

CHAPTER 2: ELECTRONIC CONTROL

MODULE 2: CONTROL EQUIPMENT

Inductive Position Detectors

- This type of position detector is widely used by instrument manufacturers (e.g., Fischer and Porter) as a means of providing a voltage change which is proportional to a positional input.
- A permeable ferrite disc is positioned by the process variable (i.e. pressure) with respect to a "sensing" coil.
- With the disk in a given position, the coil inductance (L) will cause a particular reactance ($X_L = 2\pi f L$) resultant voltage applied to the detector in Figure 1 will be $V_2 = E_x - V_1$.
- If the process pressure increases, the ferrite disk is moved closer to the sensing coil, raising the magnetic flux density in the coil (the same effect as placing an iron core in a solenoid), and therefore increases its inductance.

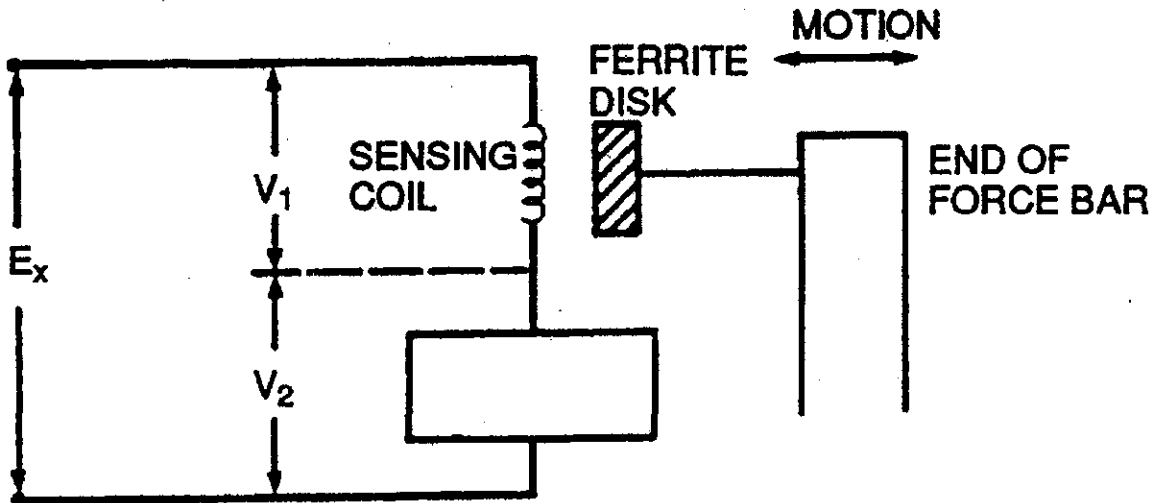


Figure 1: A Variable Inductance Position Sensor.

The resulting inductive reactance increase for the coil will cause a larger voltage drop across the coil and consequently, a lower potential applied to the detector (V_2). The net result of such a displacement detector will be a voltage change linearly related to the measured change in process pressure. This voltage can in turn be used to produce a 4-20 mA signal.

Note that the excitation voltage E_x is an a-c voltage at a fairly high frequency, typically 5000 Hz. A high frequency voltage is used because:

1. It reduces the physical size of the coil for a particular reactance ($X_L = 2 \cdot \text{frequency} \cdot L$).
2. It minimizes the effect of 60 Hz power line interference.

Variable Core Transformer Detector

The variable core transformer detector is a modified version of the inductance detector. The position of the core of a differential transformer is varied directly to the process pressure to provide a change in the secondary potential. (See Figure 2)

The core, which is a ferrite slug, is positioned half way between the two secondary coils when the differential pressure is zero. The secondary coils, which are connected in series opposition, will have the same output and therefore, the net secondary voltage is zero.

As the process pressure increases, the core is forced upwards, increasing the inductive coupling in the top winding (Sec 1) and decreasing it in the lower winding (Sec 2). This results in a net secondary voltage. The secondary output voltage can be monitored to provide an indication of the process pressure. This type of position detector is used by manufacturers such as Foxboro.

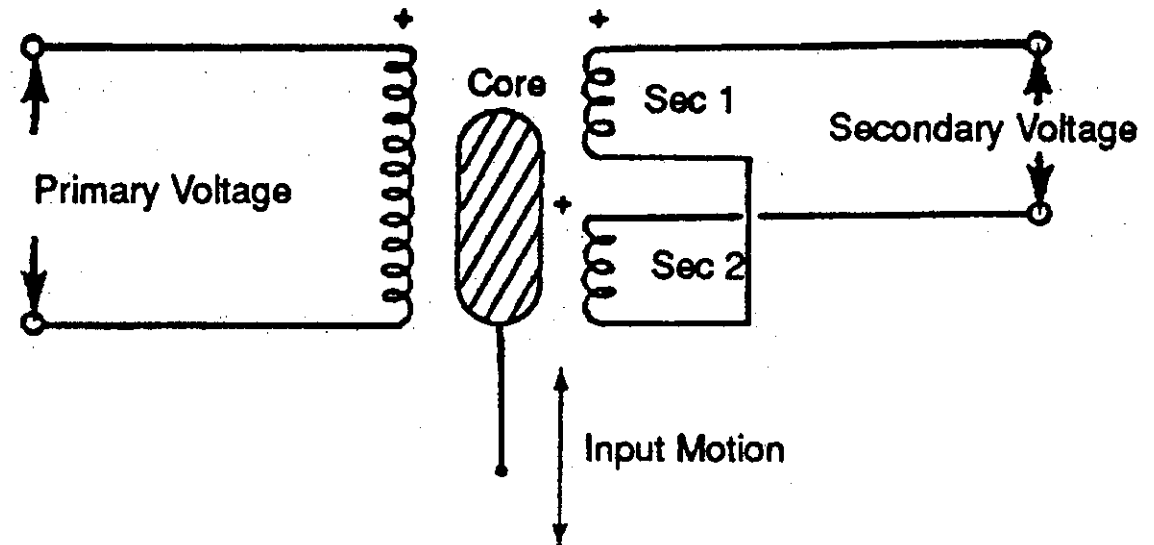


Figure 2: A Typical Variable Core Differential Transformer (Foxboro) Displacement Sensor.

Capacitive Position Detectors

The capacitive detector (manufactured by Rosemount) responds to an increase in process pressure with a decrease in capacitive reactance.

A capacitive detector employs a DP capsule in which the facing capsule sides are actually the plates of a capacitor (Figure 3).

