Chapter 4
Electronic Control Fundamentals

4-1 What is electronic control?

Electronic control is a control circuit that operates on low voltage and uses solid-state components to amplify input signals and perform control functions, such as operating a relay or providing an output signal to position an actuator.

An electronic control system comprises *a sensor, controller, and final control element*. The sensors used in electronic control systems are simple, low mass devices that provide stable, wide range, linear, and fast response. *The electronic controller is a solid-state device that provides control over a discrete portion of the sensor range and generates an amplified correction signal to control the final control element*. Electronic controllers provide two-position, proportional, or proportional plus integral (PI) control.

In general, adjustments such as set point and throttling range necessary for the process can be done at the controller via potentiometers and/or switches.

What are the main features of electronic control systems? They are include:

1- Controllers can be remotely located from sensors and actuators.
2- Controllers can accept a variety of inputs.
3- Remote adjustments for multiple controls can be located together, even though sensors and actuators are not.
4- Electronic control systems can accommodate complex control and override schemes.
5- Universal type outputs can interface to many different actuators.
6- Display meters indicate input or output values.

The sensors and output devices (e.g., actuators, relays) used for electronic control systems are usually the same ones used on microprocessor-based systems. *The distinction between them is in the handling of the input signals*. In an electronic control system, the **analog** sensor signal is amplified, and then compared to a set point through voltage or current comparison and control circuits. In a microprocessor-based system, the sensor input is converted to a **digital** form, where discrete instructions (algorithms) perform the process of comparison and control.

The increasing sophistication and the decreasing cost of electronic devices, and their easy interface to computer-based controls, are leading to their more frequent use in preference to pneumatic devices.

What are the electronic control systems characteristics? *Electronic control usually have the following characteristics:*

Controller: Low voltage, solid state.

Inputs: 0 to 1V dc, 0 to 10V dc, 4 to 20 mA, resistance element, thermistor, thermocouple.

Outputs: 2 to 10V dc or 4 to 20 mA device.

Control Mode: Two-position, proportional, proportional plus integral (PI), step.

Electronic controls are distinguished from electrical by low voltages and solid-state circuitry.

4-2 TYPICAL SYSTEM:

Figure 4-1 shows a simple electronic control system with a controller that regulates supply water temperature by mixing return water with water from the boiler. The main temperature sensor is located in the hot water supply from the valve. To increase efficiency and energy savings, the controller resets the supply water temperature set point as a function of the outdoor air temperature. The controller analyzes the sensor data and sends a signal to the valve actuator to regulate the mixture of hot water to the unit heaters.

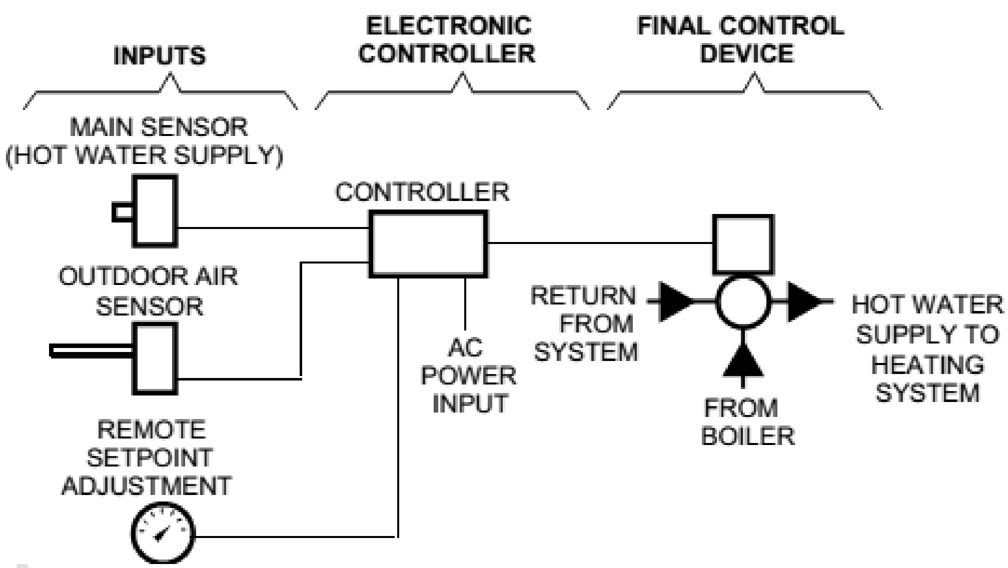


Fig. 4-1 Simple Electronic Control System

4-3 **COMPONENTS:**

An electronic control system includes sensors, controllers, output devices such as actuators and relays, final control elements such as valves and dampers, and indicating, interfacing, and accessory devices. Fig. 4-2 provides a system overview for many electronic system components.

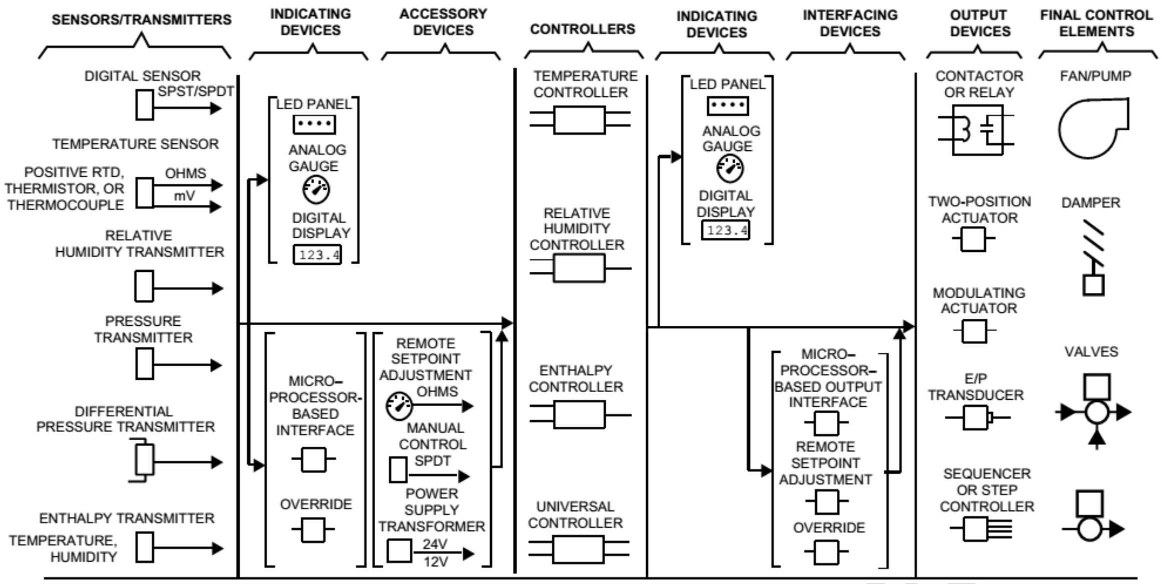


Figure 4-2 Typical Electronic Control System Components

4-4 Sensors:

4-4-1 Temperature sensors: for electronic control, temperature sensors are classified to:

1- Resistance Temperature Devices (RTDs) change resistance with varying temperature. RTDs have a positive temperature coefficient (**R** increases with **T**).

