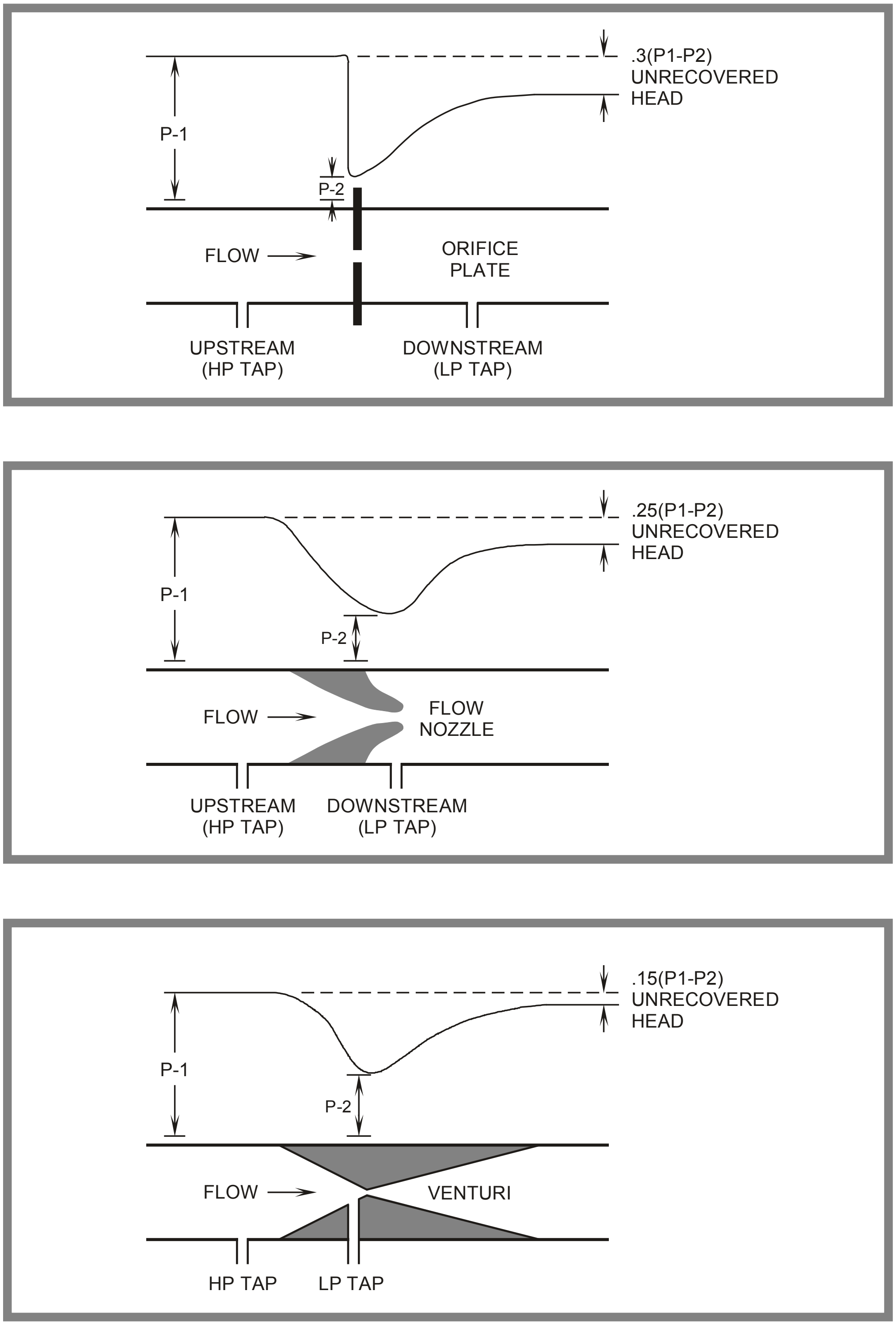


Figure 1.3-7 Primary Devices

0199-1

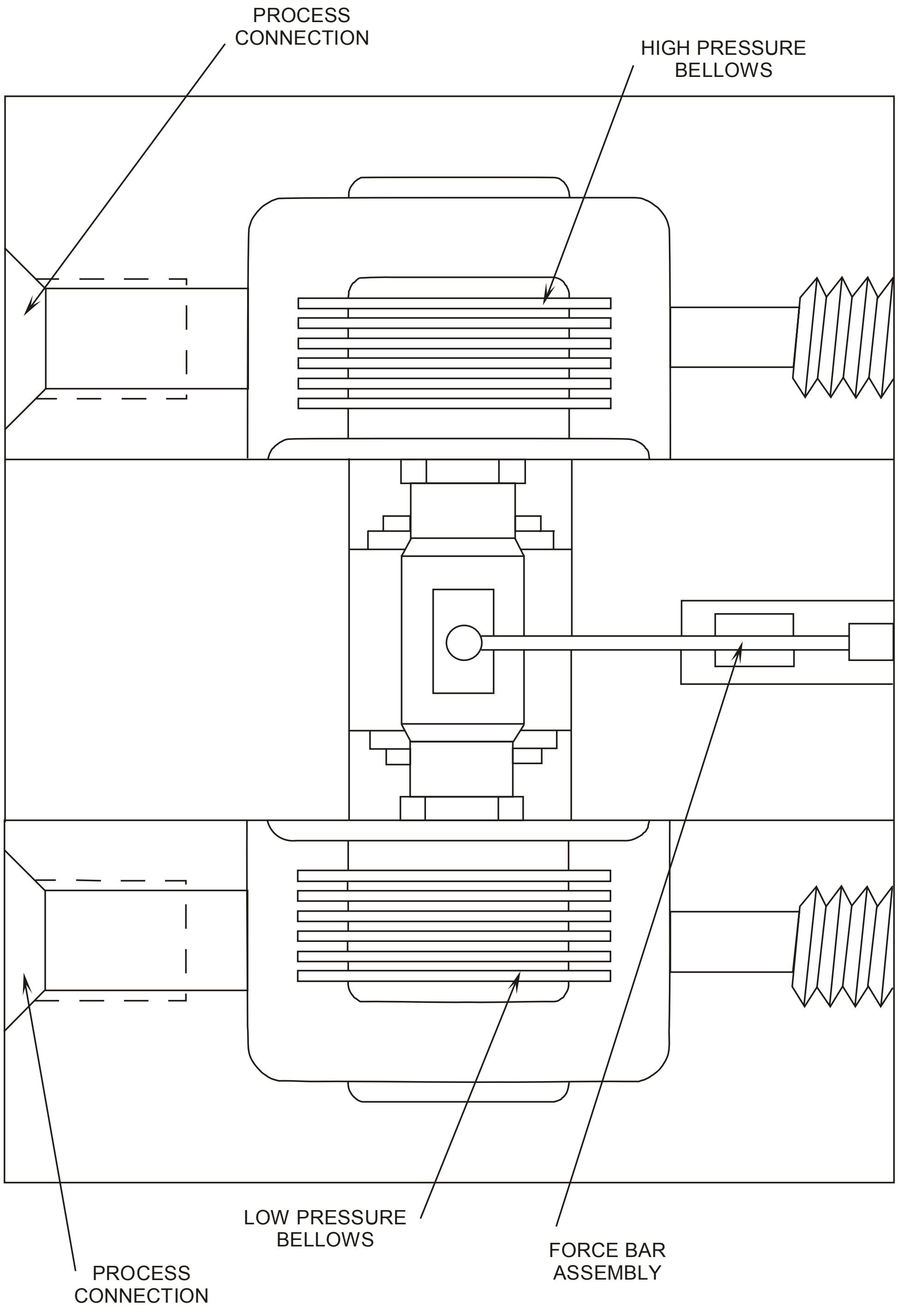


Figure 1.3-8 Bellows Flow Sensor

0199-1

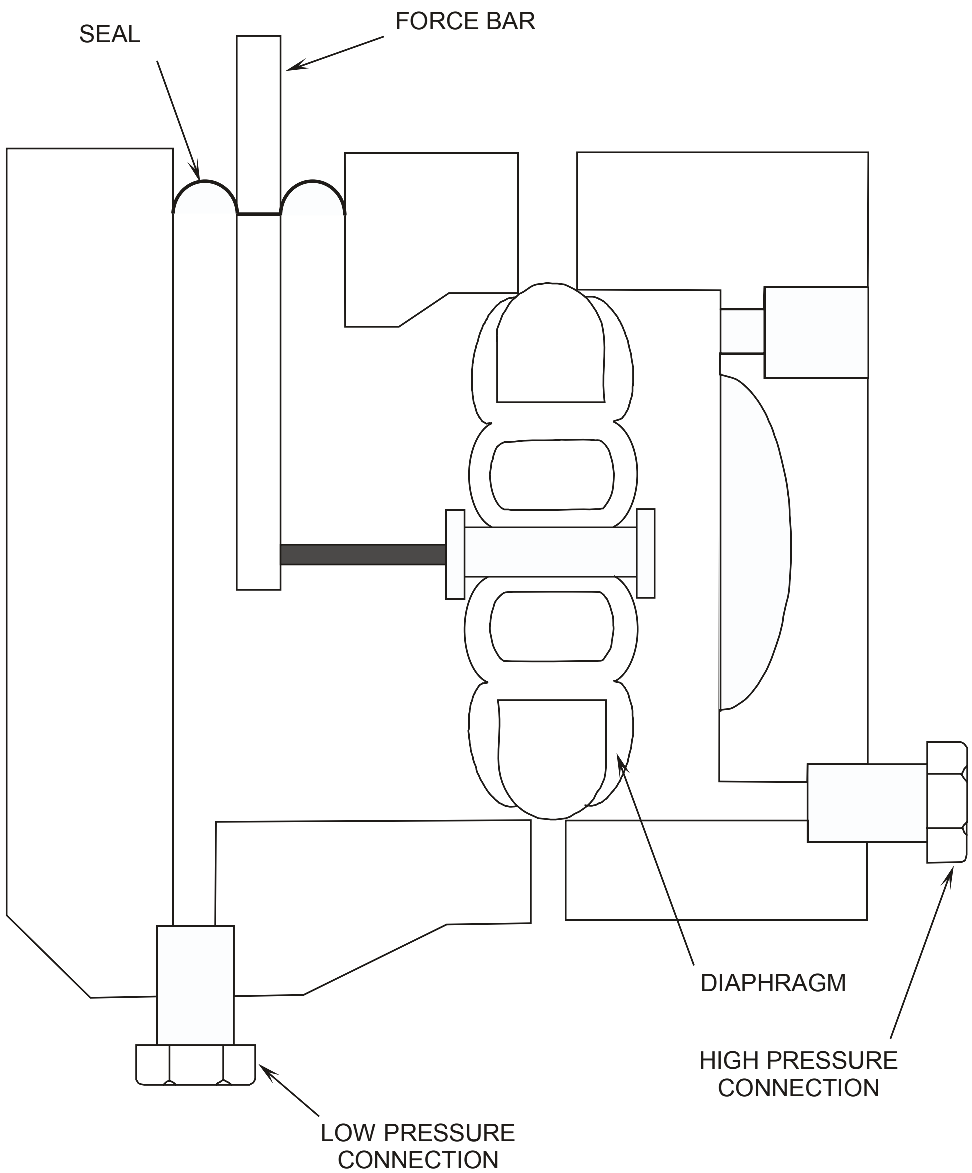