As the applied differential pressure is increased, the separation distance between the plates is decreased, thus raising the capacitance ($C = KE_0 A/d$)

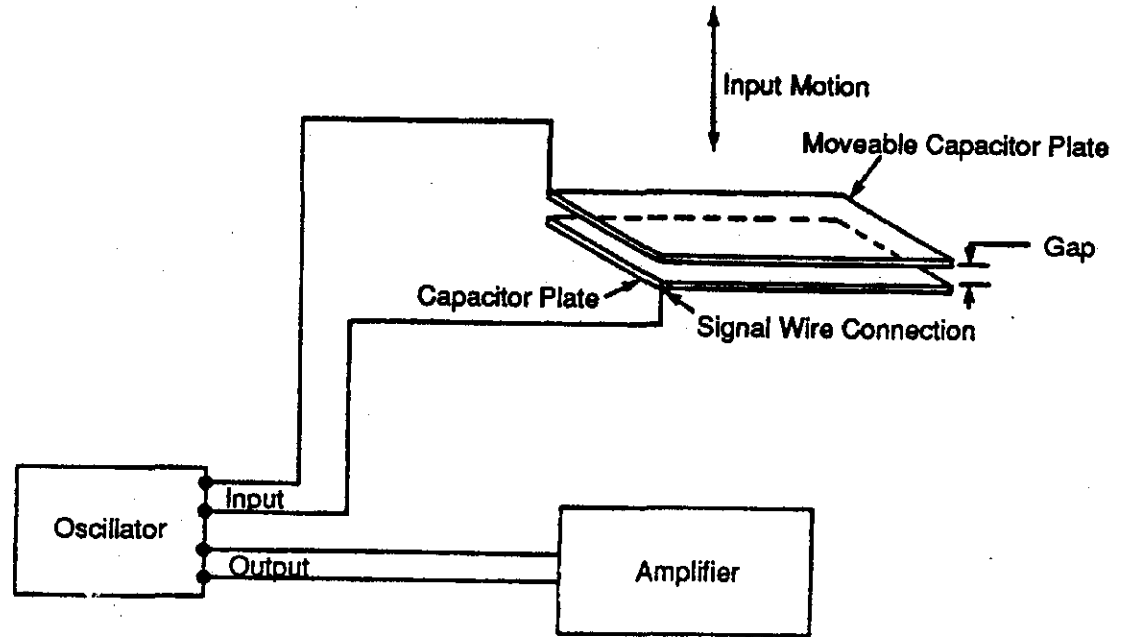


Figure 3: A Capacitance Type DP Capsule.

Figure 4 shows that an oscillator supplies and receives a-c voltage with respect to the capacitor plates. The distance between the plates determines the capacitance of the detector. In turn the capacitance determines the output frequency of the oscillator circuit. The frequency signal acts as the input to the amplifier which produces a 4-20 mA signal.

The capacitor DP capsule is sealed at the time of manufacture and is, generally, impossible to repair. Precision and reliability of manufacture make it unnecessary to maintain or service this type of detector except in unusual situations. Capacitive detector, DP transmitters, have become more popular in process applications.

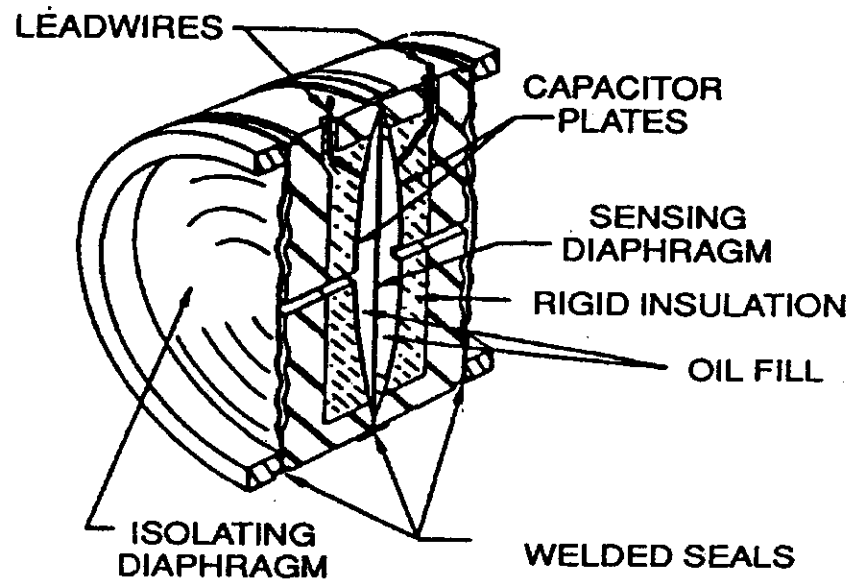


Figure 4: Typical Capacitive Capsule.

Resistive (Strain Gauge) Detectors

- The bonded strain gauge is a device which is fixed to the surface of an object to detect the strain as a force is applied to the object.
- One form of the strain gauge is a metal wire of very small diameter laid in a multi-looped configuration as shown in Figure 5.
- For a metal Resistance = $\rho \cdot \text{length} / \text{area}$
- Where ρ is the resistivity of the metal.
- When force is applied as indicated in Figure 5, the overall length of the wire tends to increase while the cross-sectional area decreases.
- The amount of increase in resistance is proportional to the force which reduced the change in length and area.
- The output of the strain gauge is a change in resistance which can be measured by the input circuit of an amplifier.

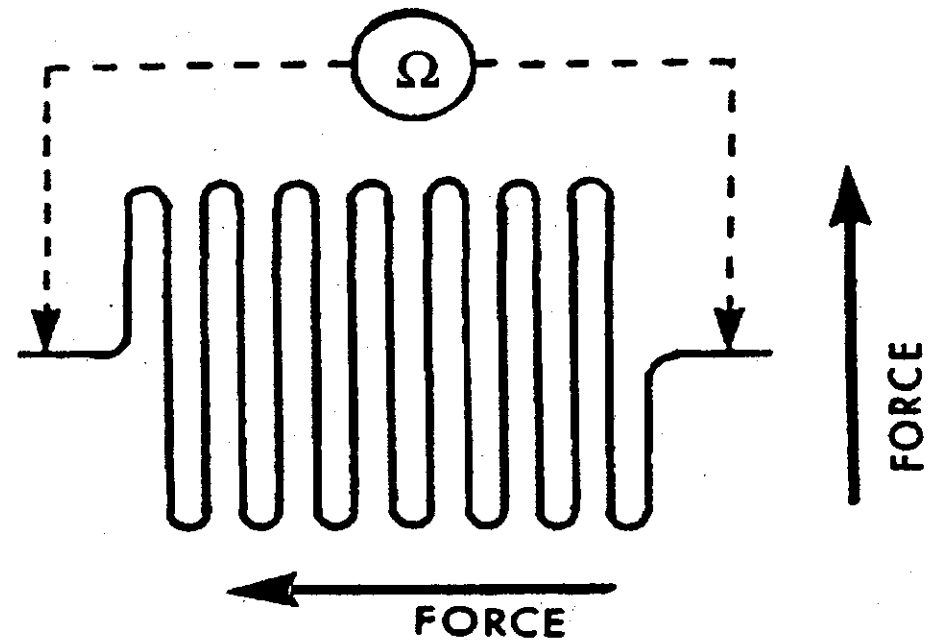


Figure 5: A Metallic Conductor Bonded Strain Gauge Device.