2- Thermistors are solid-state resistance-temperature sensors with a negative temperature coefficient.

3- Thermocouples directly generate a voltage as a function of temperature.

In general, all **Resistance Temperature Devices** (RTDs) have some common limitations:

a- The resistance of RTD elements varies as a function of temperature. Some elements exhibit large resistance changes, linear changes, or both over wide temperature ranges.

b- The controller must provide some power to the sensor and measure the varying voltage across the element to determine the resistance of the sensor. This action can cause the element to heat slightly (called self-heating) and can create an inaccuracy in the temperature measurement. By reducing the supply current or by using elements with higher nominal resistances the self-heating effect can be minimized.

c- Some RTD element resistances are as low as 100 ohms. In these cases, the resistance of the lead wires connecting the RTD to the controller may add significantly to the total resistance of the connected RTD, and can create an error in the measurement of the temperature.

d- The usable temperature range for a given RTD sensor may be limited by nonlinearity at very high or low temperatures.

e- RTD elements that provide large resistance changes per degree of temperature reduce the sensitivity and complexity of any electronic input circuit.

Solid-State Resistance Temperature Devices

Fig.4-3 shows examples of solid-state resistance temperature sensors having negative and positive temperature coefficients. Thermistors are negative temperature coefficient sensors typically enclosed in very small cases (similar to a glass diode or small transistor) and provide quick response. As the temperature increases, the resistance of a thermistor decreases.

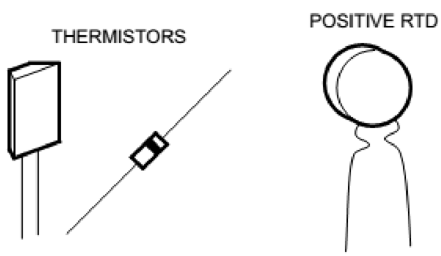


Fig. 4-3 Solid-State Temperature Sensors

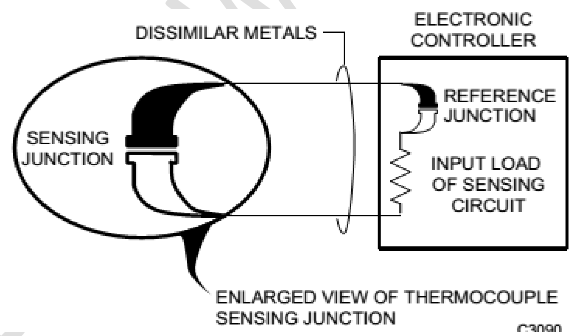


Fig.4-4 Basic Thermocouple Circuit

Thermocouples: it consists of two dissimilar metals, such as iron and constantan, welded together to form a two thermocouple junctions (Fig.4-4). Temperature differences at the junction's causes a voltage, in the millivolt range, which can be measured by the input circuits of an electronic controller.

4-4-2 RELATIVE HUMIDITY SENSOR

Various sensing methods are used to determine the percentage of relative humidity, including the measurement of changes of resistance, capacitance, impedance and frequency.

Resistance Relative Humidity Sensor

An older method that used resistance to determine relative humidity depended on a layer of hygroscopic salt, such as lithium chloride or carbon powder, deposited between two electrodes (Fig.4-5). Both materials absorb and release moisture as a function of the relative humidity, causing a change in resistance of the sensor. An electronic controller connected to this sensor detects the changes in resistance which it can use to provide control of relative humidity

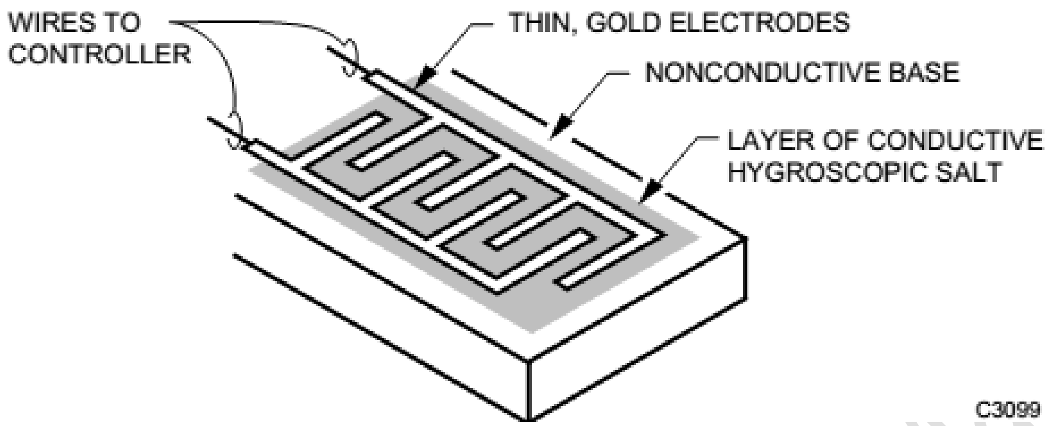


Fig. 4-5 Resistive Type Relative Humidity Sensor

Capacitance Relative Humidity Sensor: A method that uses changes in capacitance to determine relative humidity measures the capacitance between two conductive plates separated by a moisture sensitive material such as ***polymer plastic*** (Fig.4-6A). As the *material absorbs water, the capacitance between the plate's decreases and the change can be detected by an electronic circuit.* To overcome any ***hindrance*** of the material's ability to absorb and release moisture, the two plates and their electric lead wires can be on one side of the polymer plastic and a third sheet of extremely thin conductive material on the other side of the polymer plastic form the capacitor (Fig.4-6B). This third plate, too thin for attachment of lead wires, allows moisture to penetrate and be absorbed by the polymer thus increasing sensitivity and response.