Figure 1.3-9 Diaphragm Flow Sensor

0199-1

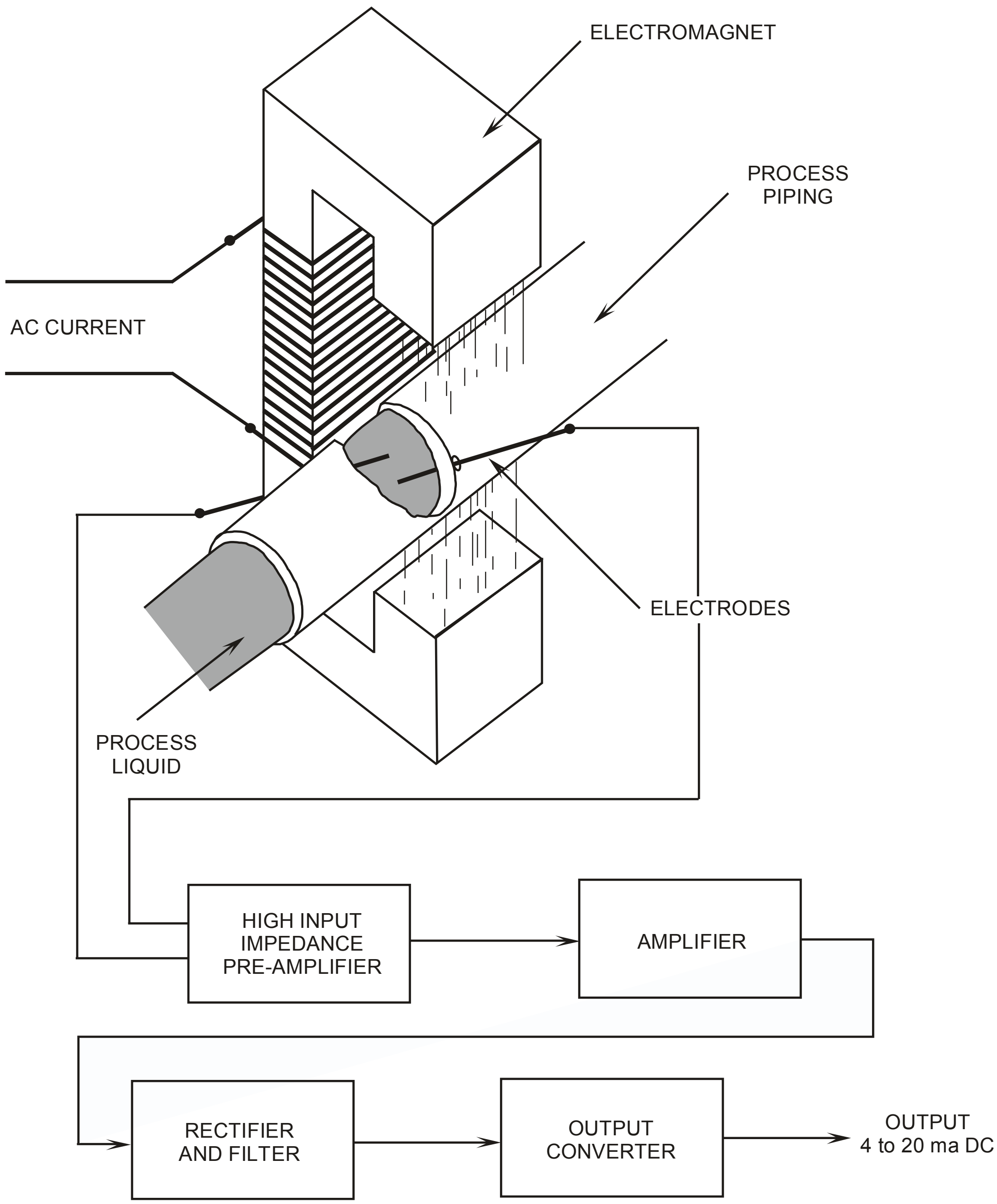


Figure 1.3-10 Magnetic Flow Meter

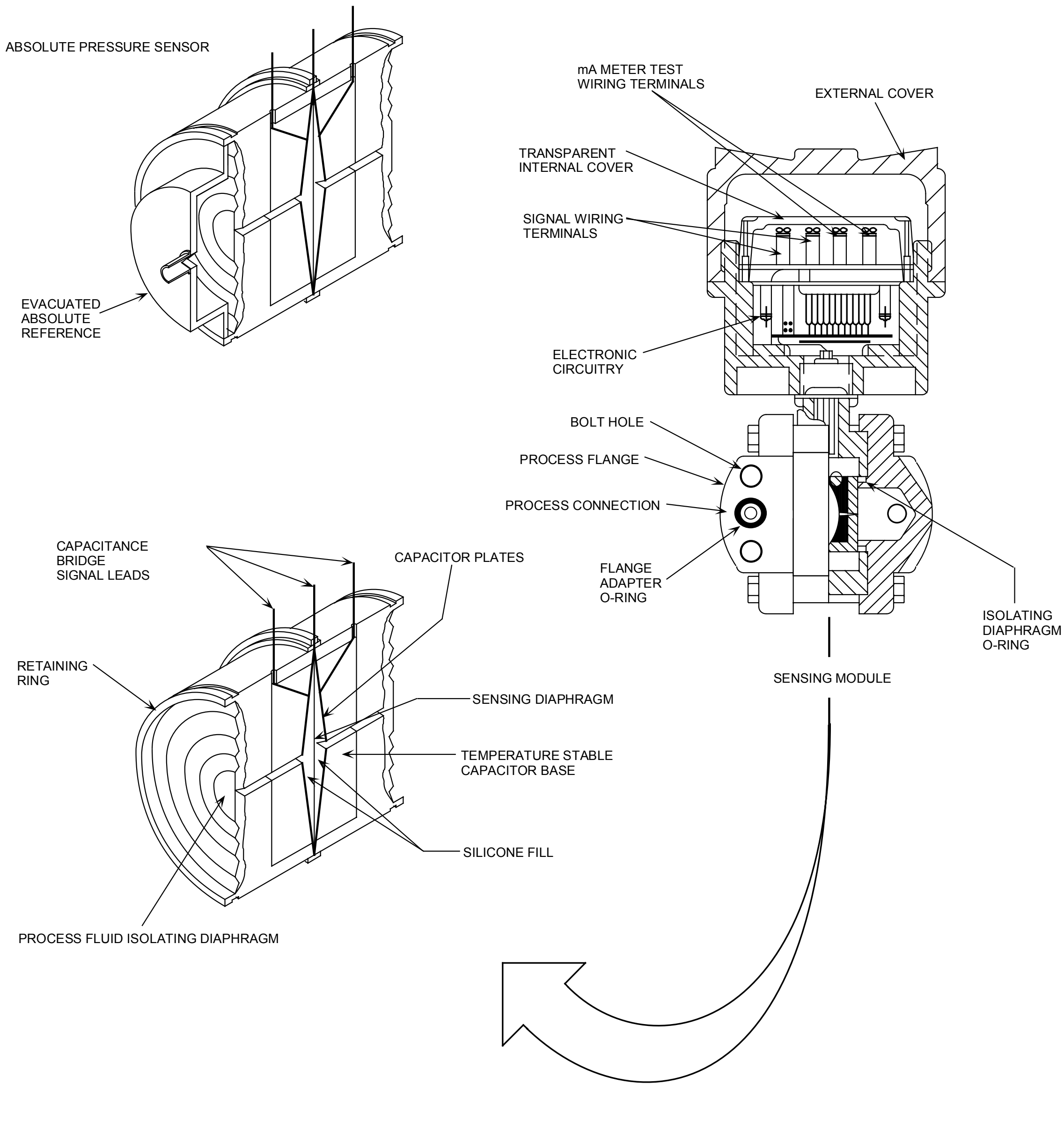


Figure 1.3-11 Variable Capacitance Differential Pressure Sensor