Strain gauges can be bonded to the surface of a pressure capsule or to a force bar positioned by the measuring element.

Shown in Figure 6 is a strain gauge that is bonded to a force beam inside the DP capsule.

The change in the process pressure will cause a resistive change in the strain gauges, which is then used to produce a 4-20 mA signal.

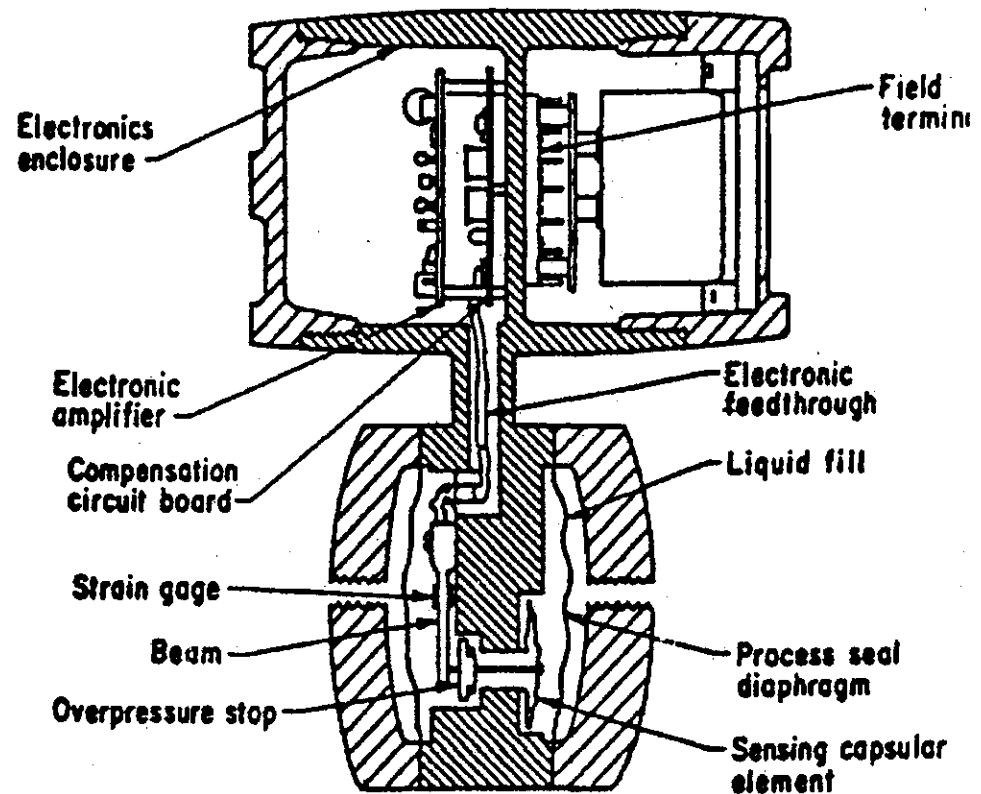


Figure 6: Resistive Pressure Transmitter.

Alarm Indicators

Suppose we have a tank with water inflow throttled by a hand valve and an outflow controlled by a centrifugal pump as illustrated in Figure 7.

- If the water level in the tank gets too high due to inflow or outflow disturbances, the tank will overflow.
- On the other hand, if the water level gets too low, suction head is reduced and pump cavitation may occur.
- In either case, devices that can warn the operator of these abnormal process conditions are needed.
- If a high level alarm and a low level alarm are installed, the operator will have enough time to intervene and adjust these abnormal process conditions before any damage occurs.
- Alarms are the first line of defense against abnormal conditions, so their correct operation is very important.

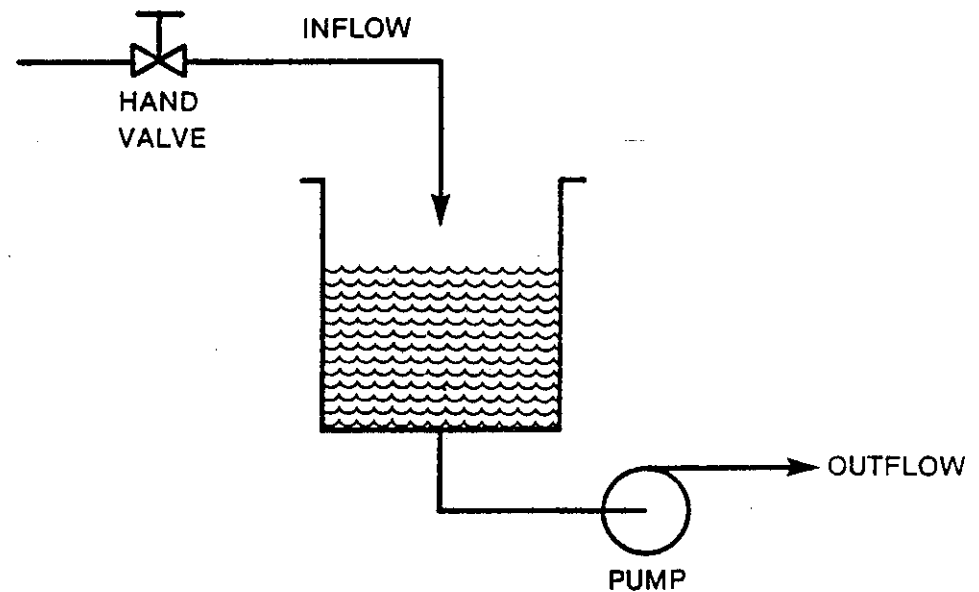


Figure 7: Simple Level Control Scheme With Hand Valve.

A typical alarm system consists of three major components:

- comparator
- detector
- relay.

A block diagram of a current alarm is shown in Figure 8.

The comparator compares the process signal (say a 4-20 mA signal from a level transmitter) with the alarm setpoint.

In the case of a high level alarm, if the process signal is above the setpoint, the detector will cause the relay to change state and therefore announce the alarm condition.

To gain a full appreciation of alarm operation, it is necessary to have a basic understanding of relay construction.

