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Industrial Instrumentation

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UNIT V TRANSMITTERS

Pneumatic transmitter: Operation - Electronic transmitter: Study of 2 wire and 4 wire transmitters – Operation of Electronics and Smart transmitters – Principle of operation of flow, level, temperature and pressure transmitters – Installation and Calibration of smart and conventional transmitters.

5.1 Pneumatic transmitter

A Transmitter is a device that converts the signal produced by a sensor into a standardized instrumentation signal such as 3-15 PSI air pressure, 4-20 mA DC electric current, Fieldbus digital signal etc., which may then be conveyed to an indicating device, a controlling device, or both. The indicating or controlling device is often located in a centralized control room. The transmitter often combines a sensor and the transmitter in a single piece. The sensor measures the process variable and generate a proportional signal. The transmitter then amplifies and conditions the sensor signal for onward transmission to the receiving or controlling device.

Pneumatics is the science and technology of pressurized air—using piped, compressed air (or a similar gas, such as nitrogen) to transmit force and energy. Pneumatics is the utilization of compressed air in science and industry in order to perform mechanical work and control. It is called either pneumatics or pneumatic systems. If the pressurized air is not used for control, then it is simply called compressed air.

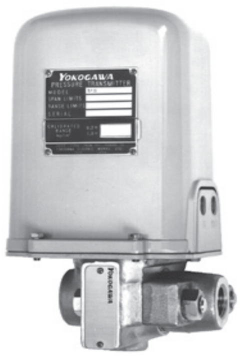


Fig 5.1.1 Pneumatic transmitter

A pneumatic transmitter is a device that senses some process variable and translates the measured value into an air pressure that is transmitted to various receiver devices for indication, recording, alarm, and control

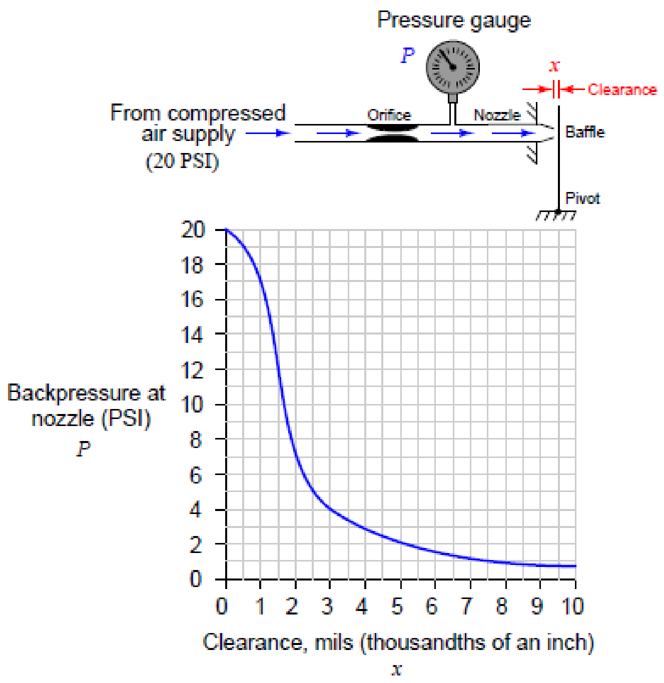
Pneumatic transmitters output a pneumatic signal corresponding to the process variable. The pneumatic signal range that is commonly used in industrial plants today is the 3 – 15 psig. 3psig corresponds to the lower range value (LRV) and 15psig corresponds to the upper range value (URV). It is still commonly used today especially in remote locations where electric power is not readily available.

A pneumatic pressure transmitter is supplied with air pressure typically 20 - 30 psig depending on the application. Process pressure is applied to the High port of the transmitter. As the process pressure varies, the transmitter produces an output signal (3 - 15 psig) that is proportional to the process pressure.

5.1.1 Operation

Pneumatic sensing elements

Most pneumatic instruments use a simple but highly sensitive mechanism for converting mechanical motion into variable air pressure: the baffle-and-nozzle assembly (sometimes referred to as a flapper and nozzle assembly). A baffle is nothing more than a flat object obstructing the flow of air out of a small nozzle by close proximity.



The physical distance between the baffle and the nozzle alters the resistance of air flow through the nozzle. This in turn affects the air pressure built up inside the nozzle (called the nozzle backpressure). Like a voltage divider circuit formed by one fixed resistor and one variable resistor, the baffle/nozzle mechanism “divides” the pneumatic source pressure to a lower value based on the ratio of restrictiveness between the nozzle and the fixed orifice. This crude assemblage is surprisingly sensitive, as shown by the graph. With a small enough orifice, just a few thousandths of an inch of motion is enough to drive the pneumatic output between its saturation limits.

Pneumatic transmitters typically employ a small sheet-metal lever as the baffle. The slightest motion imparted to this baffle by changes in the process variable (pressure temperature, flow, level, etc.) detected by some sensing element will cause the air pressure to change in response.

5.1.2 Transmitter Basics

An important legacy technology for all kinds of continuous measurement is the self-balancing principle. A "self-balance" system continuously balances an adjustable quantity against a sensed quantity, the adjustable quantity becoming an indication of the sensed quantity once balance is achieved. Pressure is easily converted into force by acting on the surface area of a sensing element such as a diaphragm or a bellows. A balancing force may be generated to exactly cancel the process pressure's force, making a force-balance pressure instrument.

The pressure being measured is applied to a bellows capsule. The force on the capsule is transmitted through a flexure to the lower end of the force bar. The metal diaphragm seal serves as both a fulcrum for the force bar and as a seal for the pressure chamber. The force is transmitted through the flexure connector to the range bar which pivots on the range wheel. Any movement of the range bar causes a minute change in the clearance between the flapper and nozzle. This produces a change in the output pressure from the amplifier to the feedback bellows until the force on the feedback bellows balances the force on the bellows capsule.

The output pressure which is established by this force balance is the transmitted signal and is proportional to the pressure applied to the bellows capsule. This signal is transmitted to a pneumatic receiver to record, indicate and/or control.

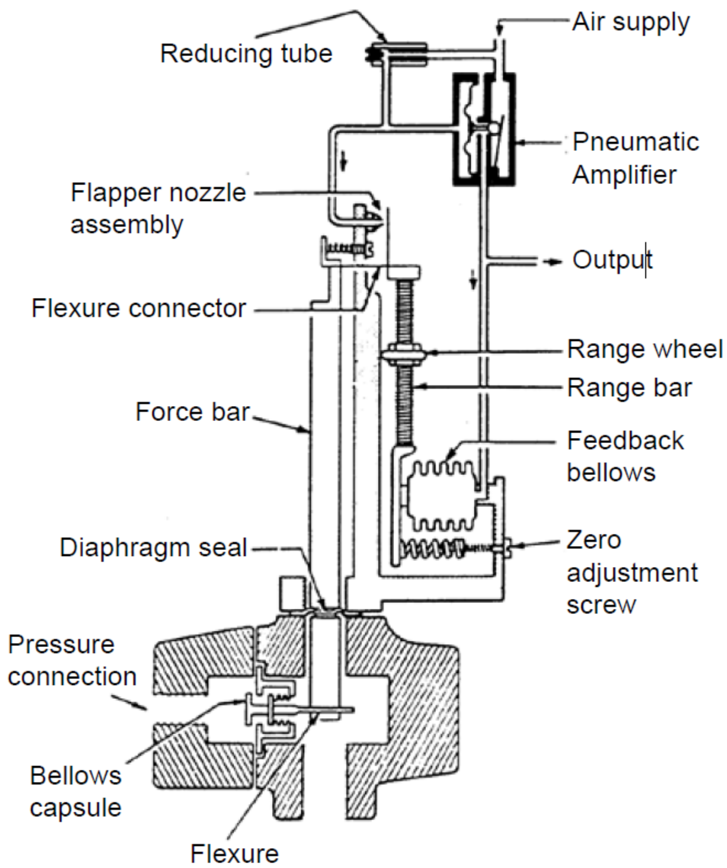


Fig 5.1.3 Schematic diagram

An increase in the measured pressure will move the force bar. The flapper is attached to the force bar by means of a flexure strip (A spring). This movement of the force bar will make the flapper move towards the nozzle. The nozzle backpressure will subsequently increase and this increased nozzle backpressure will be amplified by the relay to produce the output signal. The output signal is also applied to the feedback bellows. As the pressure increases in this bellows, the bellows will apply a force on the bottom end of the range bar. This force makes the range bar to move in the opposite direction to that caused by the force bar. The range bar is also attached to the flexure strip and the movement of the range bar will cause the flapper to move away from the nozzle. During the stable condition of the transmitter, that is, when the process pressure is not changing, the two forces are balanced. Any change in the measured pressure will upset this balance.

The sequence of events that will follow such an upset is as follows.

- A change in the measured pressure will cause the forces to become unequal.
- This will change the flapper-nozzle relationship.

- The nozzle backpressure will change.
- The changed nozzle backpressure will be amplified by the relay and will be given as the output and also to the feedback bellow.
- The output pressure will now create a new feedback force to counteract the force created by the force bar.
- At the balanced condition the flapper-nozzle relationship is such that the output will neither increase nor decrease. This specific position of the flapper with respect to the nozzle is called as the throttle position.