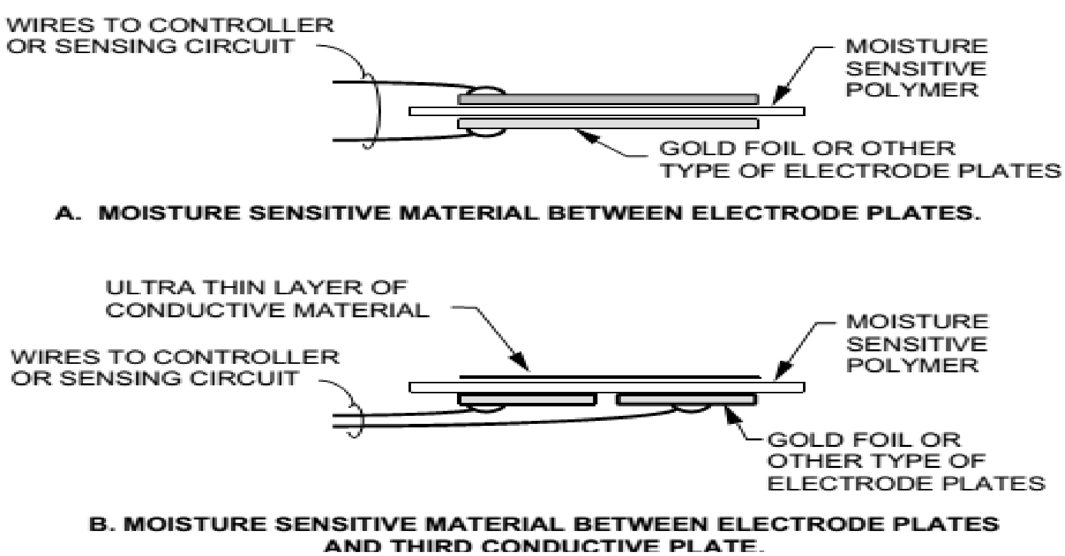


Fig. 4-6 Capacitance Type Relative Humidity Sensor

Chilled dew point mirror Humidity sensor

One of the most accurate dew-point sensors is the chilled-mirror type polished mirror is provided with a small thermoelectric cooling system and a light beam is reflected from the mirror to a photo cell (Figure 4-7). When the mirror is cooled to the ambient dew-point temperature, moisture condenses on it, changing the mirror from a specular to a diffuse relector. The resulting change in light reflectivity serves as feedback to a circuit that controls the temperature of the mirror so that it is at the dew point. The mirror temperature (the dew-point temperature) is measured by platinum RTD. The only maintenance required is periodic cleaning of the mirror. By simultaneously measuring the dry bulb temperature, one can compute the relative humidity.

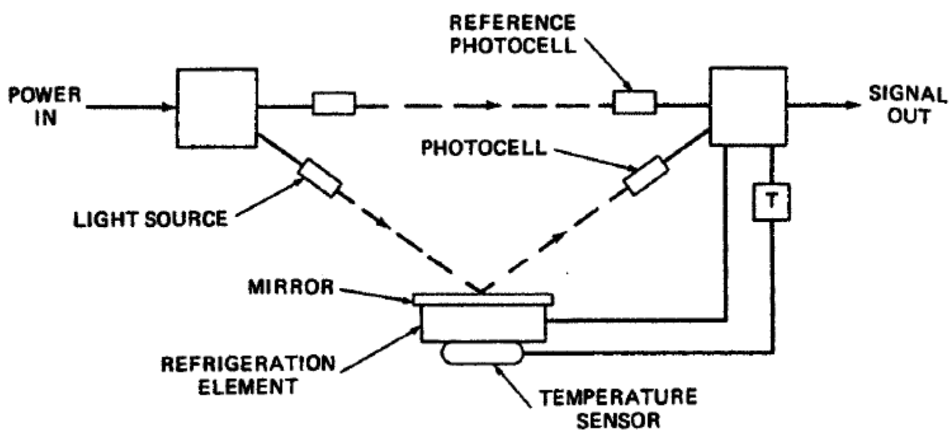


Fig. 4-7 Principle of chilled dew point mirror sensor

4-4-3 PRESSURE SENSORS

An electronic pressure sensor converts pressure changes into a signal such as voltage, current, or resistance that can be used by an electronic controller.

Resistance Pressure Sensor A method that measures pressure by detecting changes in resistance uses a small flexible diaphragm and a strain gage assembly. The strain gage assembly includes very fine (serpentine) wire or a thin metallic film deposited on a nonconductive base. The strain gage assembly is stretched or compressed as the diaphragm flexes with pressure variations. The stretching or compressing of the strain gage (shown by dotted line in Fig.4-8) changes the length of its fine wire/thin film metal, which changes the total resistance. The resistance can then be detected and amplified. These changes in resistance are small. Therefore, an amplifier is provided in the sensor assembly to amplify and condition the signal so the level sent to the controller is less susceptible to external noise interference. The sensor thus becomes a transmitter.

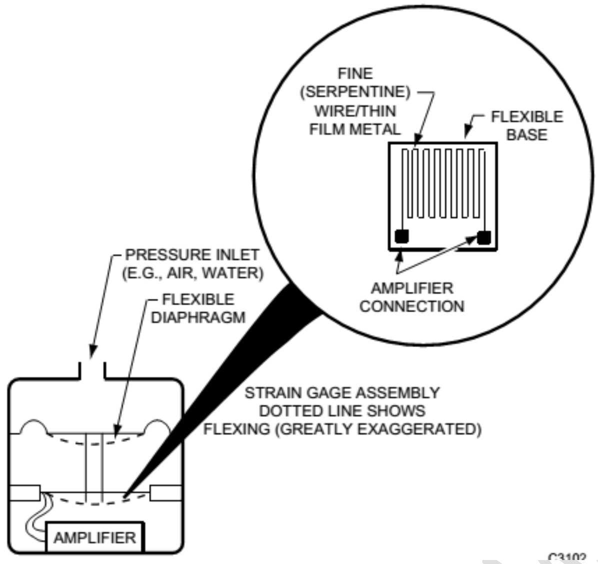
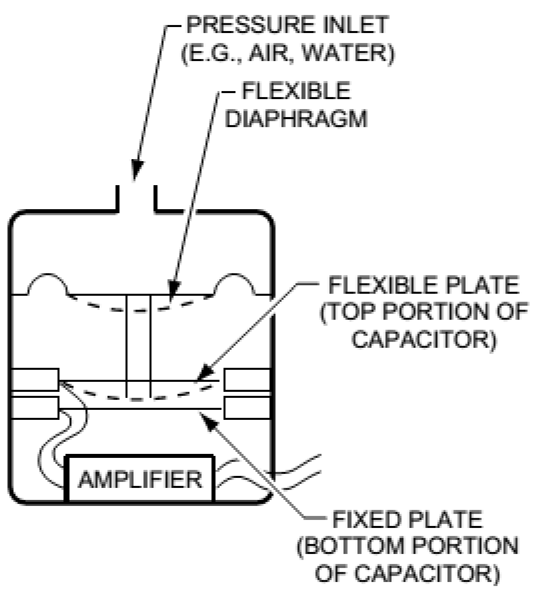


Fig. 4-8 Resistance Type Pressure Sensor

Another pressure sensing method measures capacitance (Fig.4-9). A fixed plate forms one part of the capacitor assembly and a flexible plate is the other part of the capacitor assembly. As the diaphragm flexes with pressure variations, the flexible plate of the capacitor assembly moves closer to the fixed plate and changes the capacitance.