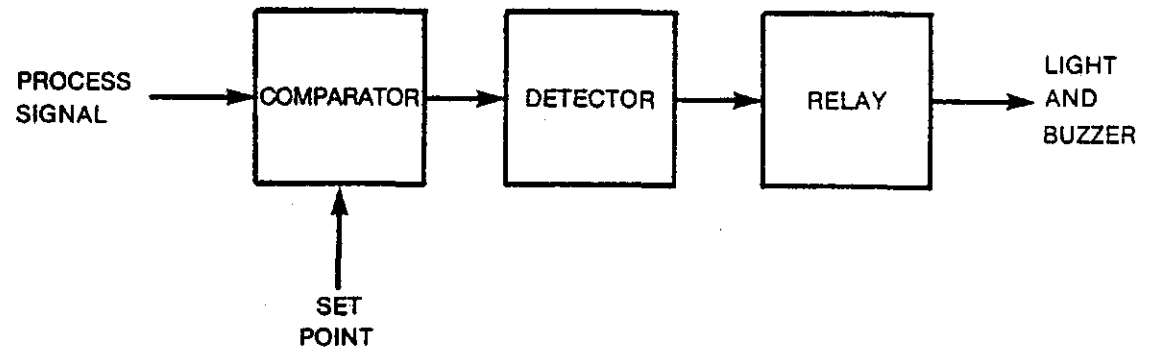


Figure 8: Block Diagram of a Current Alarm.

Relays

- A relay is basically an electromagnetic switch which controls three contacts.
- Energizing the relay coil will provide a certain contact status whereas de-energizing the relay coil will provide the opposite status. A simplified electromagnetic relay is shown in Figure 9.
- When the coil is energized, it attracts the iron plug towards the left by overcoming the spring force. This will cause the relay to change state.
- The relay contact labels are designated in the normal state.
- Normal state is with the relay in a box, on the shelf and ready for sale. That is, no power is applied to the relay in the normal state.
- In the normal state, contact #2 and #3 are shorted (closed). For this reason, contact #2 is called normally closed (N/C) contact.
- When the coil is energized, contact #2 and #3 will open while contacts #3 and #1 will be closed. Since contact #1 is open when the relay is in normal state it is called normally open (N/O) contact.
- Contact #3 is always connected to either contact #1 or #2, it is therefore called the common (C) contact.

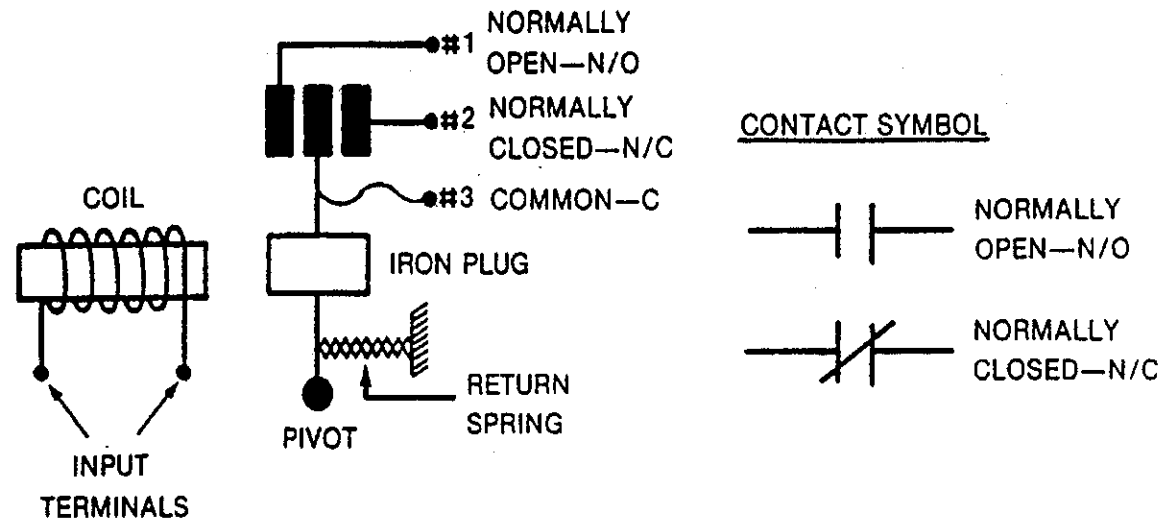


Figure 9: A Simplified Relay Circuit.

Fail-Safe Current Alarm

- Most alarms can be used as either high level or low level alarms by the flick of a switch.
- When the alarm is used as a high level alarm, the process signal (a 4-20 mA current from an electronic transmitter) is normally lower than the alarm setpoint, which is the level at which the alarm will annunciate.
- When the alarm is used as a low level alarm, the process signal is normally higher than the setpoint. In both cases the setpoint of the alarm is adjusted by means of a rheostat.

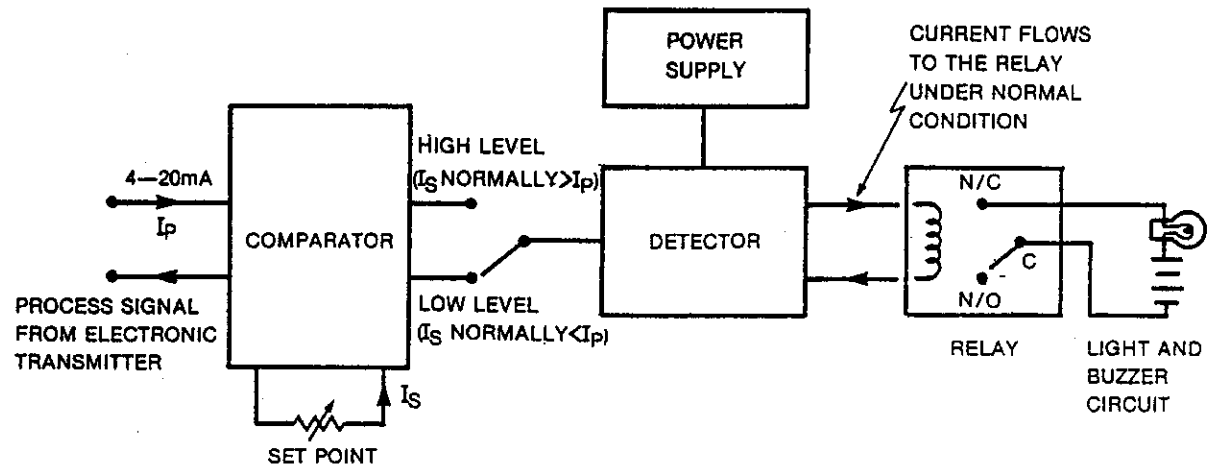


Figure 10:...A Low Level, Fail Safe Alarm Under Normal Operating Condition.

An alarm must fail safe.

- That is, upon the loss of power supply to the alarm, the light and buzzer circuit connected to the alarm has to be energized and thus annunciate the condition.
- To fulfill this requirement, all alarms are de-energized to operate.

Selectors

In control systems where redundant instrumentation or override capability is required, it is often necessary to select a particular output from several inputs. In these cases, electronic selectors that can compare the inputs and allow the designated signal to pass through as the output are required. There are three kinds of selectors, namely: high, low and median selectors.