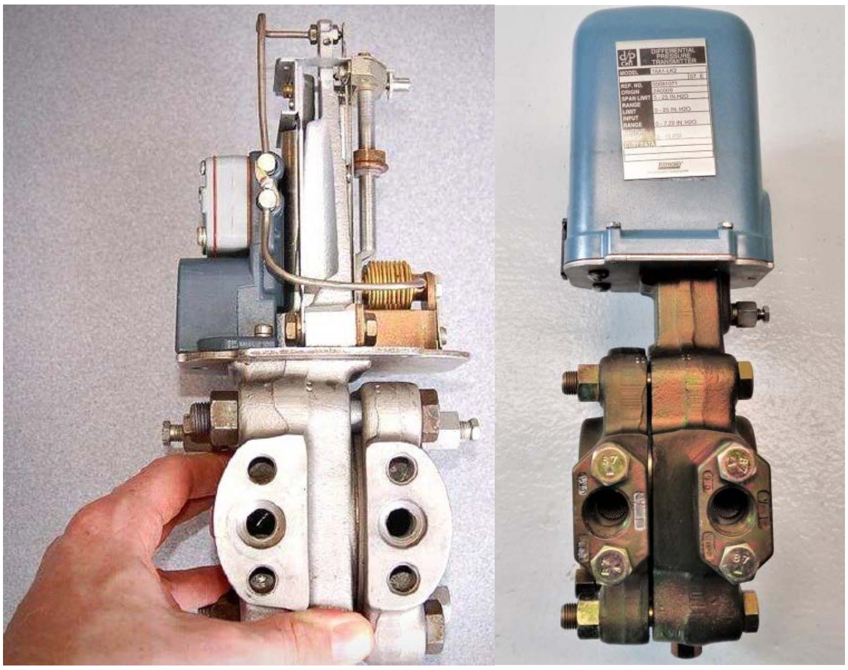
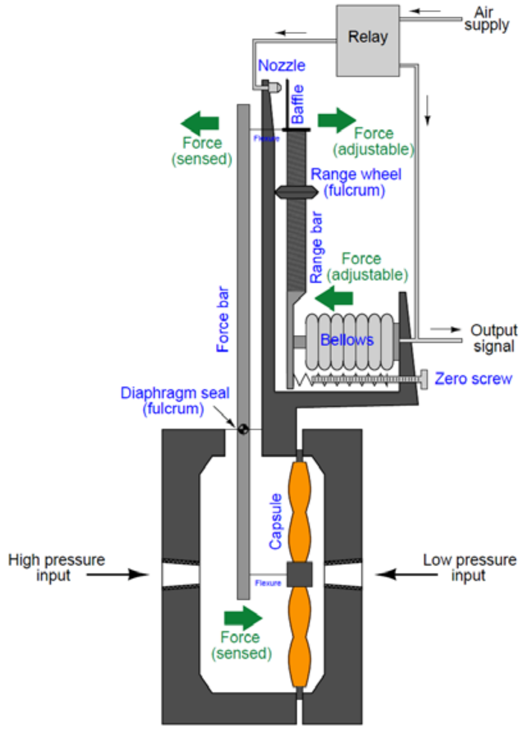


Fig 5.1.3 transmitter image



5.2 Electronic transmitter

An “analog” electronic signal is a voltage or current whose magnitude represents some physical measurement or control quantity. An instrument is often classified as being “analog” simply by virtue of using an analog signal standard to communicate information, even if the internal construction and design of the instrument may be mostly digital in nature. This is to distinguish such instruments from those making use of no analog electronic signals at all (e.g. wireless or Fieldbus instruments).

Transmitters can have any of several electrical connection schemes. The most common and easiest to use is the two-wire, loop-powered configuration. This is generally the basic configuration for industrial process control systems when digital communication is not required. As shown in Below Figure, only two wires are used to accommodate both power to the transmitter and output signal from the transmitter.

To facilitate a closed-loop control system, information from the process must be obtained before a controller can determine what action may be required by a control element. Some popular names for the sensing devices that provide the information are sensors, transducers, and/or transmitters.

The standard loop current is usually 4 to 20 mA. Important calibration parameters with a current loop are Zero, full scale, and span. With the 4- to 20mA range, the loop current is normally 4 mA when the measurand or Process Variable is at zero, and 20 mA when the measurand or Process Variable is at full scale. The difference between Zero and full scale, 16 mA, is called the span. Thus, the span corresponds to the indicated range of the measurand or Process Variable.

5.2.1 General description of the transmitter loop

The loop consists of the following elements

1. Sensor

First, there needs to be some sort of sensor which measures a process variable. A sensor typically measures temperature, humidity, flow, level or pressure. The technology that goes into the sensor will vary drastically depending on what exactly it is intended to measure, but this is not relevant for this discussion.

2. Transmitter

Second, whatever the sensor is monitoring, there needs to be a way to convert its measurement into a current signal, between four and twenty milliamps. This is where a transmitter will come into play. If, for instance, a sensor was measuring the height of a 2 Meter tank, the transmitter would need to translate zero Mter as the tank being empty and then transmit a four milliamp signal. Conversely, it would translate 2 Meter as the tank being full and would then transmit a twenty milliamp signal. If the tank were half full the transmitter would signal at the halfway point, or twelve milliamps.

3. Power Source

In order for a signal to be produced, there needs to be a source of power, just as in the water system analogy there needed to be a source of water pressure. Remember that the power supply must output a DC current (meaning that the current is only flowing in one direction).

There are many common voltages that are used with 4-20 mA current loops (9, 12, 24, etc.) depending on the particular setup. When deciding on what voltage of power supply to use for your particular setup, be sure to consider that the power supply voltage must be at least 10% greater than the total voltage drop of the attached components (the transmitter, receiver and even wire). The use of improper power supplies can lead to equipment failure.

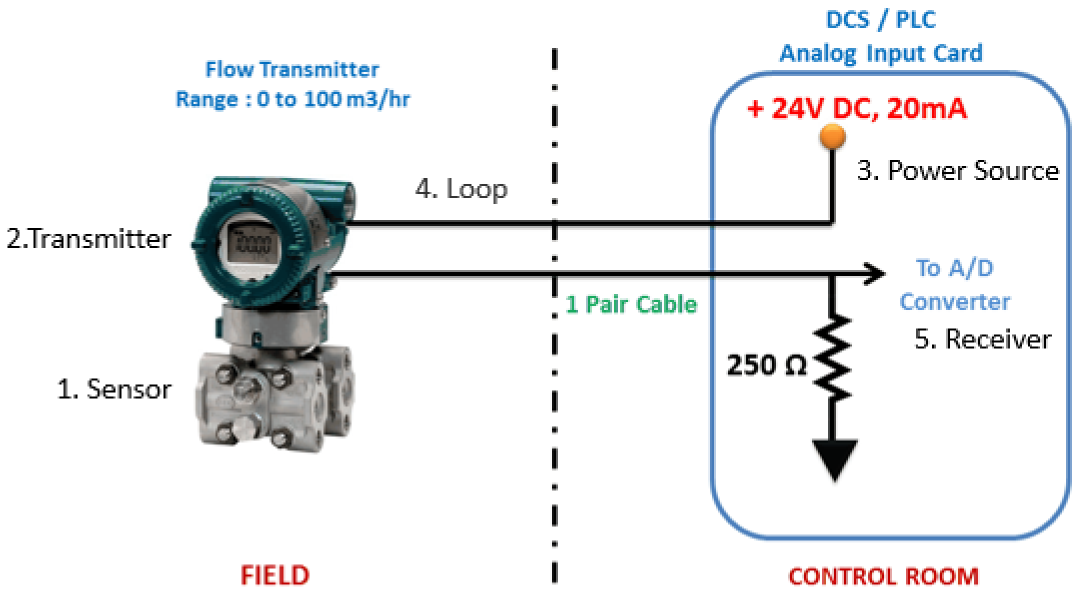
4. Loop

In addition to an adequate VDC supply, there also needs to be a loop, which refers to the actual wire connecting the sensor to the device receiving the 4-20 mA signal and then back to the transmitter. The current signal on the loop is regulated by the transmitter according to the sensor's measurement. This component is typically overlooked in a current loop setup because wire is so intrinsic to any modern electronic system, but should be considered in our exploration of the fundamentals. While the wire itself is a source of resistance that causes a voltage drop on the system, it is normally not a concern, as the voltage drop of a section of wire is minuscule. However, over long distances (greater than 1,000 feet) it can add up to a significant amount, depending on the thickness (gauge) of the wire.

5. Receiver

Finally, at someplace in the loop there will be a device which can receive and interpret the current signal. This current signal must be translated into units that can be easily understood by operators, such as the feet of liquid in a tank or the degrees Celsius of a liquid. This device also needs to either display the information received (for monitoring purposes) or automatically do something with that information. Digital displays, controllers, actuators, and valves are common devices to incorporate into the loop.

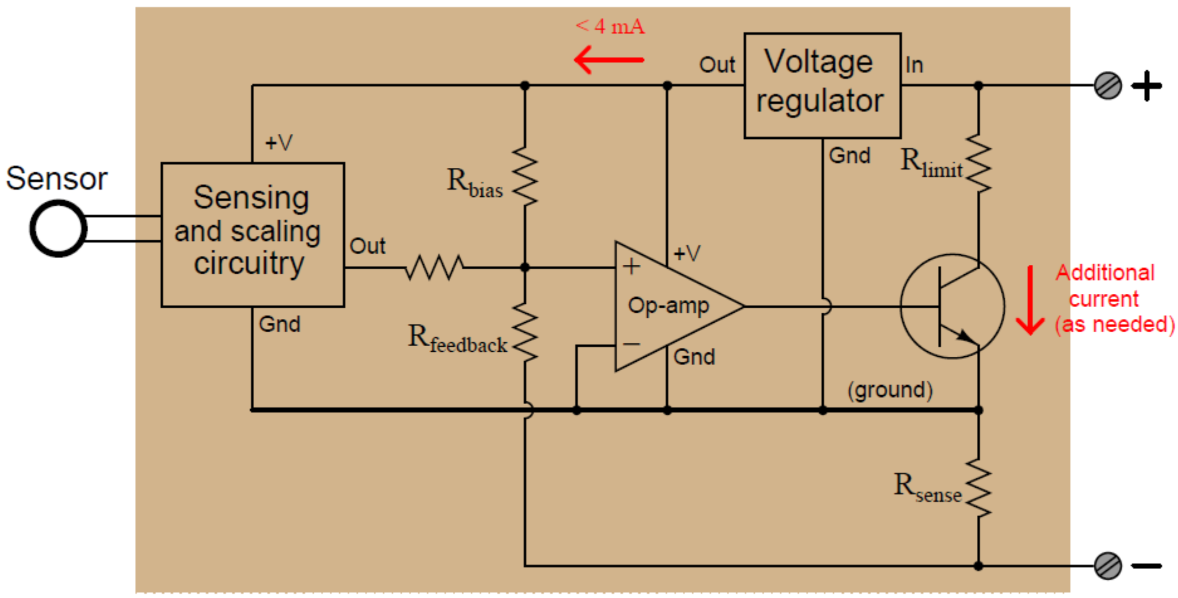
These components are all it takes to complete a 4-20 mA current loop. The sensor measures a process variable, the transmitter translates that measurement into a current signal, the signal travels through a wire loop to a receiver, and the receiver displays or performs an action with that signal.