A variation of pressure sensors is one that measures differential pressure using dual pressure chambers (Fig.4-10). The force from each chamber acts in an opposite direction with respect to the strain gage. This type of sensor can measure small differential pressure changes even with high static pressure.



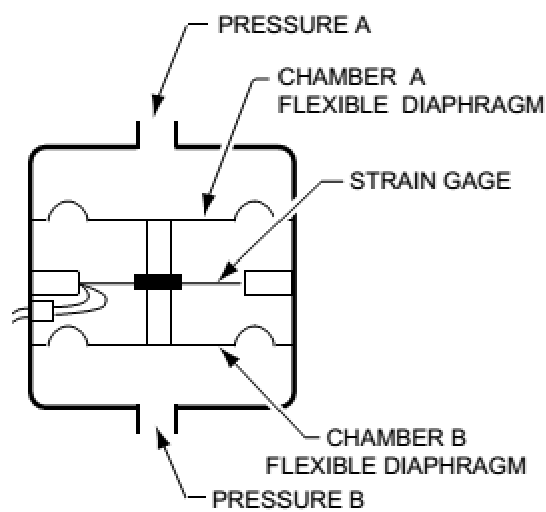


Fig. 4-9 Capacitance Type Pressure Transmitters **Fig. 4-10 Differential Pressure Sensor**

4-5 CONTROLLER:

The electronic controller receives a sensor signal, amplifies and/or conditions it, compares it with the set point, and derives a correction if necessary. The output signal typically positions an actuator. Electronic controller circuits allow a wide variety of control functions and sequences from very simple to multiple input circuits with several sequential outputs. ***Controller circuits use solid-state components such as transistors, diodes, and integrated circuits and include the power supply and all the adjustments required for proper control***.

INPUT TYPES

Electronic controllers are categorized by the type or types of inputs they accept such as temperature, humidity, enthalpy, or universal.

1- **Temperature Controllers**, typically require a specific type or category of input sensors. Some have input circuits to accept RTD sensors such as BALCO or platinum elements, while others contain input circuits for thermistor sensors. These controllers have set point and throttling range scales labeled in degrees F or C.

2- **Relative Humidity Controllers**: The input circuits for relative humidity controllers typically receive the sensed relative humidity signal already converted to a 0 to 10V dc voltage or 4 to 20 mA current signals. Set point and scales for these controllers are in percent relative humidity.

3- **Enthalpy Controllers** are specialized devices that use specific sensors for inputs. In some cases, the sensor may combine temperature and humidity measurements and convert them to a single voltage to represent enthalpy of the sensed air. In other cases, individual dry bulb temperature sensors and separate wet bulb or relative humidity sensors provide inputs and the controller calculates enthalpy. In typical applications, the enthalpy controller provides an output signal based on a comparison of two enthalpy measurements, indoor and outdoor, rather than on the actual enthalpy value. In other cases, the return air enthalpy is assumed constant so that only outdoor air enthalpy is measured. It is compared against the assumed nominal return air value.

4- **Universal Controllers**: The input circuits of universal controllers can accept one or more of the standard transmitter/transducer signals. The most common input ranges are 0 to 10V dc and 4 to 20 mA. Other input variations in this category include a 2 to 10V dc and a 0 to 20 mA signal. Because these inputs can represent a variety of sensed variables such as a current of 0 to 15 amperes or pressure of 0 to 21000 kPa, the settings and scales are often expressed in percent of full scale only.

4-6 OUTPUT CONTROL

Electronic controllers provide outputs to a relay or actuator for the final control element. The output is not dependent on the input types or control method. The simplest form of output is two-position where the final control element can be in one of two states. For example, an exhaust fan in a mechanical room can be turned either on or off. The most common output form, however, provides a modulating output signal which can adjust the final control device (actuator) between 0 and 100 percent such as in the control of a chilled water valve.

- **Two positions** devices such as relays, motor starters, and solenoid valves have only two discrete states. These devices interface between the controller and the final control element. For example, when a solenoid valve is energized, it allows steam to enter a coil which heats a room (Fig.4-11). The solenoid valve provides the final action on the controlled media, steam. Damper actuators can also be designed to be two-position devices.

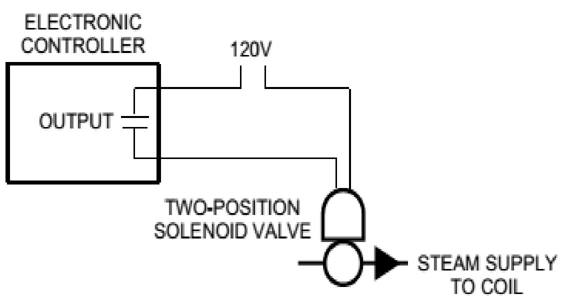


Fig. 4-11 Two-Position Control

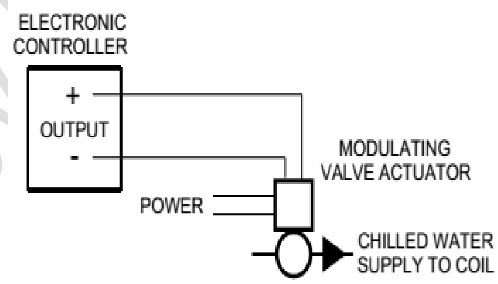


Fig.4-12 Modulating Control

- **Modulating actuators** use a varying control signal to adjust the final control element. For example, a modulating valve controls the amount of chilled water entering a coil so that cool supply air is just sufficient to match the load at a desired set point (Fig. 4-12). The most common modulating actuators accept a varying voltage input of 0 to 10 or 2 to 10V dc or a current input of 4 to 20 mA. Another form of actuator requires a pulsating (intermittent) or duty cycling signal to perform modulating functions. One form of pulsating signal is a Pulse Width Modulation (PWM) signal.

4-7 TRANSDUCERS

In some applications, a transducer converts a controller output to a signal that is usable by the actuator. For example, Figure 4-13 shows an Electronic-to-Pneumatic (E/P) transducer: electronic to-pneumatic that converts a modulating 2 to 10V dc signal from the electronic controller to a pneumatic proportional modulating 20 to 90 kPa signal for a pneumatic actuator.