High Selector

A high selector is a circuit that allows the highest of all incoming signals to pass through as the output. A block diagram of a two input high selector is shown in Figure 11.

If the magnitude of signal A is higher than signal B ($A > B$), then the output of the selector will be signal A.

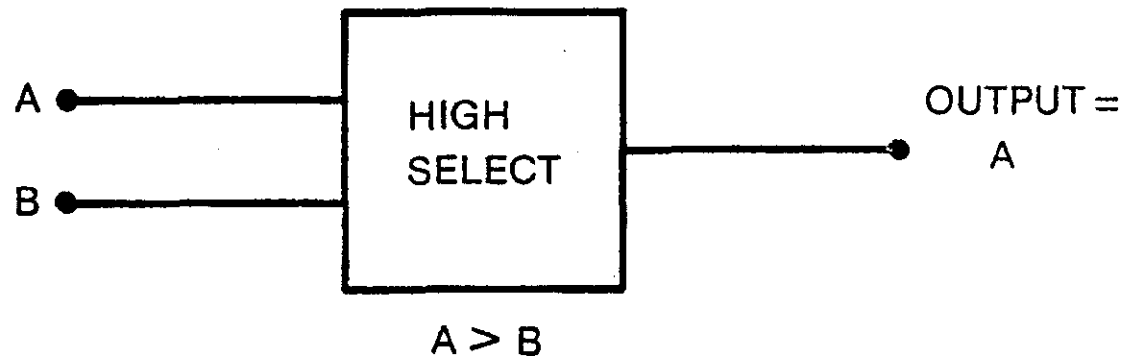


Figure 11: Block Diagram of High Selector.

An application of a high selector in a boiler feedwater flow control system is shown in Figure 12.

- The feedwater flow to a bank of three boilers comes from a single feedwater line.
- The feedwater valve is controlled in accordance with the level in the boilers.
- In this case, the highest of the signals from the three boiler level transmitters is used to control the valve movement.
- This is because high feedwater level in the boilers is undesirable as any carryover could cause permanent turbine damage.

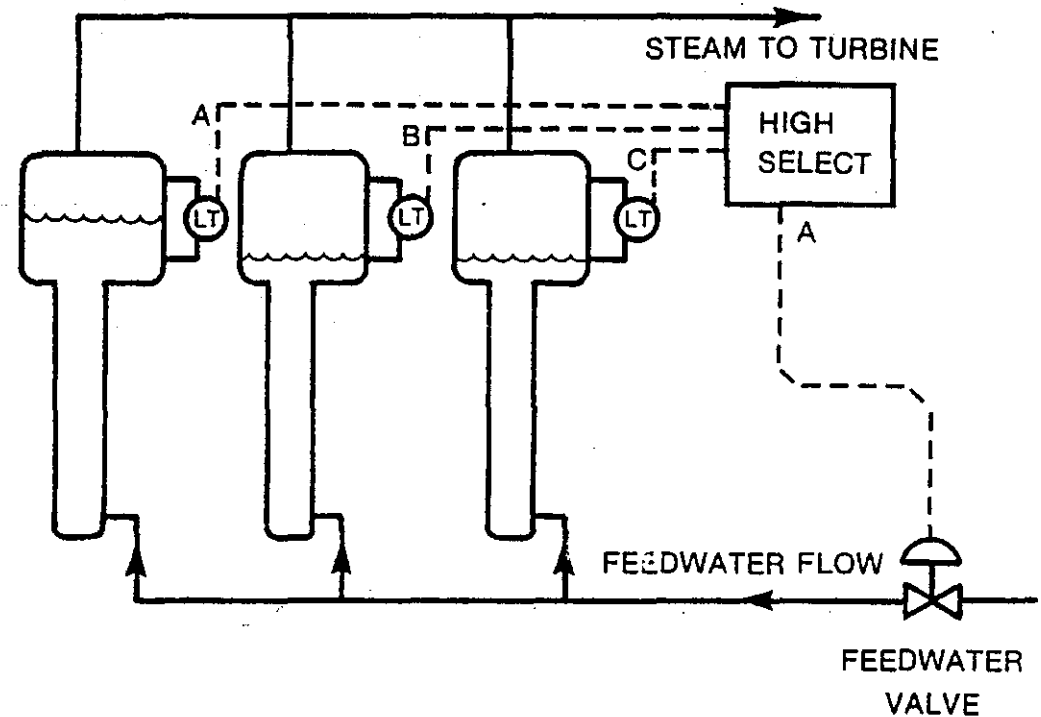


Figure 12: Simplified Feedwater Control System for a bank of three boilers.

Low Selector

- A low selector allows the lowest of all incoming signals to pass through as the output signal.
- For low selector, if the magnitude of signal A is higher than B ($A > B$), the output of the selector will be B.

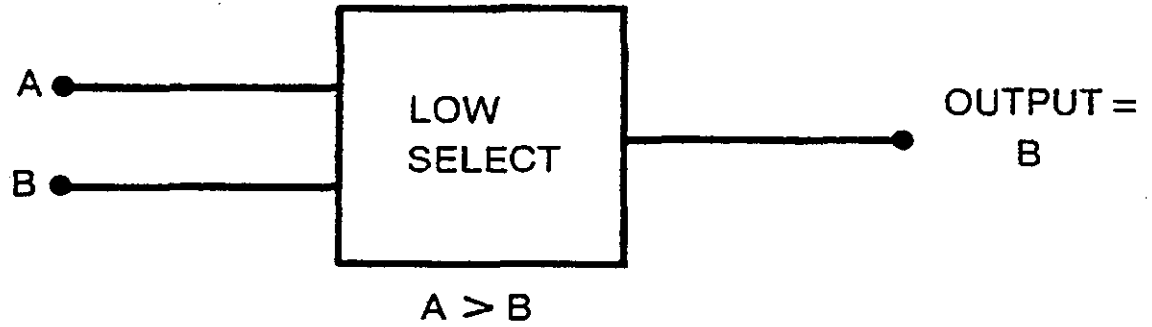


Figure 13: A Block Diagram of Low Selector.

Median Selector

- A median selector can be constructed by a combination of high and low selectors. The principle underlying the median selector is that one extreme signal is eliminated at a time, leaving only the median.
- The median selector can take either of the forms shown in Figure 14.
- A median selector in-general will eliminate erroneous or irrational signals.