5.2.2 Operation of Electronics transmitters

Electronics transmitter circuit diagram

Internally, the electronic hardware of a 2-wire transmitter circuitry resembles the following (simplified) diagram. Note that everything shown within the shaded rectangle is represented by the 2-wire transmitter.



All sensing, scaling, and output conditioning circuitry inside the transmitter must be designed to run on less than 4 mA of DC current, and at a modest terminal voltage. In order to create loop currents exceeding 4 mA – as the transmitter must do in order to span the entire 4 to 20 milliamp signal range – the transmitter circuitry uses a transistor to shunt (bypass) extra current from one terminal to the other as needed to make the total current indicative of the process measurement.

For example, if the transmitter's internal operating current is only 3.8 mA, and it must regulate loop current at a value of 16 mA to represent a condition of 75% process measurement, the transistor will bypass 12.2 mA of current.

The very low amount of electrical power available at a 2-wire transmitter's terminals limits its functionality. If the transmitter requires more electrical power than can be delivered with 4 milliamps and 19 volts (minimum each), the only solution is to go with a 4-wire transmitter where the power conductors are separate from the signal conductors. An example of a process transmitter that must be 4-wire is a chemical analyzer such as a chromatograph, requiring enough power to operate an electrical heater, solenoid valves, and an on-board computer to process the sensor data. There is simply no way to operate a machine as complex and power-draining as a 2010-era chromatograph on 4 milliamps and 19 volts.

Early current-based industrial transmitters were not capable of operating on such low levels of electrical power, and so used a different current signal standard: 10 to 50 milliamps DC. Loop power supplies for these transmitters ranged upwards of 90 volts to provide enough power for the transmitter. Safety concerns made the 10-50 mA standard unsuitable for some industrial installations, and modern microelectronic circuitry with its reduced power consumption made the 4-20 mA standard practical for nearly all types of process transmitters.

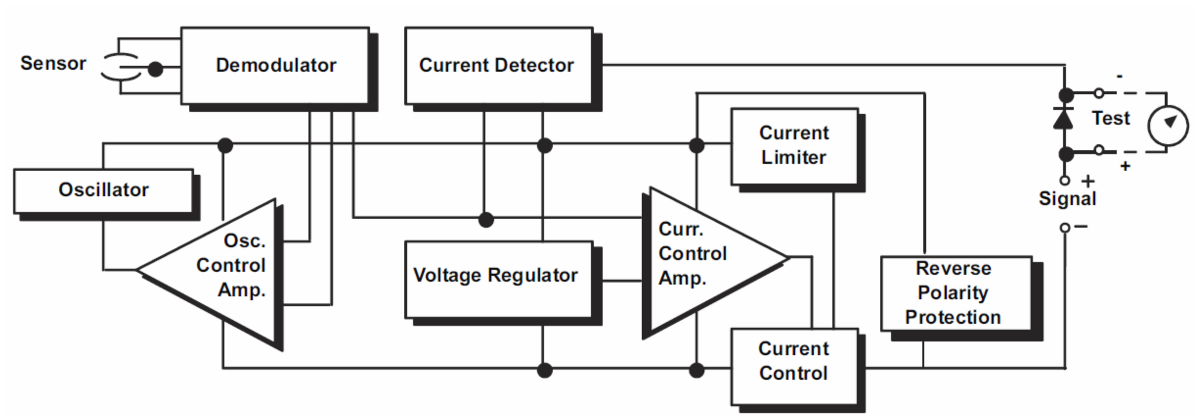
Electronics transmitter block diagram

The input loop consists of the voltage-controlled oscillator (VCO), the capacitive pressure cell, the demodulator, and the current inverter. These components act together as a feedback loop for the VCO control amplifier, which controls the frequency amplitude product of the VCO output such that the sum of the capacitance currents of the two cell halves equals the

reference current through resistor R7. The difference of the capacitance currents is fed to the output loop as the electrical analog of the pressure input. This difference current is linear with diaphragm pressure, and is approximately zero at zero diaphragm pressure.

The output loop for Code A consists of the current-sensing element and a current control amplifier that compares the span amplifier's output to the load current. Zero adjustment is incorporated in this loop. Current for powering the circuitry bypasses the current control amplifier and is returned at the circuit reference node so that total current flows through the current-sensing element.

For Code M electronics, the output loop consists of a zero offset and variable gain control of a current-to-voltage converter. The voltage regulator provides a 4.5 V positive rail and a +2 and +1 volts for circuit reference purposes.



VOLTAGE CONTROLLED OSCILLATOR (VCO) : The VCO section of a type 4046 integrated circuit phase-locked loop drives the sensor. It produces a square wave and a frequency proportional to the output of the VCO control amplifier. The associated range components set the lower limit at approximately 70 kHz and the upper limit above 300 kHz. When in control, the amplitude-frequency product will approximate the inverse of the sum of the active capacitances of the two cell halves.

DEMODULATOR : The demodulator, which converts the ac currents of the two cell capacitances and C1 to dc currents, consists of the diodes contained in the IC2 package plus associated filtering capacitors. Two diodes are associated with each cell half, producing two identical and opposite (sign) currents for each. Another pair of diodes associated with C1 subtracts the cell stray capacitance. Resistor R3 determines the degree of subtraction. The 0.01 microfarad capacitors associated with these diodes average out the pulsating current through the diodes.

CURRENT INVERTER : The current inverter inverts the signal from one of the diodes to obtain a sum of the currents from each of the cell halves. The inverter has a gain of –1 determined by resistors R8 and R9.

VCO CONTROL AMPLIFIER : Proper transmitter operation depends on maintaining a fixed current through the active capacitance of the two cell halves. To do this, the VCO control amplifier adjusts the frequency of the VCO until the amplitude and frequency of the drive to the pressure cell is sufficient to produce combined active capacitance currents from each of the cell halves equal to the reference current through resistor R7. At that point, the positive and negative inputs on the VCO control amplifier are at the same voltage.

CURRENT DETECTOR : The current detector senses and offsets the 4–20 mA signal current and scales it for comparison to the cell output. Resistor R25 is in the 4–20 mA path and provides a voltage proportional to the load current. Resistor R20 then converts that voltage to a signal current to the summing point of the amplifier. Resistor R18 performs the offsetting. Resistor R18 allows span amplifier (IC3) output to match the reference voltage when the signal current is 4 mA, thus eliminating the effects of the gain controls at the 4 mA point.

CURRENT CONTROL AMPLIFIER : The current control amplifier includes the output-damping components. The amplifier operates by controlling the 4–20 mA signal current so that the output voltage plus the rate of change of that output voltage are proportional to the sensor difference current. The result is output current that follows a nearly classical first-order response to a change in sensor current (caused by a change in pressure input). Transistor Q1 forms the output section of the amplifier.

CURRENT LIMITER : Resistors R27 and D7 limit the amount of current from the current control amplifier by reducing the drive to the output transistor as the limit point is approached. The limit current is roughly equal to the Zener voltage of 1 V divided by the value of resistor R27.

VOLTAGE REGULATOR : The voltage regulator provides a constant 6 V for the positive rail and +2 and +1 volts for circuit reference purposes.

TEMPERATURE COMPENSATION : Temperature compensation is achieved by small adjustments to the sensor sum current. By using a negative temperature coefficient thermistor (R4) with effect-limiting resistors (R5 and R6), the effective resistance of resistor R7 can be modified slightly by changing temperature. Resistor R6 in parallel with the thermistor limits the network's maximum resistance at low temperature (thermistor > 3 MOhms at –40 Degrees F [–40 Degrees C]), and resistor R5 in series with the thermistor limits the network's minimum resistance as high temperatures (thermistor > 10 kOhms at 185 Degrees F [85 Degrees C]). Because the thermistor network temperature characteristics are equal and opposites to that of the pressure sensor, conformal error is minimized, and this simple resistor network gives good span temperature compensation.

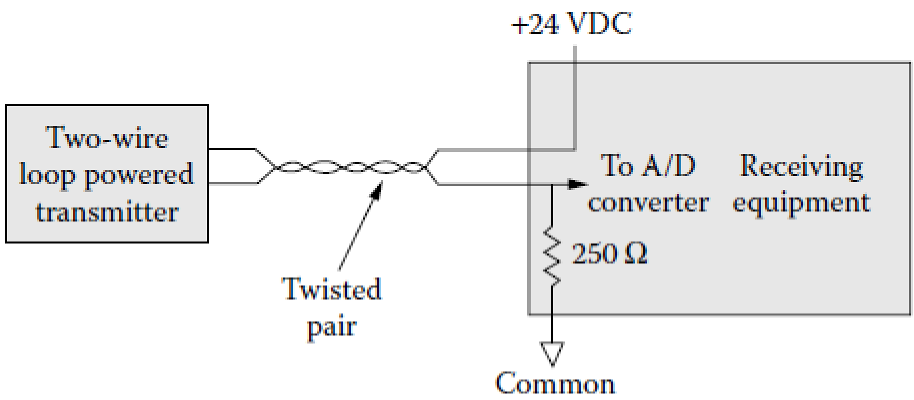
5.3 Study of 2 wire and 4 wire transmitters

The main advantage of a two-wire loop is that it minimizes the number of wires needed to run both power and signal. The use of a current loop to send the signal also has the advantages of reduced sensitivity to electrical noise and to loading effects.
The electrical noise is reduced because the two wires are run as a twisted pair, ensuring that each of the two wires receives the same vector of energy from noise sources, such as electromagnetic fields due to a changing current in a nearby conductor or electric motor. Since the receiving electronics connected to the transmitter is designed to ignore common-mode signals, the resulting common-mode electrical noise is ignored.