0199-1

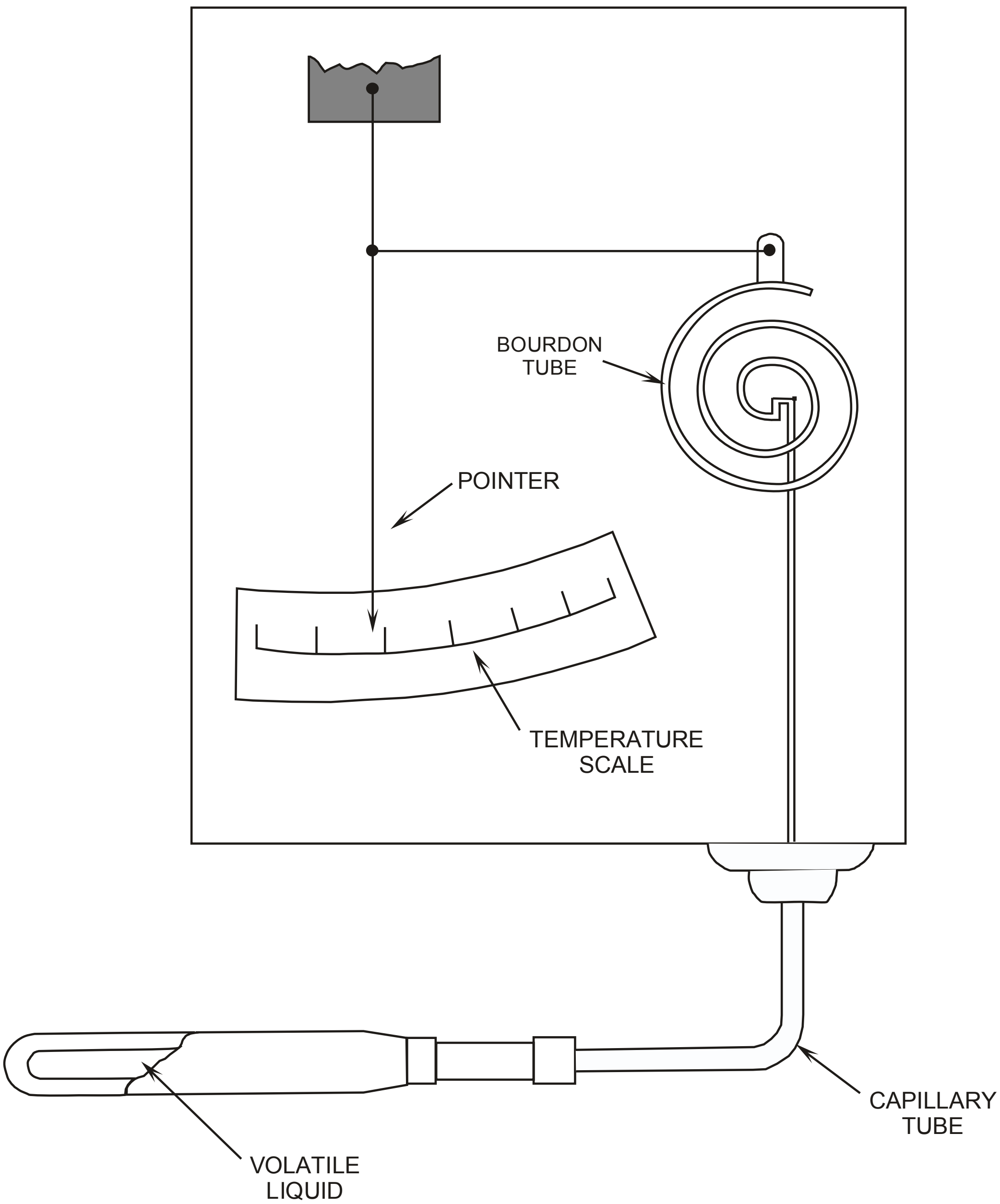


Figure 1.3-12 Fluid Filled Temperature Sensor

0199-1

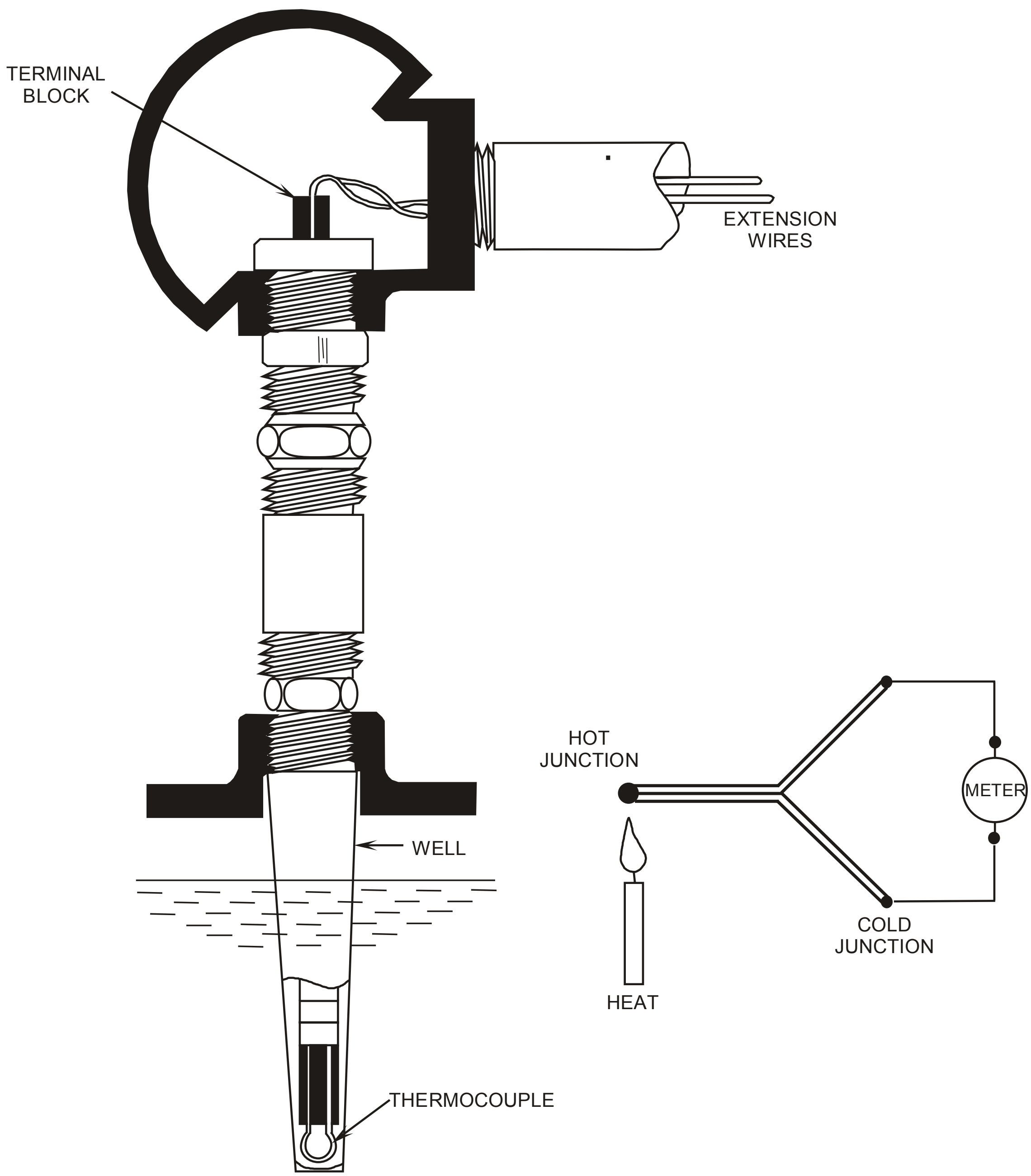


Figure 1.3-13 Thermocouple

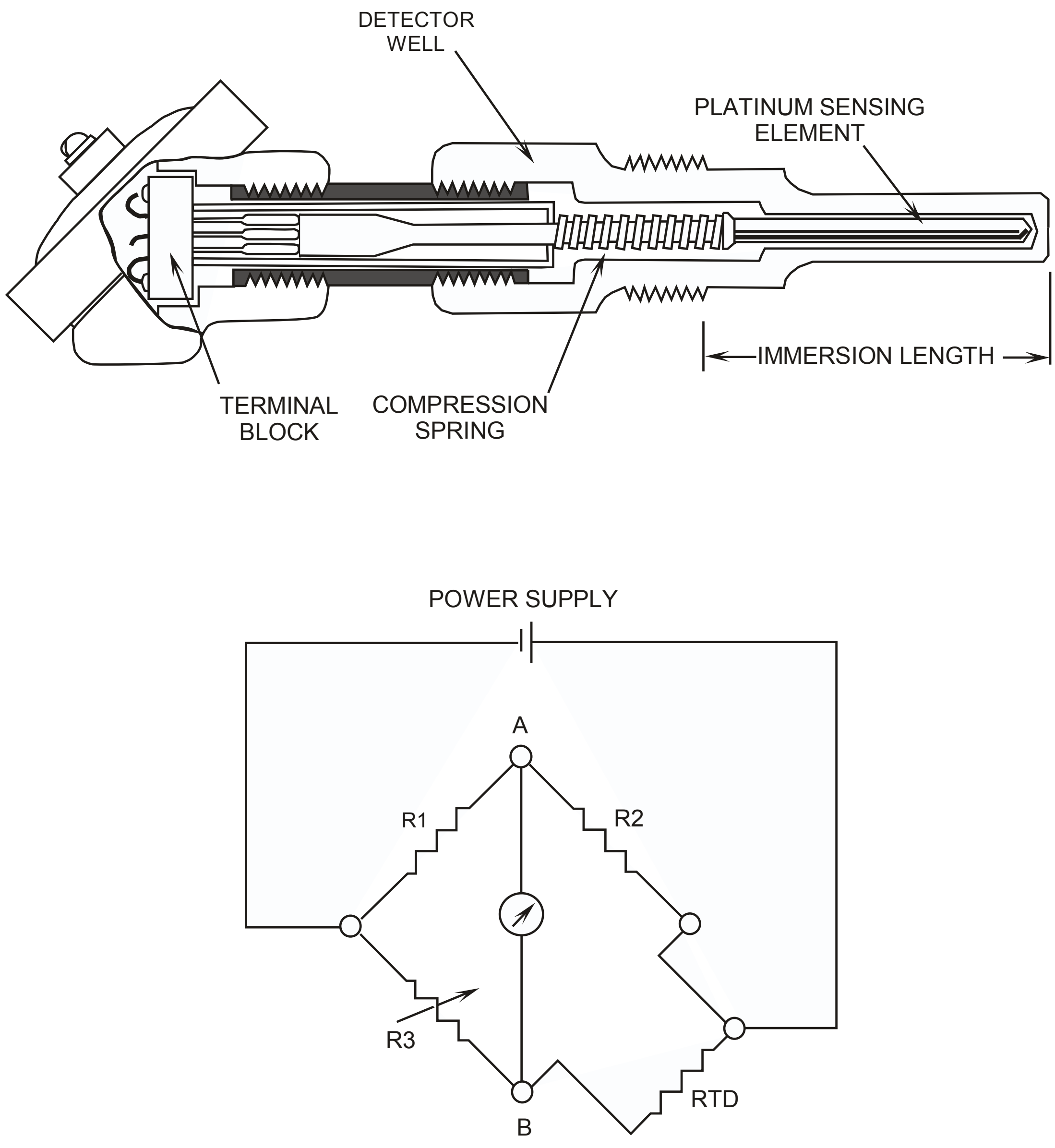