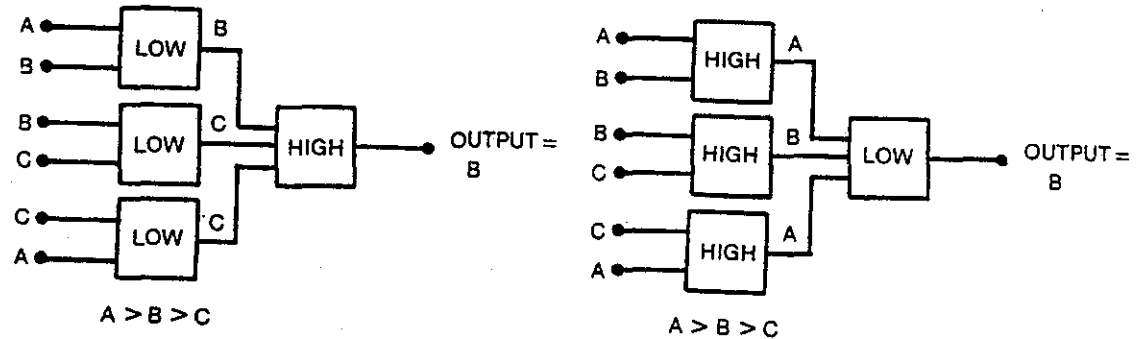


Figure 14: Two Median Select Block Diagrams.

Summing and Averaging Amplifier

- In some control schemes the sum of all incoming signals is required.
- A summing amplifier (or summer) can be used for this purpose. A block diagram of a summing amplifier is shown in Figure 15.
- The output of the summing amplifier is the sum of individual inputs multiplied by a weighting term, which is usually adjustable by varying the value of a resistor.

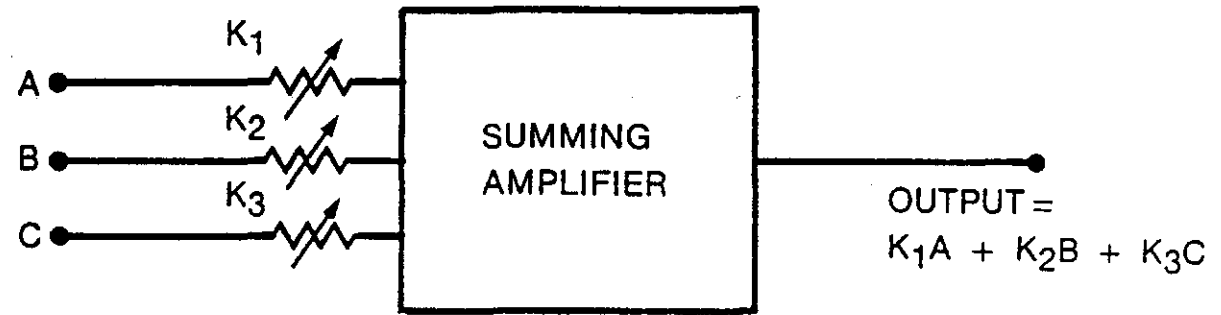


Figure 15: Block Diagram of a Summing Amplifier

A popular variation of a summing amplifier is an averaging amplifier. For a two input averaging amplifier as shown in Figure 16, the values of K_1 and K_2 are adjusted to be $1/2$. Thus the output is the average of the two input signals.

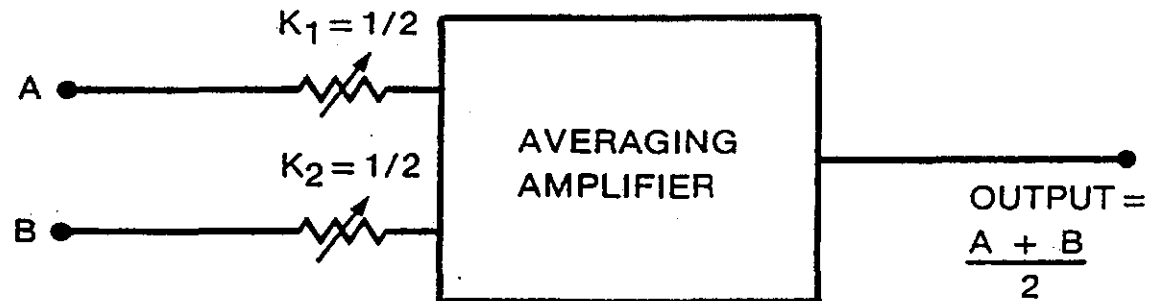


Figure 16: Two Input Averaging Amplifier.

Square Root Extractor

Up to now, our flow measurement loop can be represented by the installation shown in Figure 17.

A primary device such as an orifice plate is used to create a restriction. A flow transmitter is used to sense the differential pressure across the primary device and output a 4-20 mA signal.

The relationship between the flow rate (Q) and differential pressure (ΔP) is:

$$Q \propto \sqrt{\Delta P}$$

Rearranging the above expression yields

$$\Delta P \propto Q^2$$

To convert the signal from the flow transmitter, which is proportional to $P (\propto Q^2)$, to a signal that is proportional to the flowrate ($\propto Q$), the square root of the signal from the flow transmitter has to be taken.

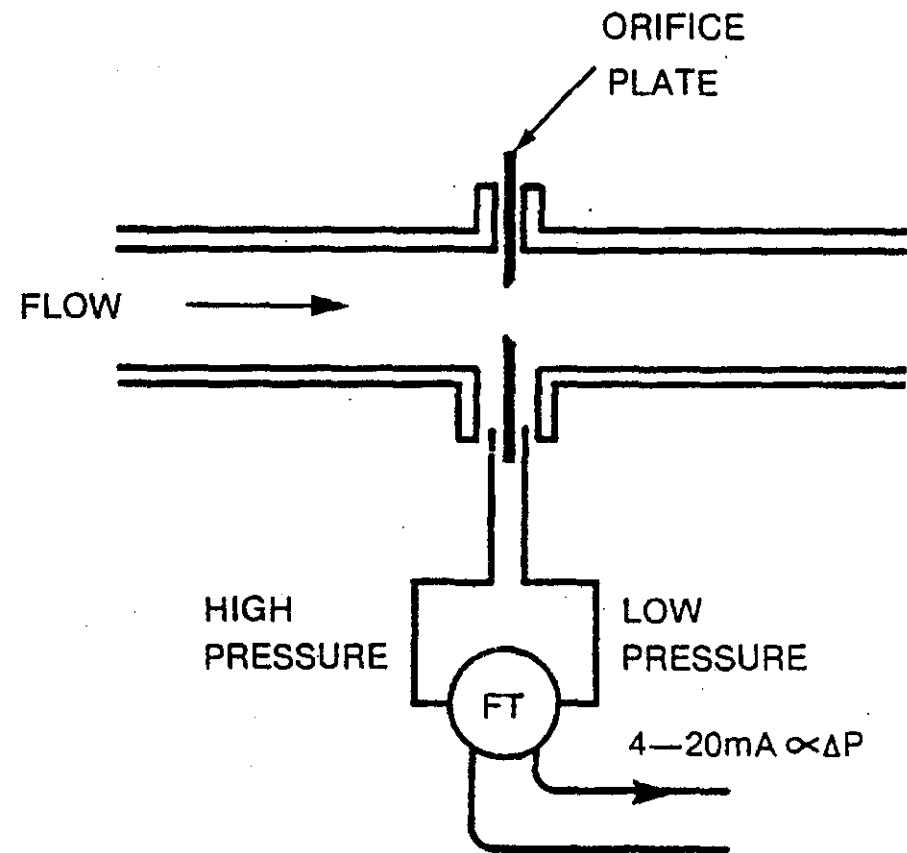


Figure 17: A Flow Loop With Orifice Plate.