The sensitivity to loading effects is reduced because the current in the twisted pair is not affected by the added resistance of long cable runs. A long cable or other series resistance will cause a greater voltage drop but does not affect the current level as long as enough voltage compliance is available in the circuit to supply the signal current. The circuit compliance to handle a given voltage drop from additional loop devices depends on the transmitter output circuit and on the power supply voltage.

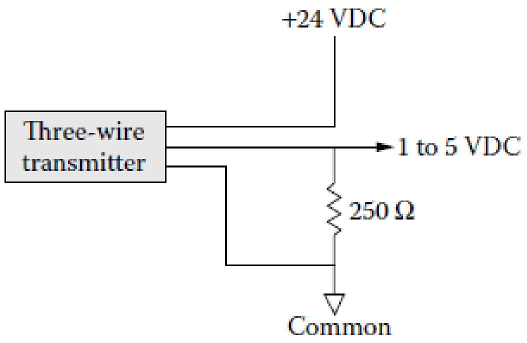
The typical power supply for industrial transmitters is 24 VDC. If 6 volts, for example, are needed to power the transmitter and its output circuit, then 18 volts of compliance remain to allow for wire resistance, load resistance, voltage drops across intrinsic safety (IS) barriers and remote displays, etc.

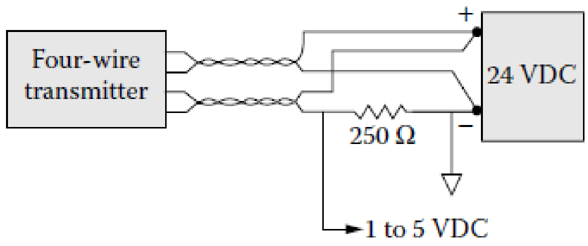
Where the current loop signal is connected to the main receiving equipment or data acquisition system, a precision load resistor of 250 ohms is normally connected. This converts the 4- to 20-mA current signal into a 1- to 5-volt signal, since it is standard practice to configure the analog-to-digital converter.



In contrast to the two-wire current-loop configuration, some current-loop devices require a three- or four-wire connection, as shown in Figure 3.6b. These are not loop powered and therefore have a separate means for providing power by adding one or two more wires.

In a four-wire configuration, the current-loop wires can be a twisted pair, and the power supply wires a separate twisted pair. This preserves the ability to reject electrical and magnetic common-mode interference. This is not so effective in a three-wire configuration due to the common connection for the return current path. Typically, though, when an instrumentation engineer specifies a current-loop transmitter for industrial process control, it is assumed that a two-wire, loop-powered 4- to 20-mA device is intended. Other data signals may also be impressed upon the same wire pair, or alternatively, various digital communication techniques can be used instead of a current loop.





DC electric current signals may also be used to communicate process measurement information from transmitters to controllers, indicators, recorders, alarms, and other input devices. Recall that the purpose of a transmitter is to sense some physical variable (e.g. pressure, temperature, flow) and then report that quantity in the form of a signal, in this case a 4 to 20 milliamp DC current proportional to that measured quantity. The simplest form of 4-20 mA measurement loop is one where the transmitter has two terminals for the 4-20 mA signal wires to connect, and two more terminals where a power source connects. These transmitters are called “4-wire” or self-powered. The current signal from the transmitter connects to the process variable input terminals of the controller to complete the loop:

Some process controllers are not equipped to directly accept milliamp input signals, but rather can only interpret DC voltage signals. For this reason we must connect a precision resistor across the input terminals to convert the 4-20 mA signal into a standardized analog voltage signal that the controller can understand. A voltage signal range of 1 to 5 volts is standard, although some models of controller use different voltage ranges and therefore require different precision resistor values. If the voltage range is 1-5 volts and the current range is 4-20 mA, the precision resistor value must be 250 ohms according to Ohm’s Law.
Since this is a digital controller, the input voltage at the controller terminals is interpreted by an analog-to-digital converter (ADC) circuit, which converts the measured voltage into a digital number that the controller’s microprocessor can interpret.

In some installations, transmitter power is supplied through additional wires in the cable from a power source located in the same panel as the controller:

The obvious disadvantage of this scheme is the requirement of two more conductors in the cable. More conductors means the cable will be larger-diameter and more expensive for a given length. Cables with more conductors will require larger electrical conduit to fit in to, and all field wiring panels will have to contain more terminal blocks to marshal the additional conductors. If no suitable electrical power source exists at the transmitter location, though, a 4-wire cable is necessary to service a 4-wire transmitter.

5.4 Operation of Smart transmitters

Transmitters are referred to as "analog," "microprocessor based," "intelligent," "smart," "fieldbus," etc. depending on the technology used. An "analog" transmitter has no microprocessor and therefore its linearization, temperature compensation, and diagnostics are rudimentary. An analog transmitter is configured by switches and jumpers and adjusted using potentiometers. A "microprocessor-based" transmitter is capable of much more sophisticated linearization, temperature compensation, and diagnostics. However, a microprocessor-based transmitter still only has an analog output, such as 4- to 20-mA, and therefore only transmits rudimentary diagnostics. A microprocessor- based transmitter is configured from the local display and buttons.

An "intelligent" transmitter too has a microprocessor, but it also has digital communication capability, which permits remote diagnostics and configuration. A "smart" transmitter is an intelligent transmitter that has analog output but that also permits simultaneous digital communication. The HART protocol is a typical example. Not all intelligent transmitters are smart because some do not provide simultaneous digital communication and analog output, as the analog output is disrupted while communicating digitally.

A "fieldbus" transmitter has only digital communication. Today, the same supplier often markets microprocessorbased, smart, and fieldbus transmitters that are externally identical but differ in their internal electronics and software (Figure). In general, a smart or fieldbus transmitter consists of the sensor or input circuitry, the microprocessor, the communication block and, in the case of smart transmitters, an analog output Analog circuits are subject to drift over time and are affected by ambient temperature variations. Moreover, there is no obvious way to check whether or not an analog signal is invalid because signal distortion just changes one valid value to another valid value, as all signal levels are valid. For example, a signal that should be 5 V may vary between 4.85 and 5.15 V due to noise, but there is no way to tell the value is true because 4.85 or 5.15 V are also valid signals.

Similarly, if, because the supply voltage is insufficient, a signal that should be 19 mA is limited to 18 mA, there is no way to tell that a distortion has occurred because 18 mA is also a valid signal. Distorted or limited signal values cannot be detected in analog circuitry because these signals cannot be distinguished from the genuine process measurements. For these reasons, there is a trend to obtain greater accuracy and stability in transmitters by eliminating more and more analog components in the measurement circuitry and aiming to convert it to a completely digital system that has digital sensors, processing, and communication.

5.4.1 Digital Sensors

In smart and fieldbus transmitters the sensor is usually digital. Keeping the sensor signal digital from the very beginning provides for more precise signal processing and lowers noise pickup and signal degradation.

The signal from a digital sensor gives the value of the measurement as a function of frequency or time. Such timebased functions do not depend on the signal amplitude. For example, a capacitance-type pressure sensing element can be a part of an oscillatory circuit with a frequency output. Similarly, an ultrasonic flow meter detects the time of flight.

Other digital sensors operate on frequency phase-shift. Timers in the microprocessor easily measure frequency and duration using precise crystal clocks. In such direct digital measurements there is no need for an A/D converter, which also eliminates the conversion error and lowers inaccuracy by eliminating quantization error.

In earlier “semismart transmitter” designs with analog sensors, the outputs from resistive strain gauges or piezo or conventional capacitance sensors were first converted to a voltage before being converted to the digital format. Most of these transmitter designs have been replaced by digital sensing. When the detector is inherently analog, such as in case of some temperature sensors, A/D converters are required, and their resolution determines the accuracy of the conversion.

5.4.2 Sensor Compensation and Characterization

Firmware in the microprocessor provides a variety of functions, including sensor temperature chatacterization and linearization, communication, self-diagnostics and sensor diagnostics, as well as flow totalization, PID control capability, and other functions depending on type of the transmitter. No sensor has perfect linearity or temperature stability. It is for that reason that the microprocessor must characterize and compensate the sensor signal. For external sensors such as thermocouples and RTD (Resistance Temperature Detectors), the relation between detected and sensor output is well established.

In these cases, standard tables or polynomials are used to convert the thermocouple's millivolt or the RTD's ohm signals to temperature in the transmitter firmware. Similarly, the temperature effect on a pH sensor is well understood, and its compensation is preprogrammed in a pH transmitter.

The characteristics of many pressure and flow transmitters are not predetermined but must be obtained by testing. In case of these units, all sensors are tested in the factor by exposing them to their operating range of inputs at different The test data obtained are used to compute the characterization coefficients that are unique to the particular sensor, and these coefficients are stored in the memory of the sensor module.

When the power supply is turned on, the transmitter loads these characterization coefficients from the sensor module into its characterization algorithm. The goal of this procedure is a temperature-compensated and linear measurement. Because the sensor characterization coefficients, along with other pertinent information such as sensor serial number, range, and materials of construction, are stored in the sensor module itself, when the sensor is replaced the new characterization coefficients are automatically loaded into the microprocessor.

By reducing the measurement error, it becomes possible to increase the rangeability of smart transmitters and provide turndowns, sometimes as high as 120:1, while still keeping the error within acceptable limits. The increased turndown makes the transmitter suitable to a wider range of applications. Two of the main limitations to accuracy is the hysteresis and the thermal hysteresis of the sensor because these cannot be corrected.