Figure 1.3-14 Resistance Temperature Detector

0199-1

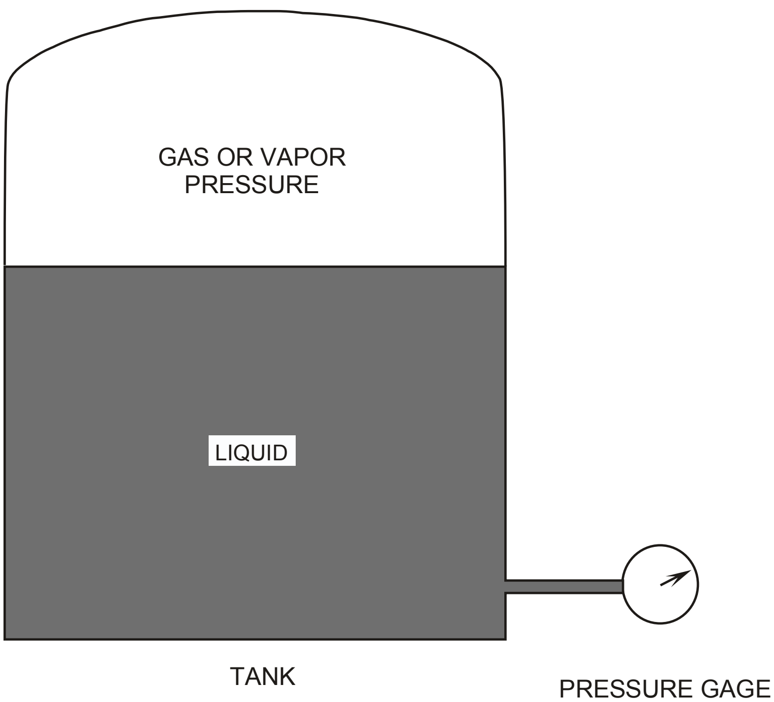


Figure 1.3-15   Direct Level Measure Devices

0199-1

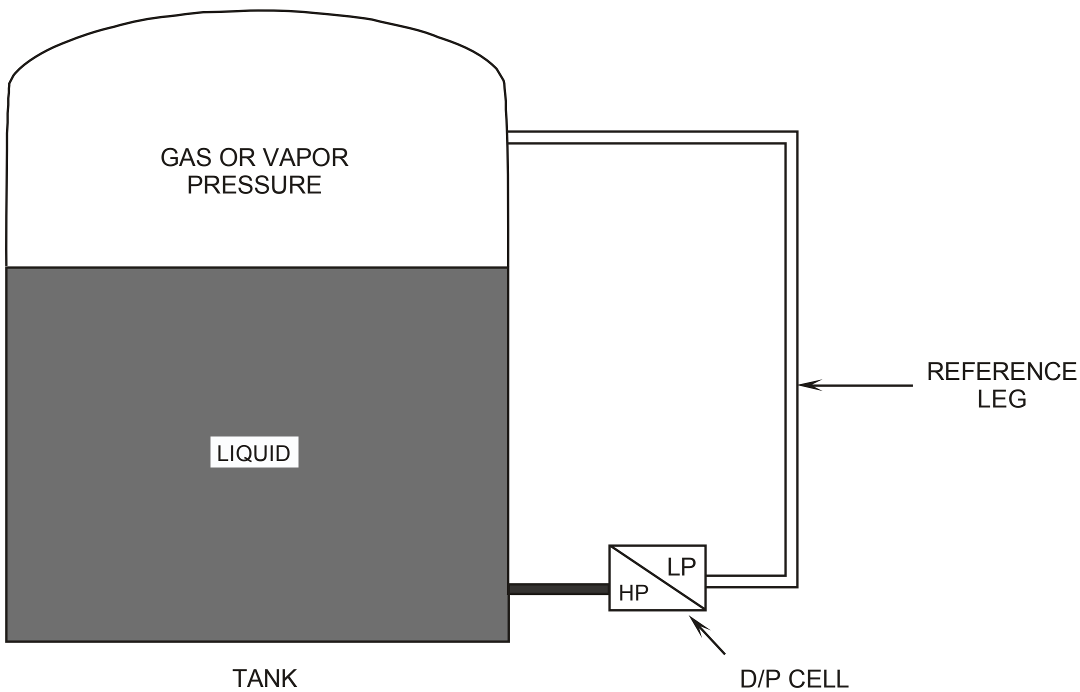