The square root extractor is an electronic (or pneumatic), device that takes the square root of the signal from the flow transmitter and outputs a corresponding linearized flow signal. Several different methods are used by the manufacturers in the construction of the square root extractor.

Figure 18 illustrates the input - output relationship of a square root extractor.

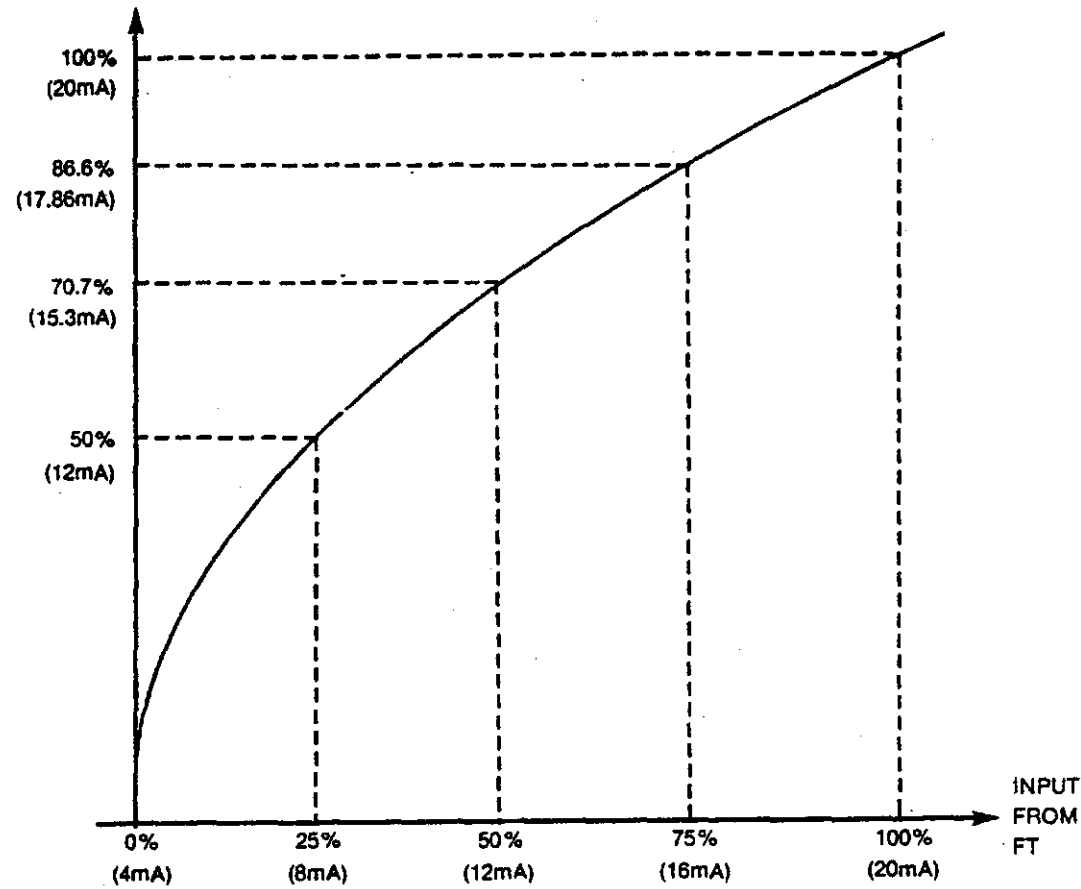


Figure 18: Input and Output Relationship of Square Root Extractor.

A typical square root extractor installation is shown in Figure 19.

- Square root extractors are usually current operated devices so they can be connected directly in the 4-20 mA current loop of a flow transmitter.
- The output of the square root extractor is again a 4-20 mA signal. This signal is directly proportional to the flowrate in the pipework.
- The signal from the square root extractor usually goes to a controller, as shown in Figure 19.
- The controller (which can be regarded as an analog computer) is used to control the final control element, usually a valve.

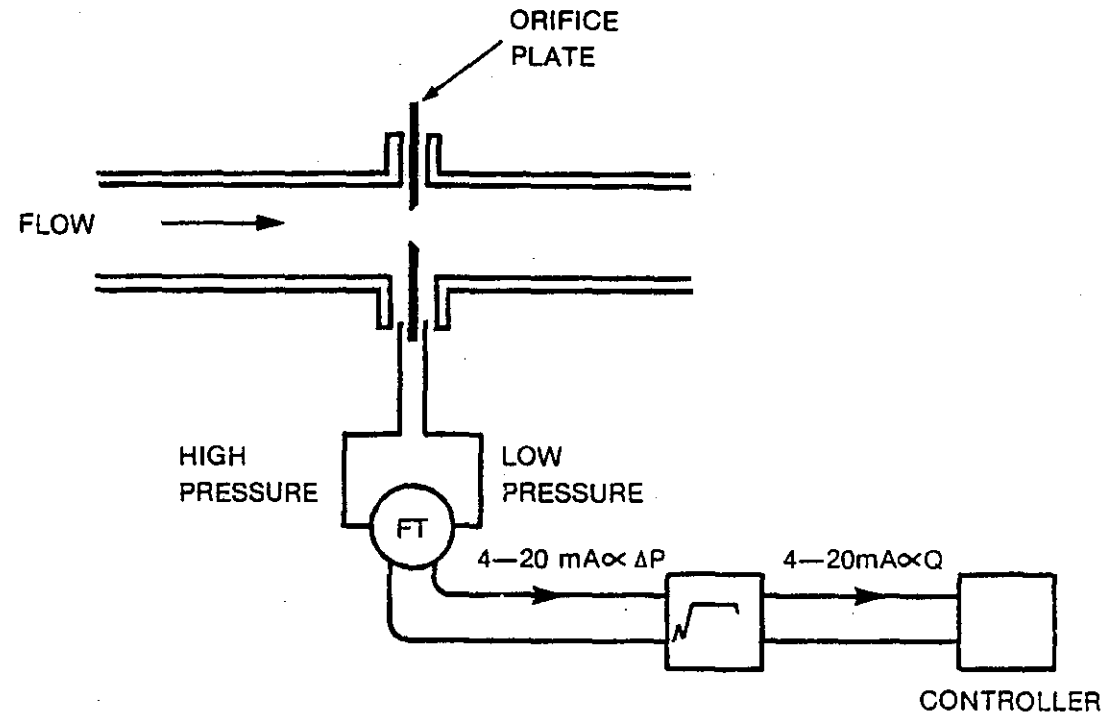


Figure 19: A Typical Square Root Extractor Installation.