5.4.3 HART Communication

Digital communication such as HART and FOUNDATION fieldbus permits remote monitoring, diagnostics, configuration, and calibration. In the case of fieldbus networks, the digital communication can also be used to perform closedloop control.

In digital transmission there are only two valid states for the signal (zero and one). Therefore, a large amount of interference is required to distort the signal by changing one to the other. This makes the digital signal very robust. In addition, error detection techniques are provided to detect errors due to noise. Errors due to D/A conversion are eliminated by not requiring such conversions at all.

HART transmitter communicates at 1200 bit/s, which is too slow for closed-loop control but adequate for the technician to perform interrogation using a handheld tool. In order to guarantee fast loop response, in most applications the analog 4- to 20-mA signal is used for control. HART transmitters are typically wired in a point-to-point fashion. Multi-dropping up to 15 transmitters on the same pair of wires is possible but is rarely used as it is slow and not well supported in control systems.

5.4.4 Fieldbus Transmitters

FOUNDATION fieldbus transmitters use the H1 version of fieldbus communication at 31.25 K bit/s, which is fast enough for closed-loop control. This speed eliminates the need for using analog signals.

Typically 12 to 16 devices, which can be a mix of types and suppliers, are multi-dropped on the same pair of wires. Fieldbus is much more than a digital equivalent of 4- to 20-mA transmission. Fieldbus can be used in place of Distributed Control Systems (DCS) because the devices in the field can also perform the control functions. This reduces the controller and I/O-subsystem complexity because the majority of controls tend to be simple monitoring and basic control functions, computation, or logic, which all can be done in the field instruments.

Fieldbus transmits the measurement status information along with the sensor’s reading. The status information includes measurement quality and limit condition information. The measurement quality is usually stated as Good, totally Bad, or Uncertain, e.g., having an error of not exceeding a few percent. Other function blocks use this measurement quality information to automatically initiate safety steps or to exclude that measurement when doing selection or calculating an average.

Smart and fieldbus transmitters use their auxiliary sensors to provide temperature and static pressure compensation of the primary sensor’s reading. Such compensated smart transmitters still have only one output because the other measurements only serve to detect the existing conditions under which the primary sensor operates.

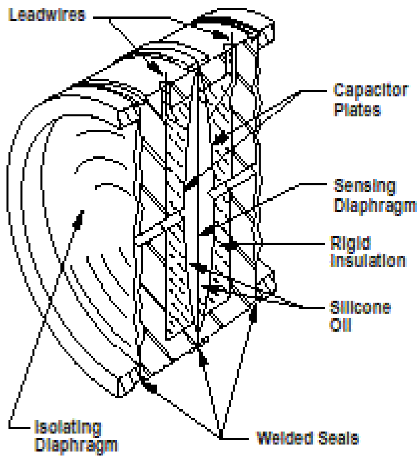
5.4.5 BENEFITS OF ADVANCED TRANSMITTERS

Many benefits resulted from the use of digital circuitry, microprocessors, and digital communications in smart and fieldbus transmitters. These include greater accuracy and stability, lower temperature sensitivity, greater flexibility due to higher turndown ratio, remote parameterization, calibration, diagnostics, and monitoring. Online diagnostics also improve plant safety.

5.5 Principle of operation of pressure transmitters

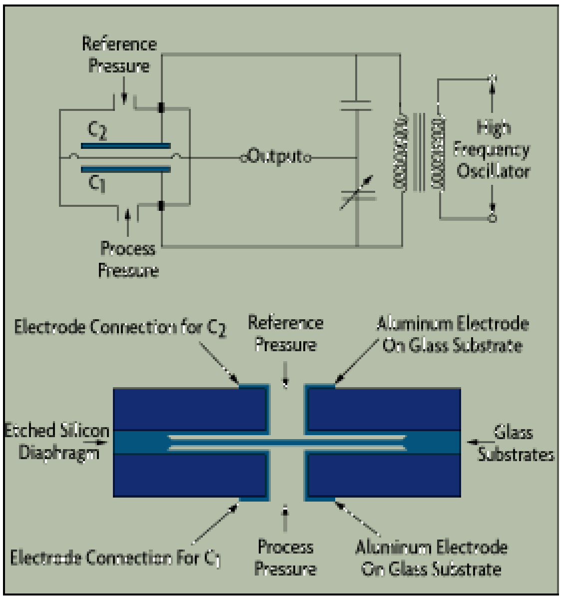
An electronic-type transmitter is shown in the figure above. This particular type utilizes a two-wire capacitance technique.

Process pressure is transmitted through isolating diaphragms and silicone oil fill fluid to a sensing diaphragm in the center of the cell. The sensing diaphragm is a stretched spring element that deflects in response to differential pressure across it. The displacement of the sensing diaphragm is proportional to the differential pressure. The position of the sensing diaphragm is detected by capacitor plates on both sides of the sensing diaphragm. The differential capacitance between the sensing diaphragm and the capacitor plates is converted electronically to a 4-20 mA dc signal.



Capacitance pressure transducers were originally developed for use in low vacuum research. This capacitance change results from the movement of a diaphragm element. The diaphragm is usually metal or metal-coated quartz and is exposed to the process pressure on one side and to the reference pressure on the other. Depending on the type of pressure, the capacitive transducer can be either an absolute, gauge, or differential pressure transducer.

Stainless steel is the most common diaphragm material used, but for corrosive service, high-nickel steel alloys, such as Inconel or Hastelloy, give better performance. Tantalum also is used for highly corrosive, high temperature applications. As a special case, silver diaphragms can be used to measure the pressure of chlorine, fluorine, and other halogens in their elemental state. In a capacitance-type pressure sensor, a high-frequency, high-voltage oscillator is used to charge the sensing electrode elements. In a two-plate capacitor sensor design, the movement of the diaphragm between the plates is detected as an indication of the changes in process pressure.



As shown in Figure the deflection of the diaphragm causes a change in capacitance that is detected by a bridge circuit. This circuit can be operated in either a balanced or unbalanced mode. In balanced mode, the output voltage is fed to a null detector and the capacitor arms are varied to maintain the bridge at null. Therefore, in the balanced mode, the null setting itself is a measure of process pressure. When operated in unbalanced mode, the process pressure measurement is related to the ratio between the output voltage and the excitation voltage.

Single-plate capacitor designs are also common. In this design, the plate is located on the back side of the diaphragm and the variable capacitance is a function of deflection of the diaphragm. Therefore, the detected capacitance is an indication of the process pressure.

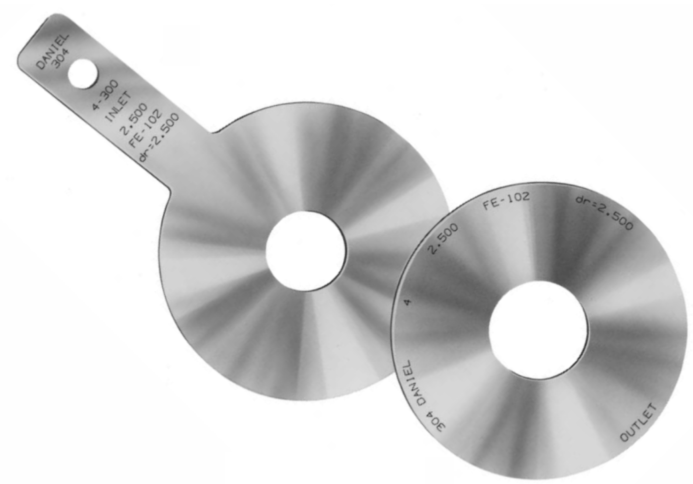
The capacitance is converted into either a direct current or a voltage signal that can be read directly by panel meters or microprocessor-based input/output boards.

Capacitance pressure transducers are widespread in part because of their wide rangeability, from high vacuums in the micron range to 10,000 psig (70 MPa). Differential pressures as low as 0.01 inches of water can readily be measured. And, compared with strain gage transducers, they do not drift much. Better designs are available that are accurate to within 0.1% of reading or 0.01% of full scale. A typical temperature effect is 0.25% of full scale per 1000¡ F.

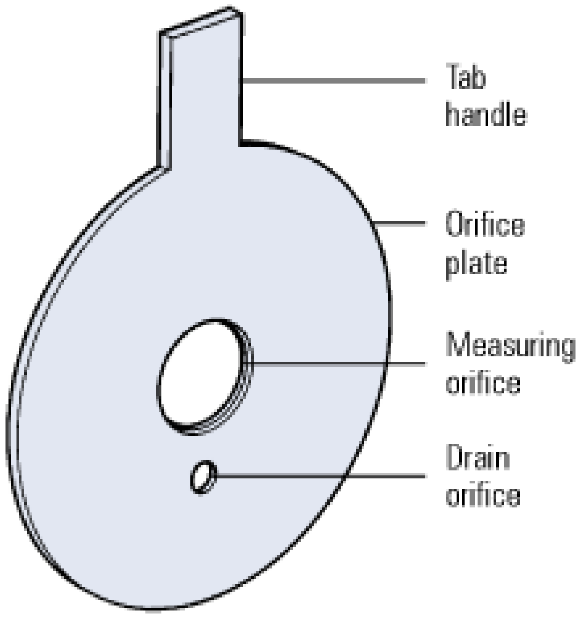
Capacitance-type sensors are often used as secondary standards, especially in low-differential and low-absolute pressure applications. They also are quite responsive, because the distance the diaphragm must physically travel is only a few microns. Newer capacitance pressure transducers are more resistant to corrosion and are less sensitive to stray capacitance and vibration effects that used to cause "reading jitters" in older designs.