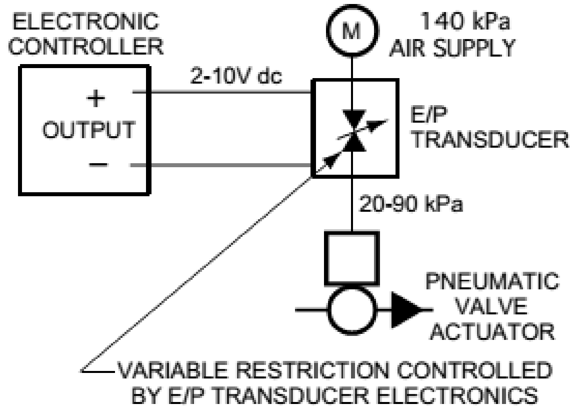


Fig. 4-13 Electric-to-Pneumatic Transducer

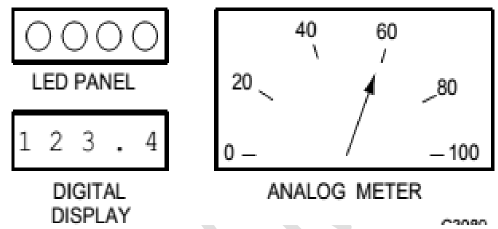


Fig.4-14 Indicating Devices

4-8 INDICATING DEVICES

An electronic control system can be enhanced with visual displays that show system status and operation. Many electronic controllers have built-in indicators that show power, input signal, deviation signal, and output signal. Figure 4-14 shows some types of visual displays. An indicator light can show on/off status or, if driven by controller circuits, the brightness of a light can show the relative strength of a signal. If a system requires an analog or digital indicating device and the electronic controller do not include this type of display, separate indicating devices can be provided.

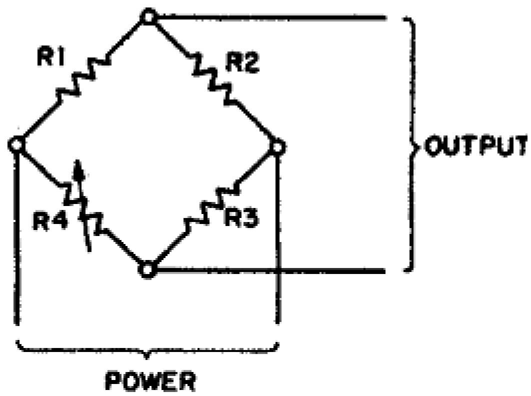
4-9 INTERFACES WITH OTHER SYSTEMS

It is often necessary to interface an electronic control device to a system such as a microprocessor-based building management system. An example is an interface that allows a building management system to adjust the set point or amount of reset (compensation) for a specific controller. Compatibility of the two systems must be verified before they are interconnected

4-10 Bridge Circuits

The original and most commonly used bridge circuit is the Wheatstone bridge (Fig.4-15) Bridge is formed by four resistances connected as shown. Power is connected to two corners of the bridge, and output to the two opposite corners. One or more of the resistances may be variable. (R4 is shown here as variable by the arrow across it.) When all resistances are equal the output is zero. If one or more of the resistances is changed, the bridge becomes unbalanced, and an output signal results that is approximately proportional to the resistance change.

In the ordinary electronic sensor, the variable resistor is the sensing element and is often mounted remote from the rest of the bridge and the amplifier (Figure 4-16). When remote mounting is required, some method may be needed to compensate for the resistance of the connecting wire.



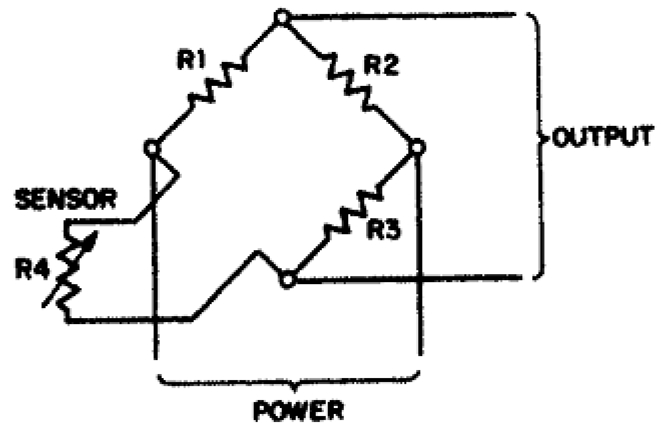


Figure 4-15 Wheatstone bridge **Figure 4-16 Wheatstone bridge with remote sensor**

This very simple arrangement does not allow for adjustment of the set point or calibration. For these functions it is necessary to add two more resistances (Fig.4-17). The set point adjustment is in series (or parallel) with the sensor resistor, and the calibration adjustment is a potentiometer with an adjustable wiper arm.

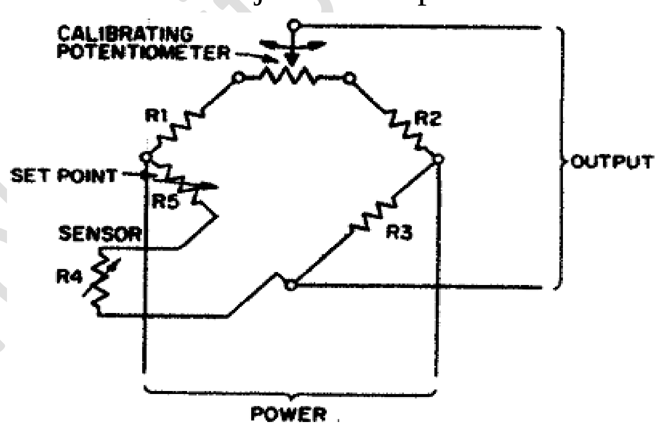


Figure 4-17 Bridge with calibration and set point

To provide negative feedback for modulating controls a throttling range bridge must be added to the circuit. This is wired in series with the main bridge (Figure 4-18). It includes a variable potentiometer with a wiper arm that is driven by the controlled device motor. When the main bridge is unbalanced and causes the motor to run, this potentiometer adjusts the throttling range bridge to offset the effect of the sensor and rebalance the system. In a simpler arrangement, the motor-driven potentiometer may be placed in series with the sensor, but then the throttling range is not adjustable.