Cut-Off Relay

- At the low end of the scale, the square root extractor has very high gain.
- For example, a 0.49% input implies a 7% output.
- If due to noise, temperature or other disturbances, the input drifted from 0% to 1% (i.e., from 4 mA to 4.16 mA), the output would have changed from 0% to 10% (4 mA to 5.6 mA). This is a significant error and it has to be eliminated.
- For this reason, square root extractors are equipped with cut-off relays.
- The setting for the relay can be adjusted from 6% to 10% of output.
- Shown in Figure 20 is a response curve for a cut-off relay set at 7% output. In this case, any input signal below $(0.07)^2$ or 0.49% would be ignored by the extractor.
- The output of the extractor would remain at 0% as long as input is below 0.49%.
- When the input exceeded 0.49%, the output would resume its normal curve, starting at 7%.

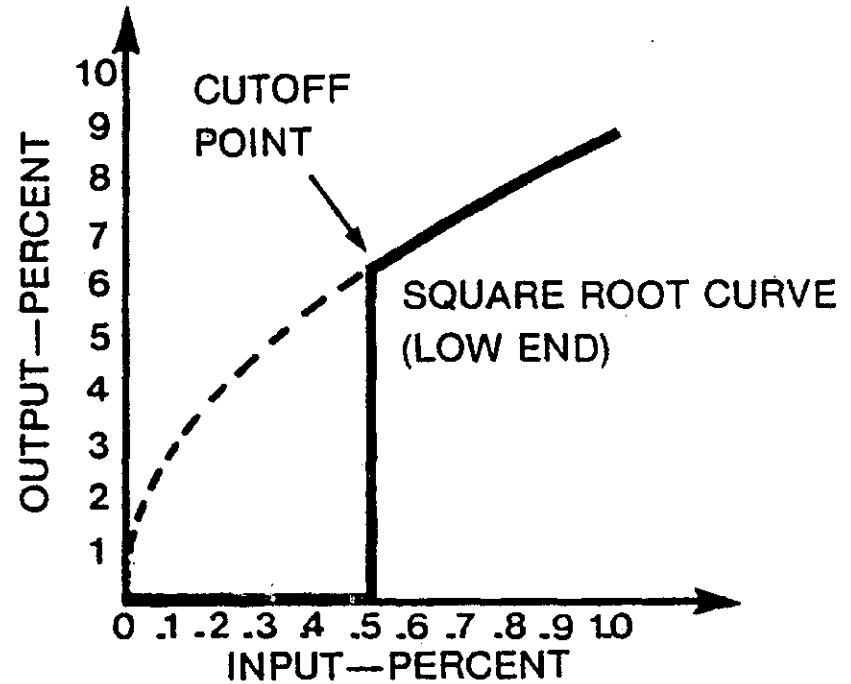


Figure 20: Response Curve for Extractor with 7% Cut-Off Setting.

Current to Pressure (I/P) Transducer

The signal we have been dealing with up to now is electronic (i.e., 4-20 mA). However, in practice, most of the control loops end up with valves that are pneumatically operated. A typical flow control loop is shown in Figure 21.

- In this loop, a pneumatic valve is used to control the flow.
- The electronic signal from the square root extractor is fed to a controller, which determines the opening of the valve.
- The controller outputs another 4-20 mA electronic signal.
- Since the valve is pneumatically operated, a means of converting the electronic signal to a corresponding pneumatic signal which will operate the valve is required.

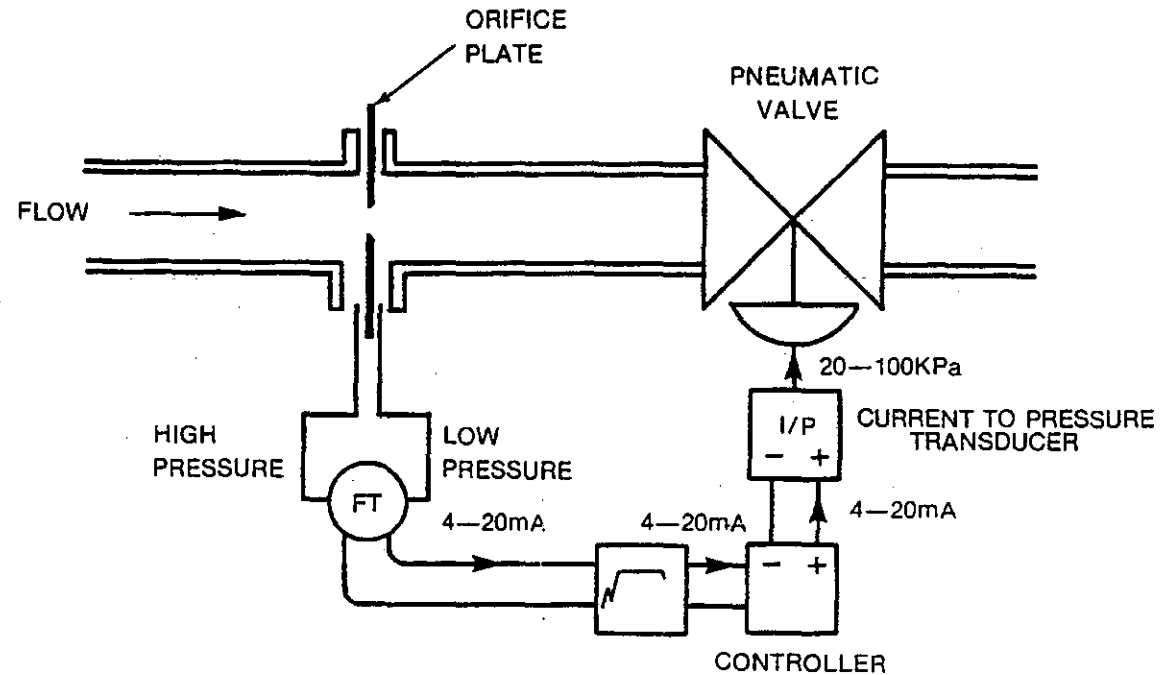


Figure 21: A Closed Loop Flow Control Scheme.

A current to pressure (I/P) transducer (sometimes called A/X, i.e., A - current, X - transducer) as shown in Figure 21, is used for this purpose. It takes the electronic signal from the controller as an input and outputs a pneumatic signal to control the valve action. The output signal from the I/P transducer is in the range of 20-100 kPa.