5.6 Principle of operation of flow transmitters

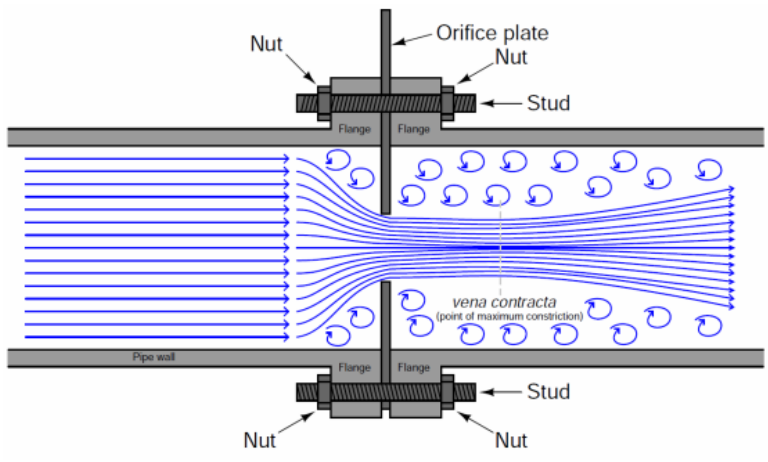
An Orifice flow meter is the most common head type flow measuring device. An orifice plate is inserted in the pipeline and the differential pressure across it is measured.



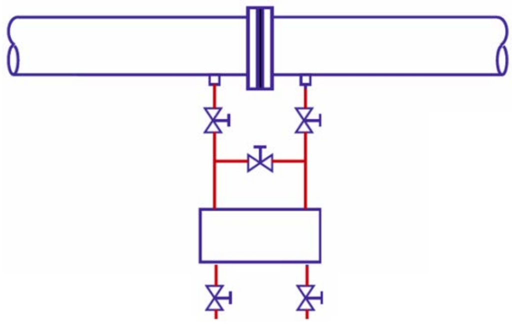
The orifice plate inserted in the pipeline causes an increase in flow velocity and a corresponding decrease in pressure. The flow pattern shows an effective decrease in cross section beyond the orifice plate, with a maximum velocity and minimum pressure at the venacontracta.

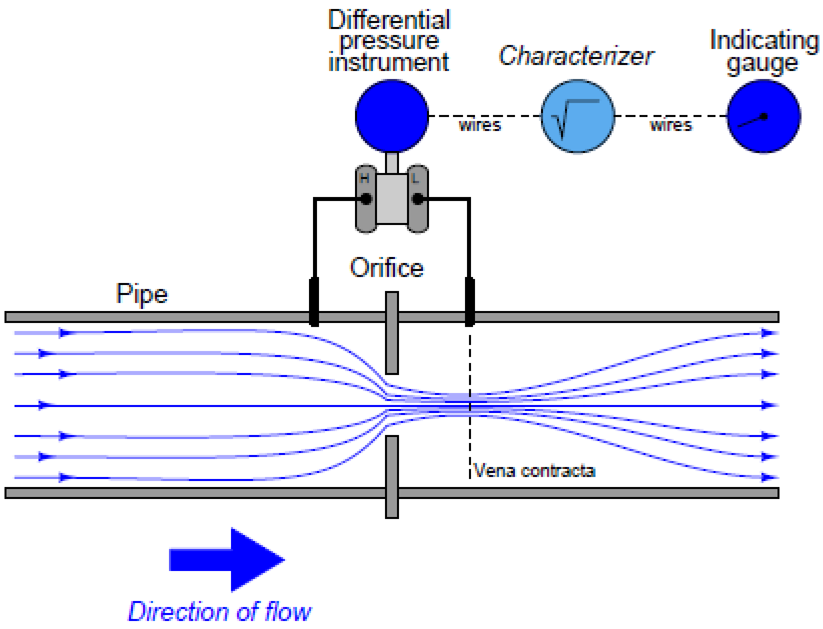


The flow pattern and the sharp leading edge of the orifice plate which produces it are of major importance. The sharp edge results in an almost pure line contact between the plate and the effective flow, with the negligible fluid-to-metal friction drag at the boundary.



Orifice plates are the simplest and cheapest form of primary elements and are used more frequently than all other types.



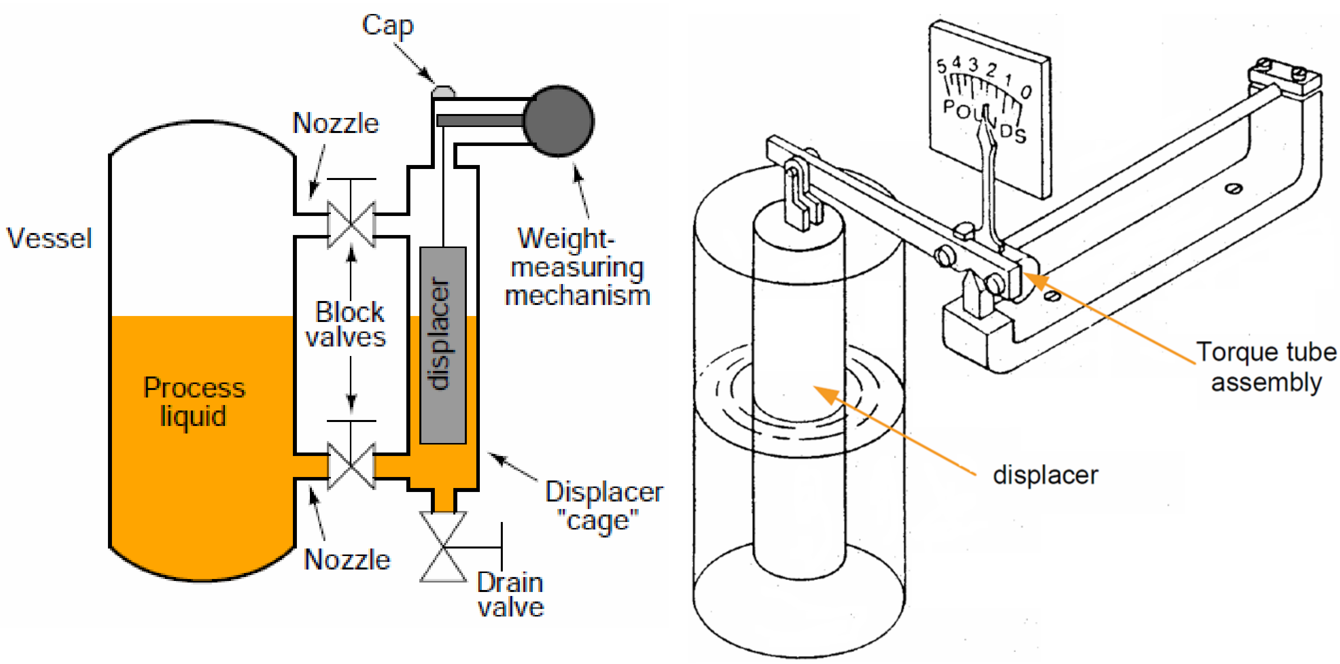


5.7 Principle of operation of level transmitters

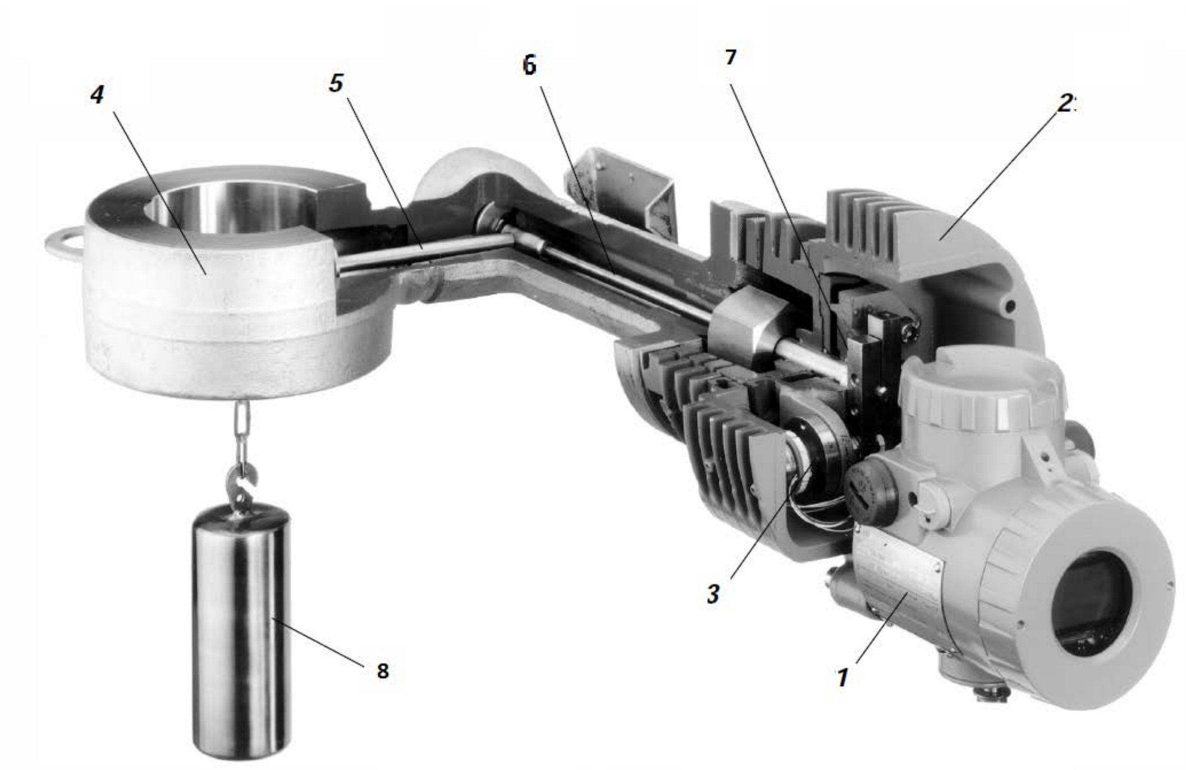
Displacer level instruments exploit Archimedes' Principle to detect liquid level by continuously measuring the weight of an object (called the displacer) immersed in the process liquid. As liquid level increases, the displacer experiences a greater buoyant force, making it appear lighter to the sensing instrument, which interprets the loss of weight as an increase in level and transmits a proportional output signal.