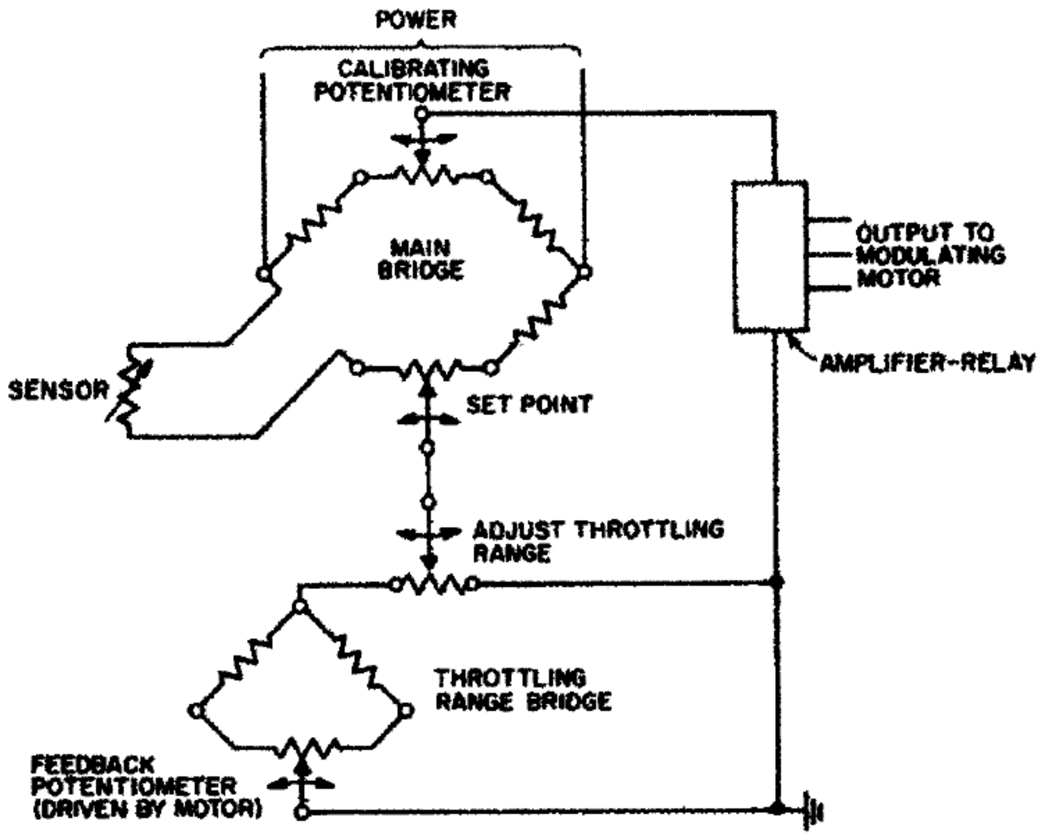


Figure 4-18 Throttling range bridge.

Sensing and relating of two control points, such as room temperature and discharge temperature, may be done with a single bridge circuit (Figure 4-19). Here the two sensors are shown on opposite sides of the bridge, but the room sensor has the same basic resistance as the other legs of the bridge. The discharge sensor usually has only 10% to 20% of the basic resistance, with the balance being finished by fixed resistors. This gives the discharge sensor less authority, the amount being expressed as the ratio of discharge sensor resistance to room sensor resistance. Typical values are 1000 ohms for the room sensor and 100 ohms for the discharge sensor. Then the authority of the discharge sensor is 100: 1000 or lo%, which means that a 10-degree rise in discharge temperature is necessary to rebalance the bridge after a one-degree fall in room temperature.

Thus, when the room temperature decreases, the resistance of the room sensor R1 is decreased. This unbalances the bridge and causes an output to the amplifier. This may cause a hot water valve to open, which increases the discharge air temperature. This is sensed by the discharge sensor R2 and results in an increased resistance at the sensor until the bridge is rebalanced.

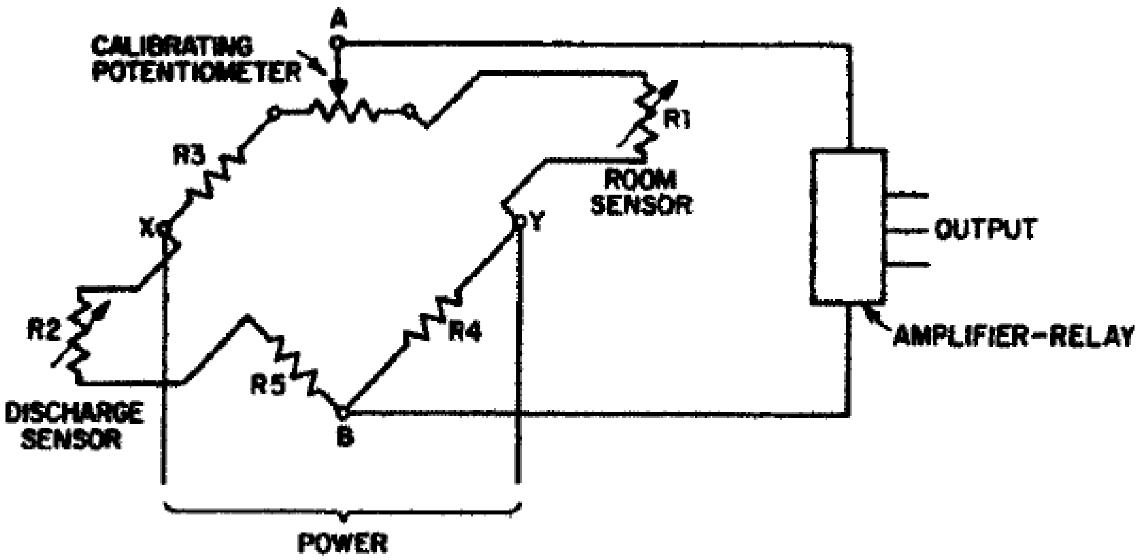


Figure 4-19 Bridge with two sensors.