Figure 1.3-16 Differential Pressure Level Detector

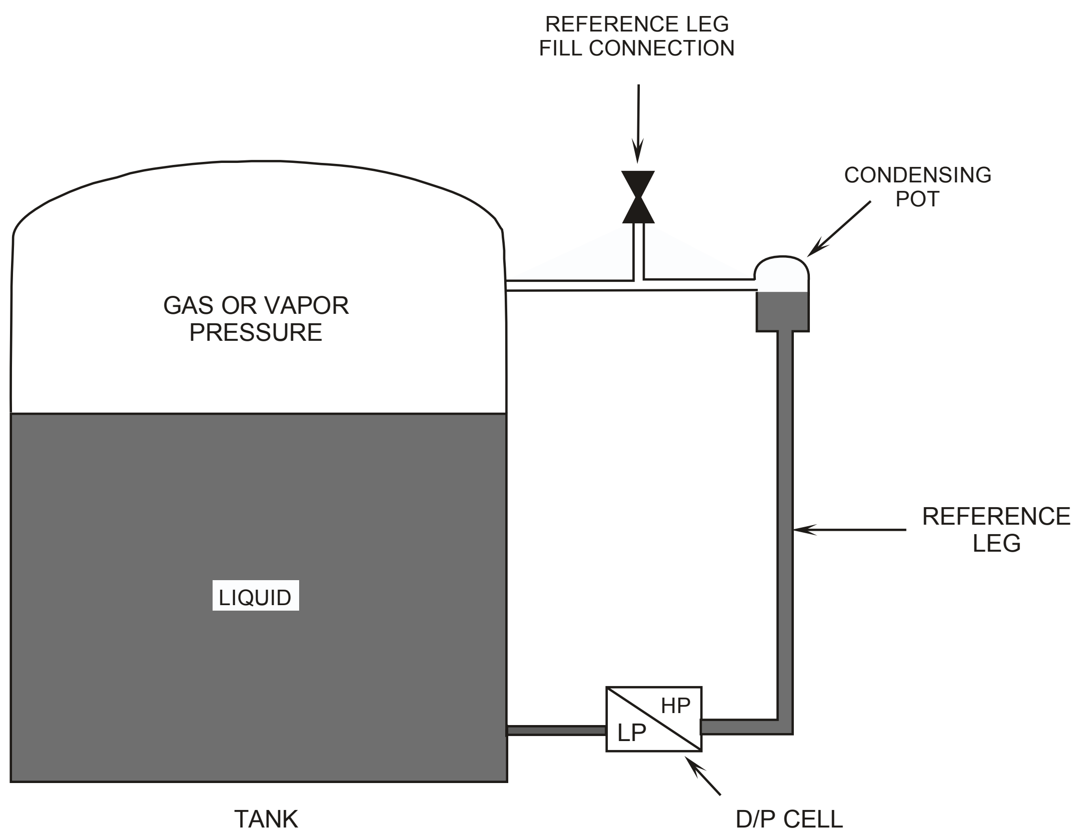


Figure 1.3-17 Reference Leg Differential Pressure System

0199-1

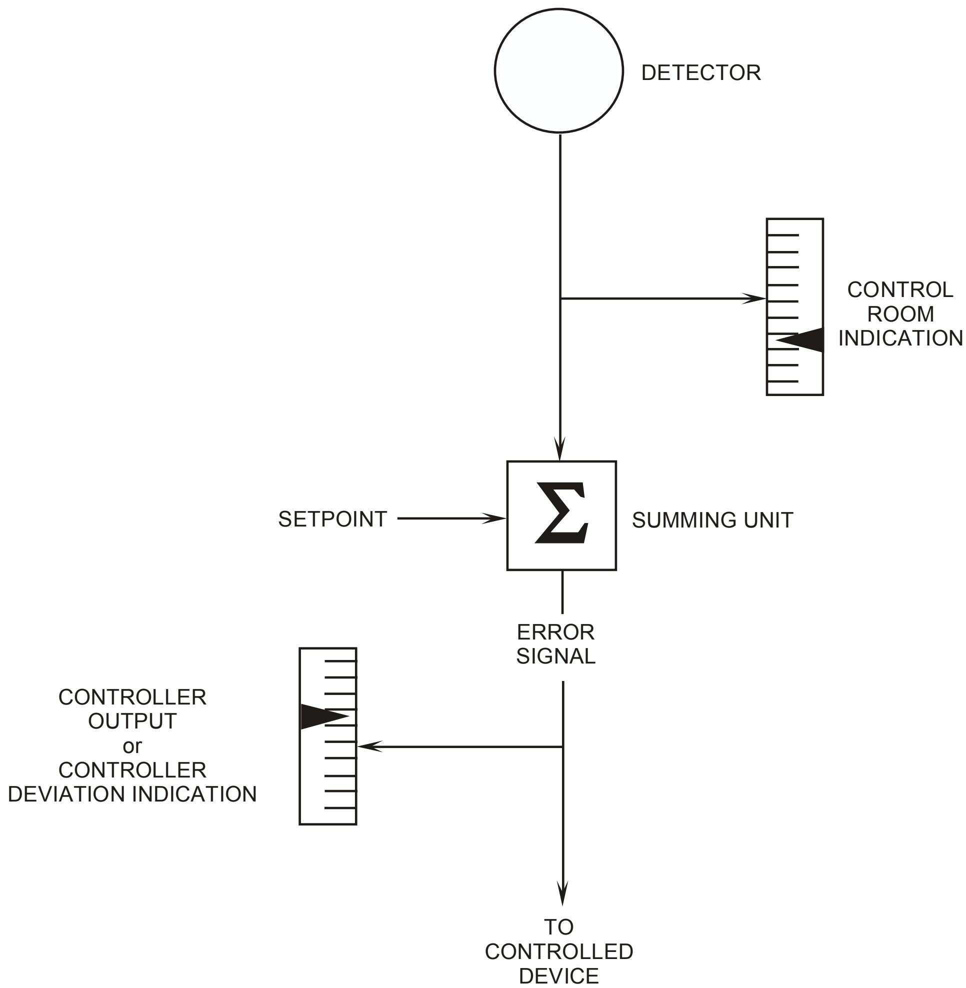
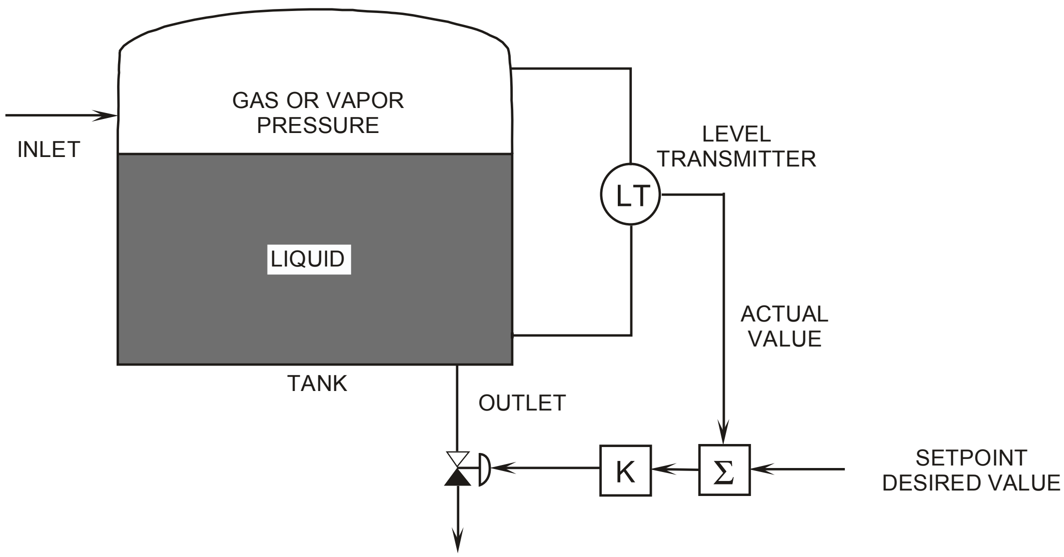