The displacer itself is usually a sealed metal tube, weighted sufficiently so it cannot float in the process liquid. It hangs within a pipe called a "chamber or cage" connected to the process vessel through two block valves and nozzles. These two pipe connections ensure the liquid level inside the cage matches the liquid level inside the process vessel, much like a sightglass. If liquid level inside the process vessel rises, the liquid level inside the cage rises to match. This will submerge more of the displacer's volume, causing a buoyant force to be exerted upward on the displacer. Remember that the displacer is too heavy to float, so it does not float on the surface of the liquid nor does it rise the same amount as the liquid's level – rather, it hangs in place inside the cage, becoming "lighter" as the buoyant force increases. The weight-sensing mechanism detects this buoyant force when it "sees" the displacer becoming lighter, interpreting the decreased (apparent) weight as an increase in liquid level. The displacer's apparent weight reaches a minimum when it is fully submerged, when the process liquid has reached the 100% point inside the cage.

It should be noted that static pressure inside the vessel will have negligible effect on a displacer instrument's accuracy. The only factor that matters is the density of the process fluid, since buoyant force is directly proportional to fluid density and liquid height ($F = \rho H$).



The chamber / cage pipe is coupled to the process vessel through two block valves, allowing isolation from the process. A drain valve allows the cage to be emptied of process liquid for instrument service and zero calibration. Some displacer type level sensors do not use a cage, but rather hang the displacer element directly in the process vessel. These are called "cageless" sensors. Cageless instruments are of course simpler than cage-style instruments, but they cannot be serviced without de-pressurizing (and perhaps even emptying) the process vessel in which they reside. They are also susceptible to measurement errors and "noise" if the liquid inside the vessel is agitated, either by high flow velocities in and out of the vessel, or by the action of motor-turned impellers installed in the vessel to provide thorough mixing of the process liquid(s).



1 Amplifier
2 Sensor housing
3 Sensor
4 Wafer body with heat sink and torque tube
5 Transmission lever
6 Torque tube
7 Clamping lever
8 Displacer with suspension chain

We may apply this torque tube mechanism to the task of measuring liquid level in a pressurized vessel by replacing the weight with a displacer, attaching the flange to a nozzle welded to the vessel, and aligning a motion-sensing device with the small rod end to measure its rotation. As liquid level rises and falls, the apparent weight of the displacer varies, causing the torque tube to slightly twist. This slight twisting motion is then sensed at the end of the small rod, in an environment isolated from the process fluid pressure.

5.8 Principle of operation of temperature transmitters

A temperature transmitter is a device that connects to a temperature sensor to transmit the signal elsewhere for monitoring and control purposes. Typically, the temperature sensor is either an RTD, Thermisor or Thermocouple type sensor and will interface with a PLC, DCS, data logger or display hardware.

The temperature transmitter's role is to isolate the temperature signal, filter any EMC noise, amplify and convert the temperature sensor's signal to a 4-20mA or 0-10V DC range for further use.

4-20ma temperature transmitters are common in manufacturing as the majority of industrial equipment communiciates via this signal range. The transmitted temperature signal can be scaled inside the temperature transmitter to accommodate the needs of the application, e.g. the 4mA can be used to represent -17.7°C (0° Fahrenheit) and the highest value in the range (20mA) can be used to represent 37.7° C (100° Fahrenheit)

Input signals types for a temperature transmitter
An RTD (Resistance Temperature Detector or Resistance Temperature Device) is one of the most prevalent temperature sensors used in industry today. Also commonly referred to as PT100, its resulting popularity is due to its accuracy and repsonse at temperatures between -300 to + 600 ° F.

The RTD sensor comprises of a resistor that changes value with temperature. The most common RTD by far is the PT100 385. This element measures 100 Ohms @ 0 degrees C (32 °F) and 138.5 Ohms @ 100 °C (212.0 °F).

A thermomcouple sensor has a pair of dissimilar metal wires joined at one end. The junction produces a low level voltage proportional to the difference in temperature between the open and closed ends.

As shown in the schematic above, a two wire temperature transmitter accepts a thermocouple or three wire Pt100 input and converts the ''temperature'' output into a 4-20mA current signal. The transmitter usually requires a 24VDC supply which is connected in series with the two wire interface or provided by the host instrument. The amplified temperature signal can be transmitted via a long cable run if required. This is a key advantage especially when dealing with large site installations.

Signal conditioning is the process of modifying the raw input signal in one or more ways to facilitate communication and measurement. The transmitter is a simple form of signal conditioner but signal conditioners usually provide linearization scaling facilities and other functions.

Signal conditioners are particularly useful when different parameters are measured in a process (e.g. Pt100 and thermocouple outputs, flow rates, pressure and force). The output from all of the appropriate sensors or transducers can then be rationalised into a common interface such as 4-20mA or 1-5V.

Owing to advancement in technology, most transmitters are becoming intelligent end devices largely because they are micro-processor based. Most of these devices are now regarded as “smart”devices that can be programmed to achieve a desired result in the plant. These programmable and so called “smart” transmitters effectively combine transmission and signal conditioning functions. In addition to manipulating the input-output function, a variety of transmission modes can be selected. Isolation of input to output further enhances their scope of applications; for example a multi-sensor installation with individual transmitters can be used without danger of earth loops establishing spurious potentials. Programming is performed via a PC using software normally supplied or via a plug-in module.

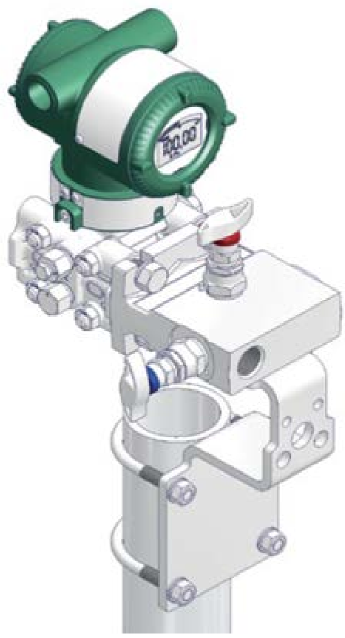
When a thermocouple or its extension wires are connected to the terminals of a device like a thermocouple transmitter the cold junction is at the room temperature T1°C. If both temperatures of the hot and the cold junctions are above 0°C, the device receives a lower emf than when the cold junction temperature is 0°C. In order to measure the temperature accurately, we need to add the emf value which corresponds to T1 to the measured emf. To add this emf is called cold junction compensation. A dedicated sensor inside the transmitter measures the ambient temperature and compensates to the main sensor.

5.8 **Installation of smart and conventional transmitters.**

Installation should be carried out using the best engineering practices by skilled personnel who are fully acquainted with the safety requirements and regulations governing a plant site. Prior to commencement of the work for a specific project, installation design details should be made available which define the scope of work and the extent of material supply and which give detailed installation information related to location, fixing, piping, and wiring. Such design details should have already taken account of established installation recommendations and measuring technology requirements.

5.8.1 Mounting and accessibility

When instruments are mounted in their intended location, either on pipe stands, brackets, or directly connected to vessels, etc., they should be vertically plumbed and firmly secured. Instrument mountings should be vibration free and should be located so that they do not obstruct access ways which may be required for maintenance to other items of equipment. They should also be clear of obvious hazards such as hot surfaces or drainage points from process equipment. Locations should also be selected to ensure that the instruments are accessible for observation and maintenance. Where instruments are mounted at higher elevations, it must be ensured that they are accessible either by permanent or temporary means.



Instruments should be located as close as possible to their process tapping points in order to minimize the length of impulse lines, but consideration should be paid to the possibility of expansion of piping or vessels which could take place under operating conditions and which could result in damage if not properly catered for. All brackets and supports should be adequately protected against corrosion by priming and painting. When installing final control elements such as control valves, again, the requirement for maintenance access must be considered, and clearance should be allowed above and below the valve to facilitate servicing of the valve actuator and the valve internals.

5.8.2 Piping systems

All instrument piping or tubing runs should be routed to meet the following requirements:

1. They should be kept as short as possible;
2. They should not cause any obstruction that would prohibit personnel or traffic access;
3. They should not interfere with the accessibility for maintenance of other items of equipment;
4. They should avoid hot environments or potential fire-risk areas;
5. They should be located with sufficient clearance to permit lagging which may be required on adjacent pipework;
6. The number of joints should be kept to a minimum consistent with good practice;
7. All piping and tubing should be adequately supported along its entire length from supports attached to firm steelwork or structures.

These are the lines containing process fluid which run between the instrument impulse connection and the process tapping point, and are usually made up from piping and pipe fittings or tubing and compression fittings. Piping materials must be compatible with the process fluid. Generally, tubing is easier to install and is capable of handling most service conditions provided that the correct fittings are used for terminating the tubing. Such fittings must be compatible with the tubing being run (i.e., of the same material).

Impulse lines should be designed to be as short as possible, and should be installed so that they are self-draining for liquids and self-venting for vapors or gases. If necessary, vent plugs or valves should be located at high points in liquid-filled lines and, similarly, drain plugs or valves should be fitted at low points in gas or vapor-filled lines. In any case, it should be ensured that there are provisions for isolation and depressurizing of instruments for maintenance purposes. Furthermore, filling plugs should be provided where lines are to be liquid scaled for chemical protection and, on services which are prone to plugging, rodding-out connections should be provided close to the tapping points.