4-11 Electronic Controllers:

The basic element in an electronic controller is a device called an operational amplifier (OP Amp) (figure 4-20). ***The OP Amp is a solid-state amplifier that can provide a large gain while handling signals that vary with time and over a wide frequency range.*** *The gain of the OP Amp is the negative of the ratio of voltage out to voltage in; thus*: $\mu = -(V_O/V_i)$

Because the gain of an OP Amp is very high (essentially infinity in the idealization of an OP Amp), any small input current or corresponding input voltage will produce a very large negative output voltage. ***To make the OP Amp useful, resistors and capacitors are used as parts of the input and feedback circuits***

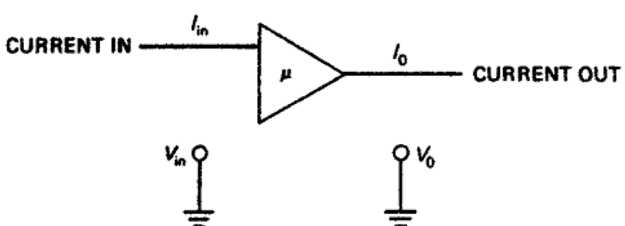


Figure 4-20 Ideal operational amplifiers (OP amp)

Figure **4-21** shows a proportional amplifier. To understand how this device works, recall that any input current to the OP Amp will create a large negative output voltage. Acting through the feedback resistor, this negative voltage will cause the input voltage to drop to a value very near zero. For this to occur, almost all the current must flow around the OP Amp though the feedback resistor. We can now see how the proportional amplifier functions. For example, suppose that both the input resistor and the feedback resistor have the same value and Vi is 5 V. If all the current is to flow around the OP Amp, and the input voltage to the OP Amp is to be near zero, the output of the OP Amp must be -5 V. Similarly, if Vi is **10** V, the output of the circuit will be **-10** V. Now suppose that the feedback resistor has twice the resistance of the input resistor. We see that in this case if Vi is 5 V, the output of the circuit will be **-10** V. This shows how ***the <u>gain</u> of the proportional amplifier is determined by the ratio of the feedback to input resistors***. The symbol for a proportional amplifier used in control diagrams is also shown in Figure **4-21**

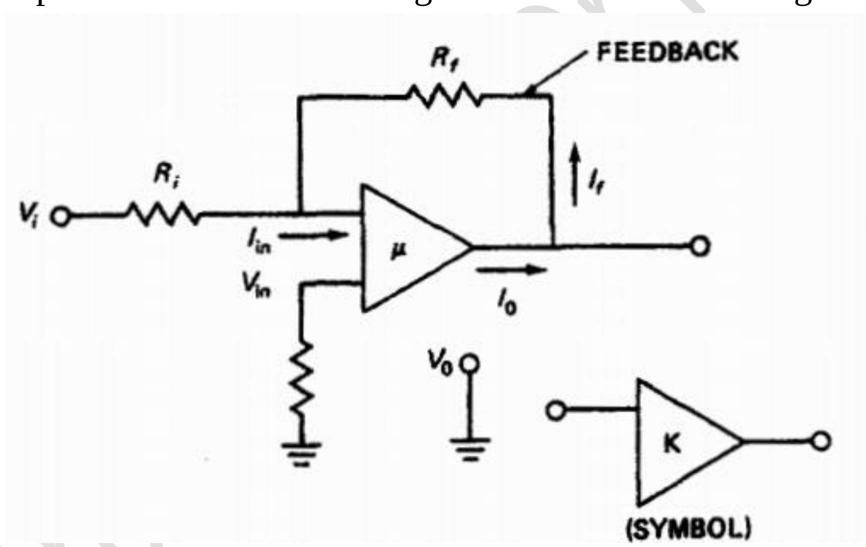


Figure 4-21 Basic proportional OP amp.

To build circuits that integrate or differentiate an input signal, a combination of capacitance and resistance must be used. ***Figure 4-22shows the integral mode arrangement with an input resistor and a feedback capacitor***. ***The gain becomes a function of the charging time of the capacitor.***

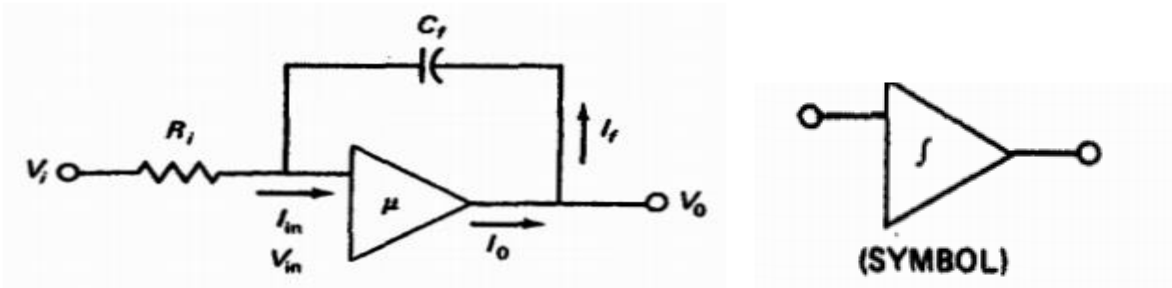


Figure 4-22 Integrating OP amp.

Figure 4-23 shows a derivative mode arrangement with an input capacitor and a feedback resistor. To combine the various modes, other **OP** Amps are used as summing. The simple "summing" circuitry is shown in Figure 4-24. Subtraction is shown in Figure 4-25**.**

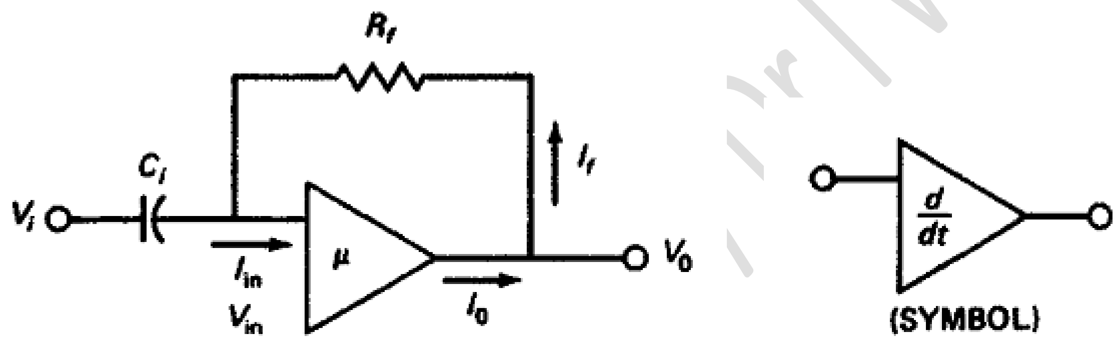


Figure 4-23 Derivative OP amp

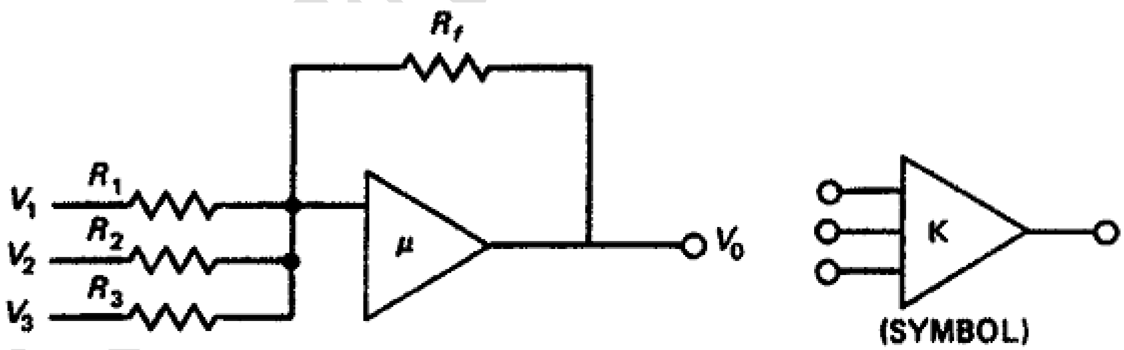


Figure 4-24 Summing OP amp.