Figure 1.3-18 Basic Control Diagram

0199-1



(A) SIMPLIFIED LEVEL PROPORTIONAL CONTROL CIRCUIT

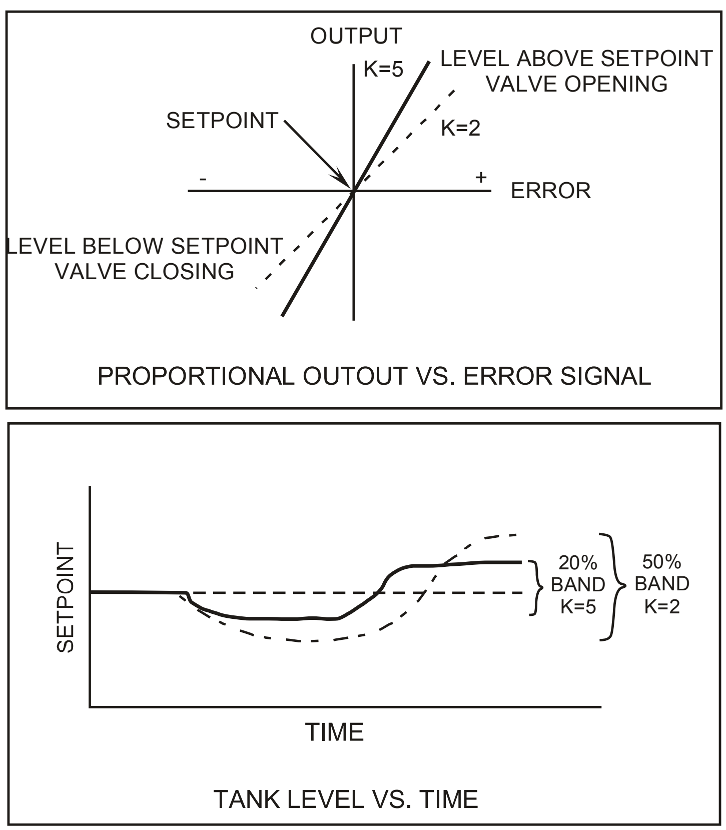


Figure 1.3-19 Proportional Controller

0199-1

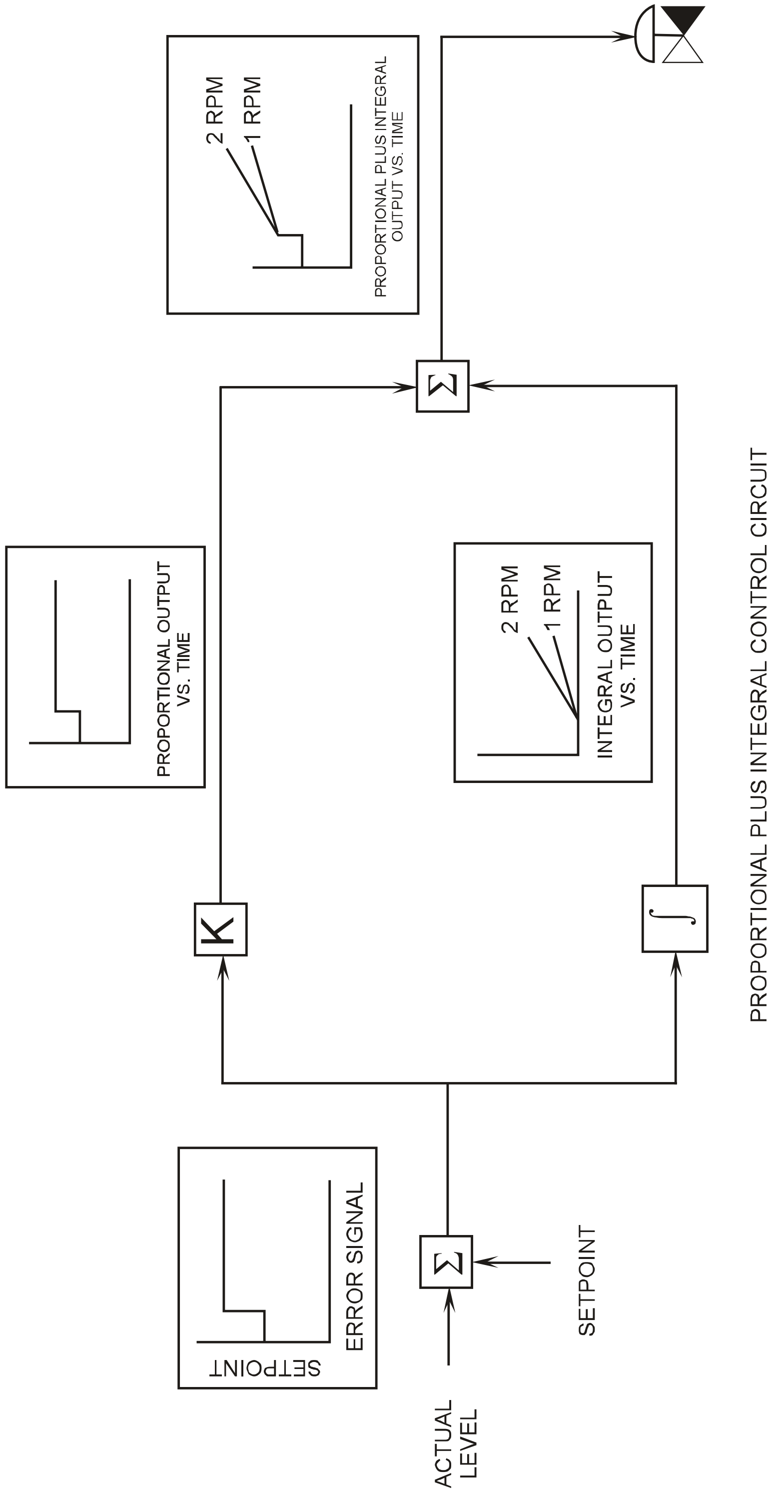


Figure 1.3-20 Proportional Plus Integral Controller

0199-1

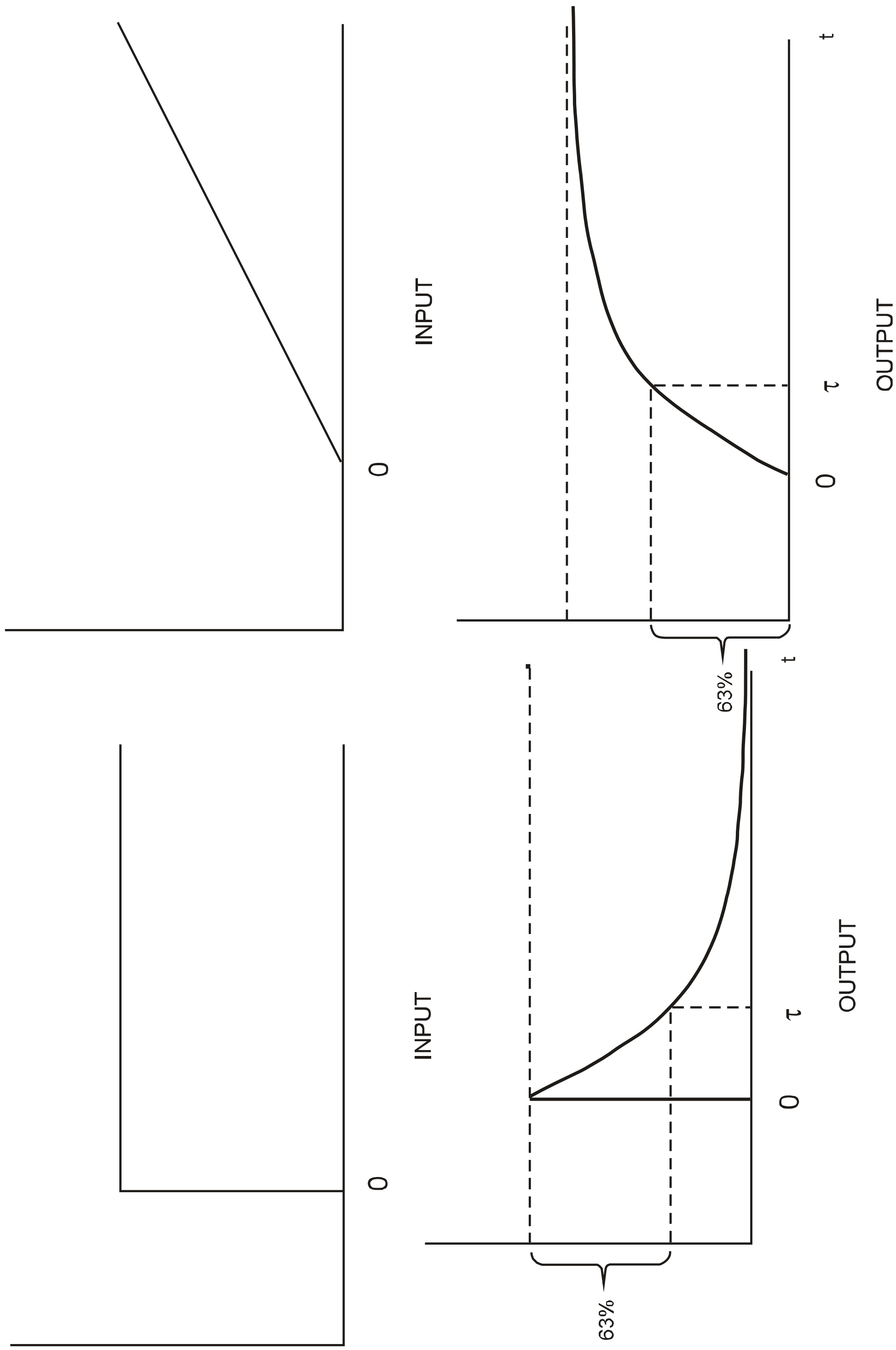


Figure 1.3-21 Time Constant