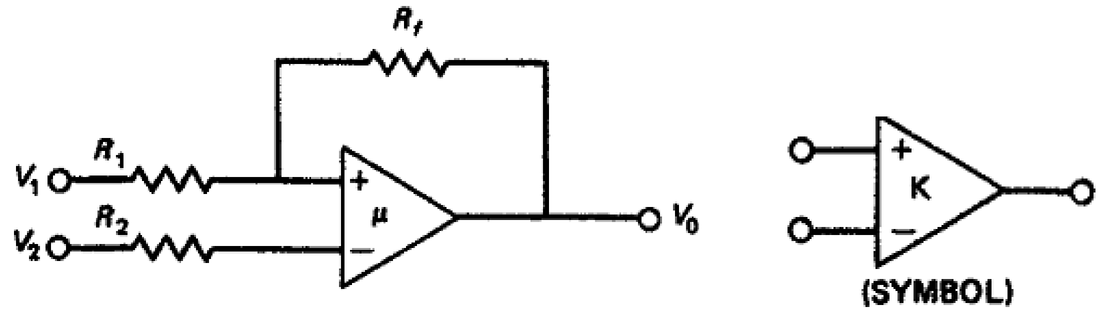


Figure 4-25 Subtraction OP amp.

To form a complete electronic controller, two input voltages are added algebraically (with due regard for negative and positive signs) to compare the set point and the measured value of the variable (the measured value might be the output from a Wheatstone bridge circuit, for example). The output from this sum is fed to up to three other OP Amp circuits where proportional, integral, and derivative control signals are produced. These are fed to a sum to produce the final output as shown in Figure 4-26.

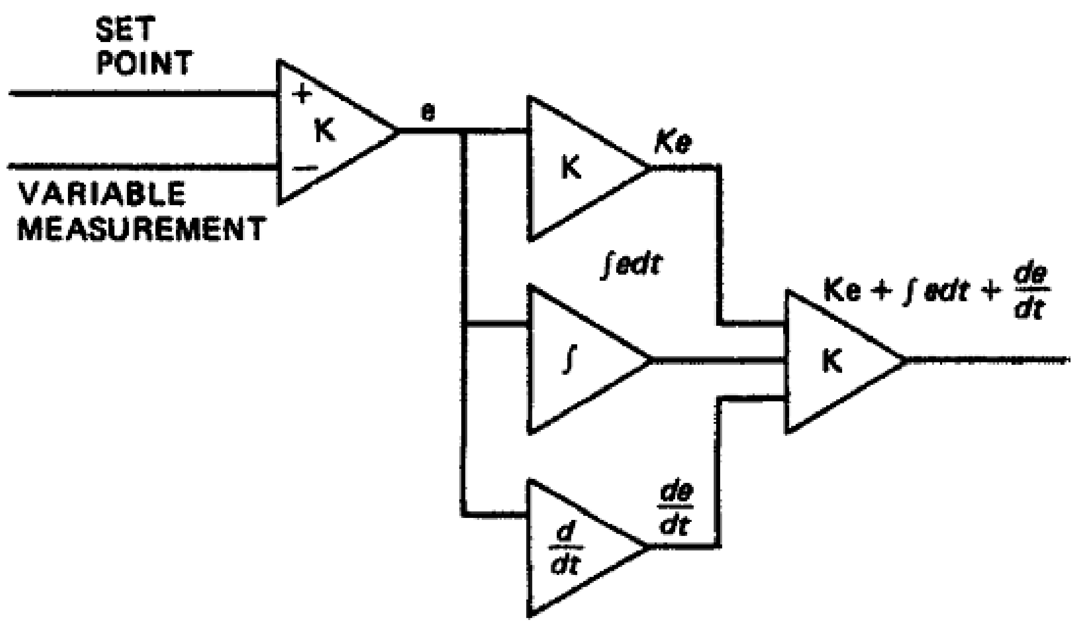


Figure 4-26 Ideal OP amp PID controllers.

All the circuits illustrated are in simplified form, showing only the essential elements. In practice, additional circuitry is required to power the circuits, provide constant voltage for bridge circuits, provide sufficient output power, filter out high frequency noise, signals and provide other conveniences. Adjustable resistors and capacitors are needed to allow operators to adjust set points and proportional, integral, and derivative gains.

Questions and Answers

1- What are the main features of electronic control systems?
2- What are the electronic control systems characteristics?
3- What is the main distinction between electronic and electric control systems?
4- Draw a schematic diagram shows a simple electronic control system with a controller that regulates supply water temperature by mixing return water with water from the boiler?
5- What is the main distinction between electronic and microprocessor control system?
6- What are three classifications of temperature sensors in electronic control systems?
7- List two types of relative humidity sensors in electronic control systems?
8- List four types of electronic controllers used in HVAC systems?
9- Draw a schematic diagram showing a Wheatstone bridge with remote sensor?
10- Draw a schematic diagram showing a Wheatstone bridge with calibration and set point?
11- Define the following: Electronic control, Thermistor, Operational amplifier,
12- What are the Rationalization of:

- Electronic control devices are more used in preference to pneumatic devices?
- For operational amplifier (OP Amp) any .small input current or corresponding input voltage will produce a very large negative output voltage?
- For Operational amplifier (OP Amp) resistors and capacitors are used as parts of its input and feedback circuits?

13- Draw the circuits in simplified form, showing only the essential elements of:

   1- Ideal operational amplifiers (OP amp) controller?
   2- Basic proportional OP amp controller?
   3- Integrating OP amp controller?
   4- Derivative OP amp controller?
   5- Summing OP amp controller?
   6- Subtraction OP amp. Controller? .
   7- Ideal OP amp PID controller?

14- Answer the following sentences by **Yes or No, then correct the Wrong one**:

- The gain of the OP Amp is the *positive* of the ratio of voltage out to voltage in.
- To make the OP Amp useful, *actuators* are used as parts of the input and feedback circuits.
- The gain of the proportional amplifier is determined by the ratio of the *input to feedback resistors.*