0199-1

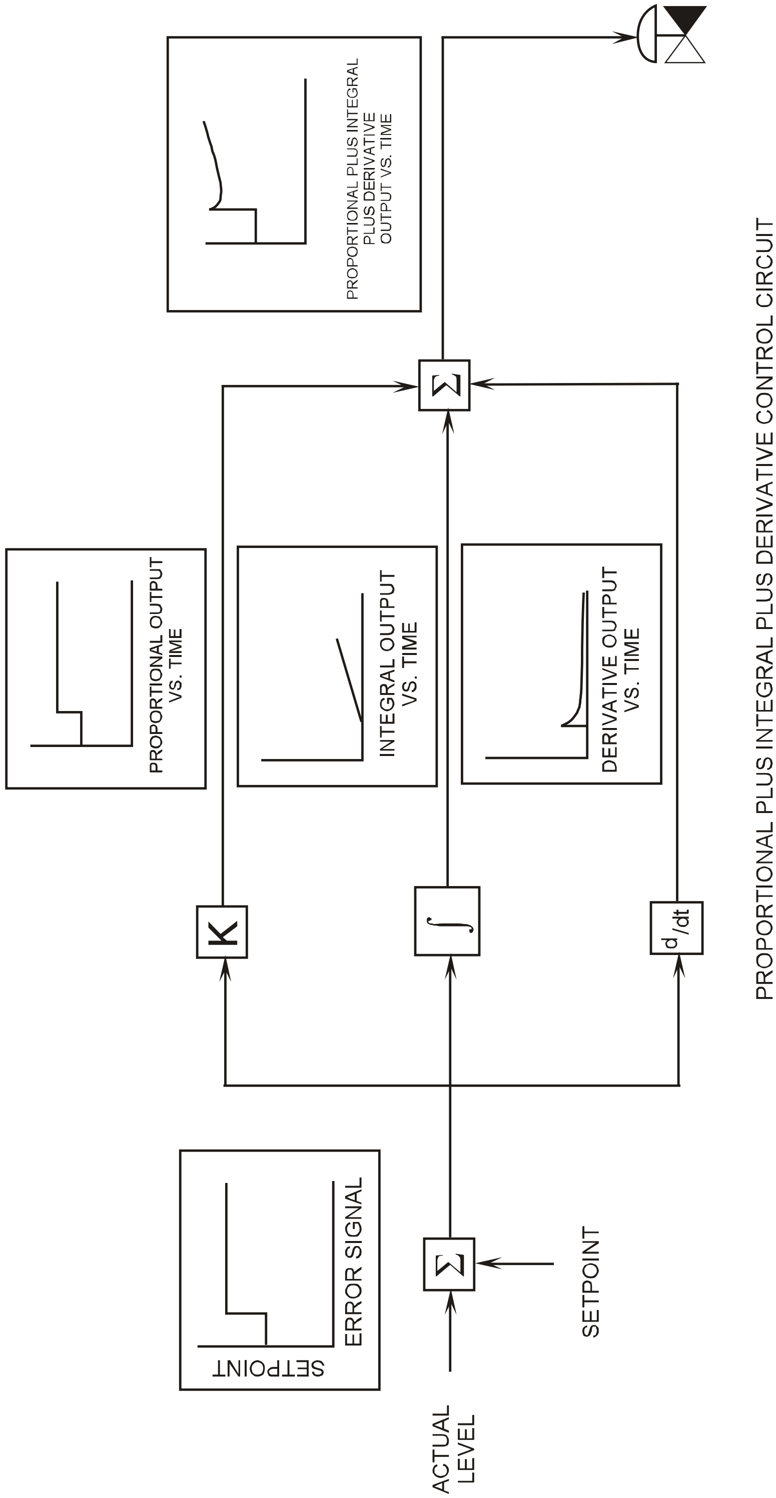


Figure 1.3-22 Proportional Plus Integral Plus Derivative Controller

0199-1

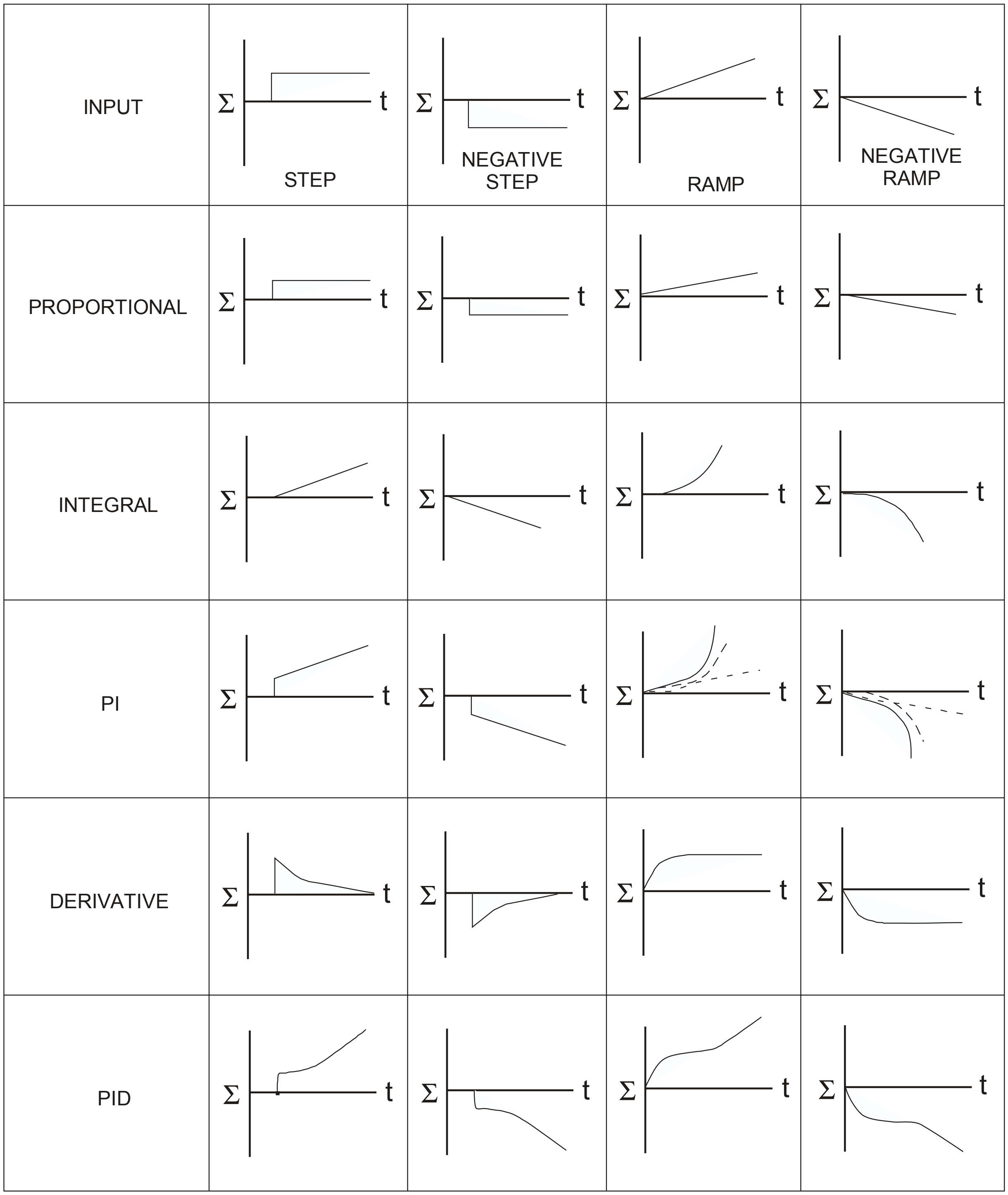


Figure 1.3-23 PID Controller Responses

0199-1

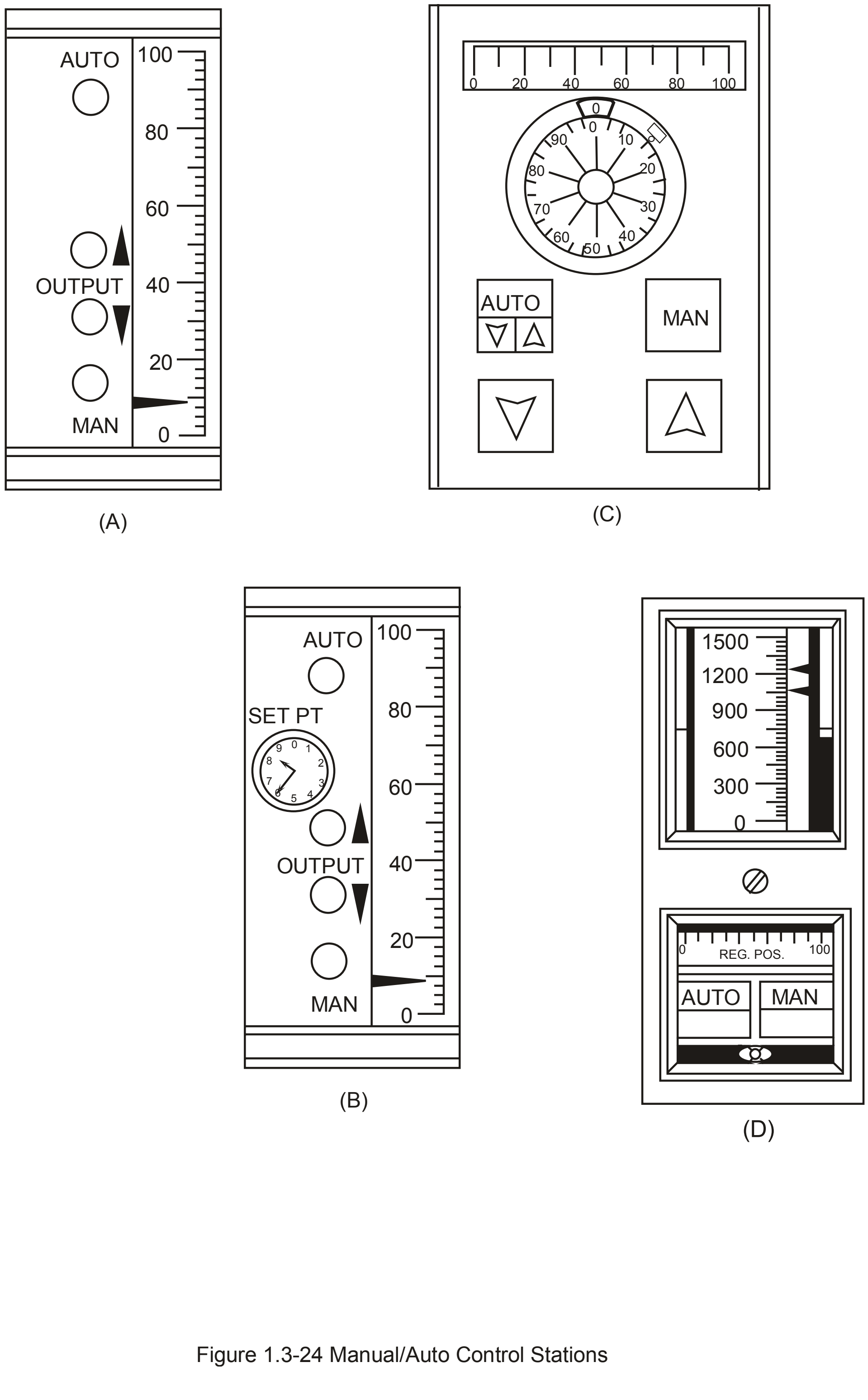


Figure 1.3-24 Manual/Auto Control Stations

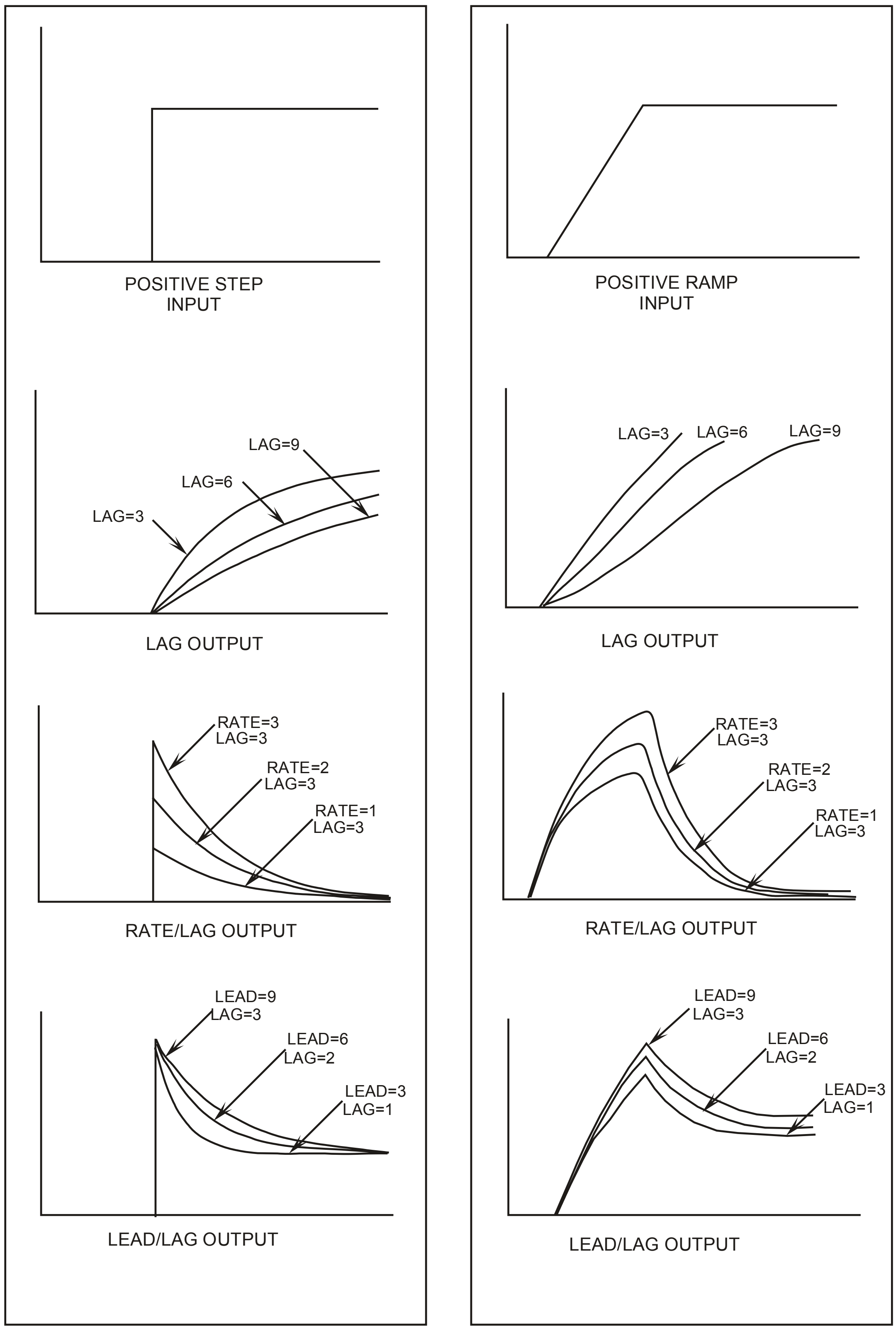


Figure 1.3-25 Signal Conditioning Output with Varying Time Constants

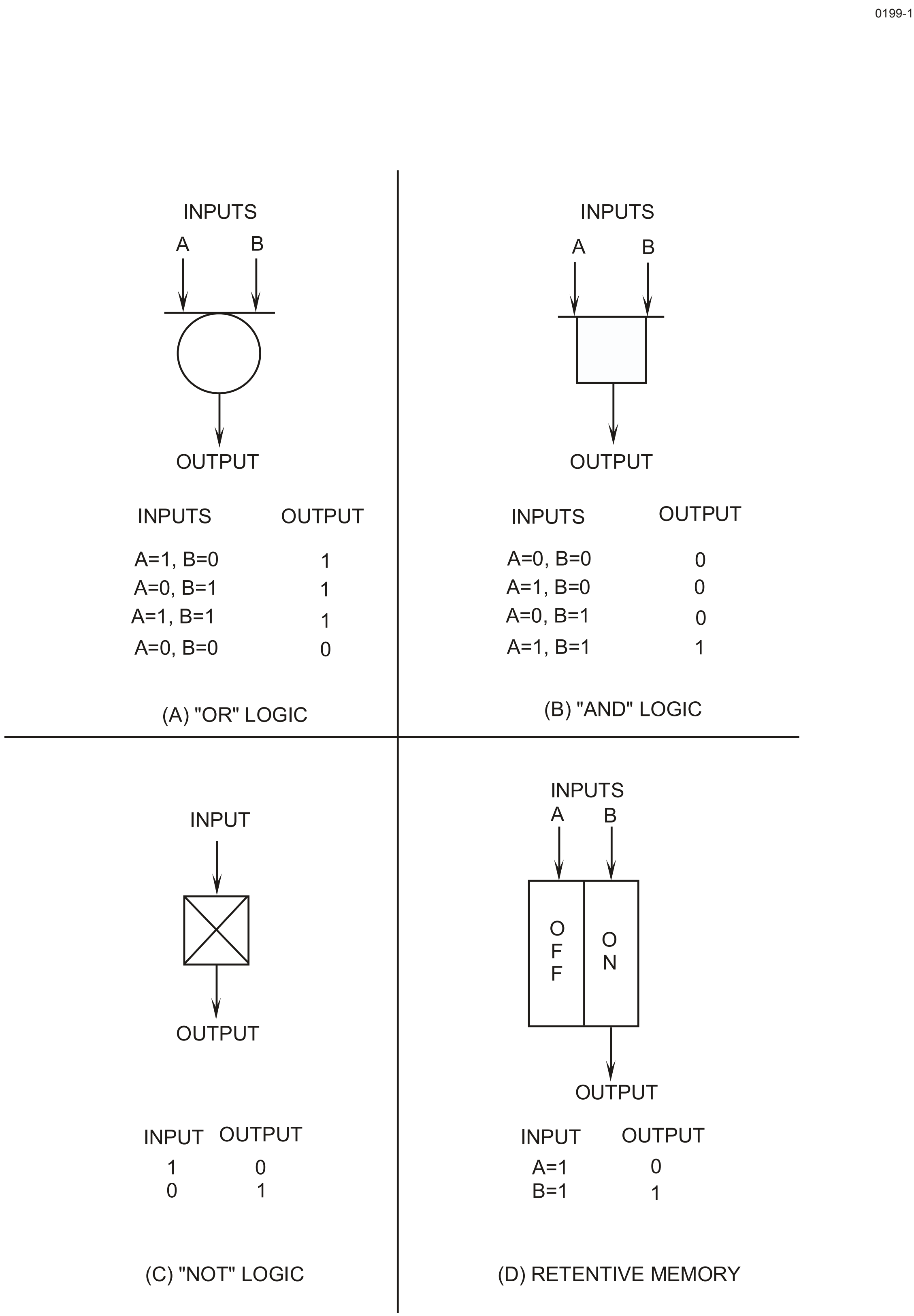
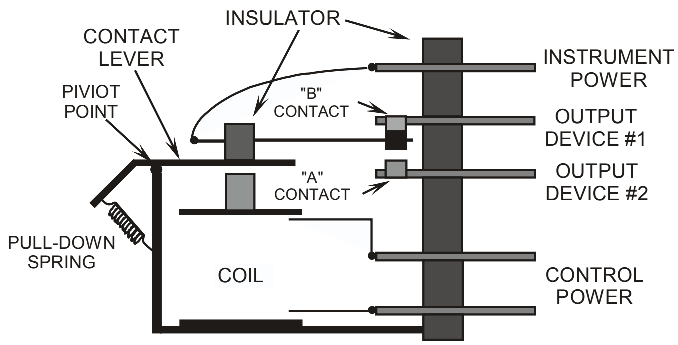


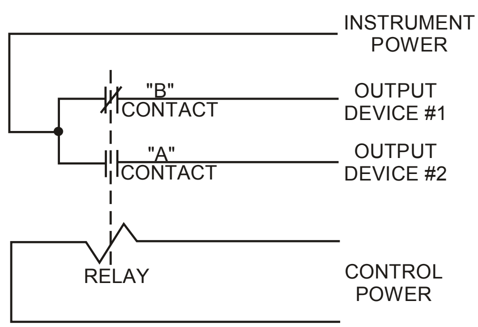
Figure 1.3-26 Logic Functions

0199-1



RELAY - MECHANICAL OPERATION

RELAY SHOWN DE-ENERGIZED



RELAY - ELECTRICAL OPERATION

RELAY SHOWN DE-ENERGIZED

Figure 1.3-27 Relay