5.8.3 Air supplies

Air supplies to instruments should be clean, dry, and oil free. Air is normally distributed around a plant from a high-pressure header (e.g., 6-7 bar g), ideally forming a ring main. This header, usually of galvanized steel, should be sized to cope with the maximum demand of the instrument air users being serviced, and an allowance should be made for possible future expansion or modifications to its duty. Branch headers should be provided to supply individual instruments or groups of instruments. Again, adequate spare tapings should be allowed to cater for future expansion. Branch headers should be self-draining and have adequate drainage elblow- off facilities. On small headers this may be achieved by the instrument air filter/regulators. Each instrument air user should have an individual filter regulator. Piping and fittings installed after filter regulators should be non-ferrous.

5.8.4 Pneumatic signals

Pneumatic transmission signals are normally in the range of 0.2-1.Obarg (3-15psig), and for these signals copper tubing is most commonly used, preferably with a PYC outer sheath. Other materials are sometimes used, depending on environmental considerations (e.g., alloy tubing or stainless steel).

Although expensive, stainless steel tubing is the most durable and will withstand the most arduous service conditions. Plastic tubing should preferably only be used within control panels. There are several problems to be considered when using plastic tubes on a plant site, as they are very vulnerable to damage unless adequately protected, they generally cannot be installed at subzero temperatures, and they can be considerably weakened by exposure to hot surfaces. Also, it should be remembered that they can be totally lost in the event of a fire.

Pneumatic tubing should be run on a cable tray or similar supporting steelwork for its entire length and securely clipped at regular intervals. Where a number of pneumatic signals are to be routed to a remote control room they should be marshaled in a remote junction box and the signals conveyed to the control room via multitube bundles. Such junction boxes should be carefully positioned in the plant in order to minimize the lengths of the individually run tubes.

5.8.5 Cabling

Instrument cabling is generally run in multicore cables from the control room to the plant area (either below or above ground) and then from field junction boxes in single pairs to the field measurement or actuating devices.

For distributed microprocessor systems the inter-connection between the field and the control room is usually via duplicate data highways from remote located multiplexers or process interface units. Such duplicate highways would take totally independent routes from each other for plant security reasons.

Junction boxes must meet the hazardous area requirements applicable to their intended location and should be carefully positioned in order to minimize the lengths of individually run cables, always bearing in mind the potential hazards that could be created by fire.

Cable routes should be selected to meet the following requirements:

1. They should be kept as short as possible.

2. They should not cause any obstruction that would prohibit personnel or traffic access.

I nstrurnent / Mounting post / Manifold

3. They should not interfere with the accessibility for maintenance of other items of equipment.

4. They should avoid hot environments or potential fire-risk areas.

5. They should avoid areas where spillage is liable to occur or where escaping vapors or gases could present a hazard.

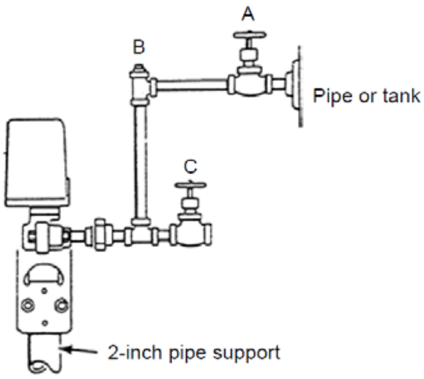
5.8.6 Grounding

Special attention must be paid to instrument grounding, particularly where field instruments are connected to a computer or microprocessor type control system. Where cable screens are used, ground continuity of screens must be maintained throughout the installation with the grounding at one point only, i.e.. in the control room. At the field end the cable screen should be cut back and taped so that it is independent from the ground. Intrinsically safe systems should be grounded through their own ground bar in the control room. Static grounding of instrument cases, panel frames, etc., should be connected to the electrical common plant ground.

Instrument grounds should be wired to a common bus bar within the control center, and this should be connected to a remote ground electrode via an independent cable (preferably duplicated for security and test purposes). The resistance to ground, measured in the control room, should usually not exceed 1 ohms unless otherwise specified by a system manufacturer or by a certifying authority.

5.8.7 Examples

After transmitter is mounted, tighten all bolts. Pipe may be clamped to another pipe, or flanged and bolted to floor or wall. U-bolt secures assembly to 2" (nominal 50 mm) pipe. U-bolt may be revolved 90° for use with horizontal pipe. Optional air-set can be mounted as illustrated below.

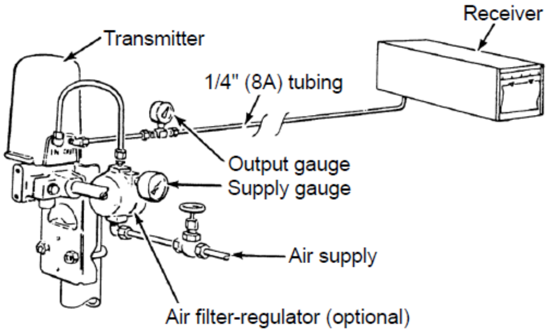


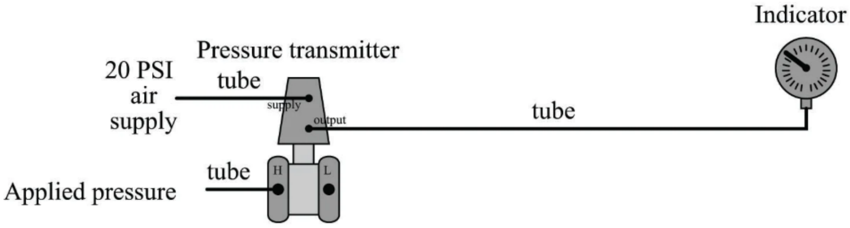
A – Isolation valve

B – Vent plug

C – Drain valve

Air Supply and Transmission Piping





5.9 **Calibration of conventional transmitters.**

Calibration is the comparison of measurement values delivered by a device under test with those of a calibration standard of known accuracy. Such a standard could be another measurement device of known accuracy, a device generating the quantity to be measured such as a voltage, a sound tone, or a physical artifact, such as a meter ruler.

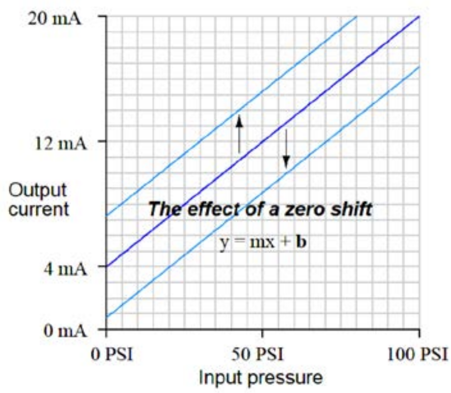
Calibration is the process where known inputs are applied to a measuring system and the output are observed and compared with the standard instruments derived from comparison with the primary standards kept at Standard Laboratories.

Calibration is required if the transmitter has been taken apart for cleaning or for parts replacement, if a change of range is desired, or if the amount of zero elevation or zero suppression (if transmitter is so equipped) is changed substantially. If the capsule was removed or the flexure cap screw loosened, before calibrating, make the flexure cap screw adjustment. The transmitter may be calibrated to 0.2-1.0 kgf/ cm2, 20-100 kPa, 0.2-1.0 bar, or 3-15 psi signal pressure range. These four ranges are not exactly equivalent; therefore the transmitter must be calibrated to the same signal pressure range as the receiver with which it is used.

5.9.1 Errors

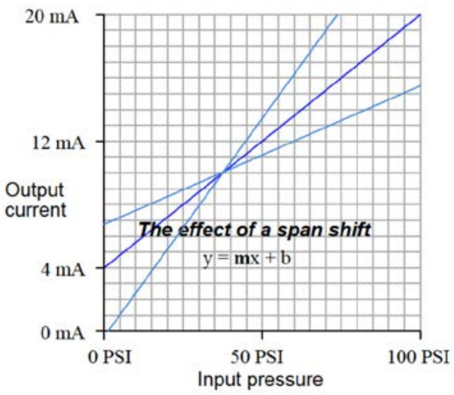
Zero Shift Calibration Error

A zero shift calibration error shifts the function vertically on the graph, which is equivalent to altering the value of b in the slope-intercept equation. This error affects all calibration points equally, creating the same percentage of error across the entire range.



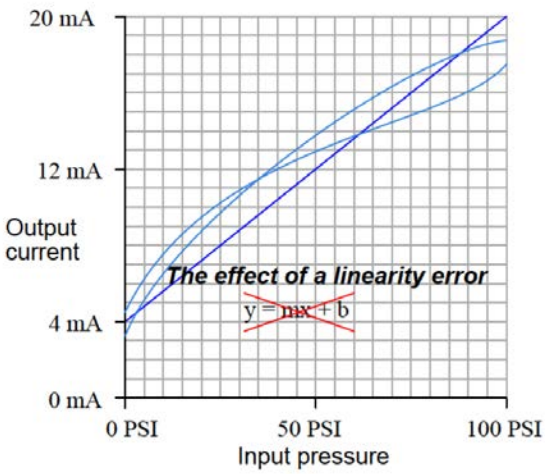
Span Shift Calibration Error

A span shift calibration error shifts the slope of the function, which is equivalent to altering the value of m in the slope-intercept equation. This error's effect is unequal at different points throughout the range.



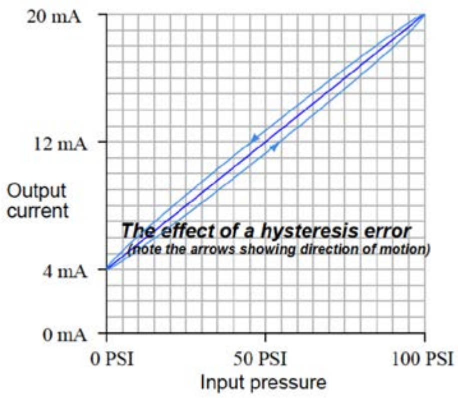
Linearity Calibration Error

A linearity calibration error causes the instrument's response function to no longer be a straight line. This type of error does not directly relate to a shift in either zero (b) or span (m) because the slope-intercept equation only describes straight lines.



Hysteresis Calibration Error

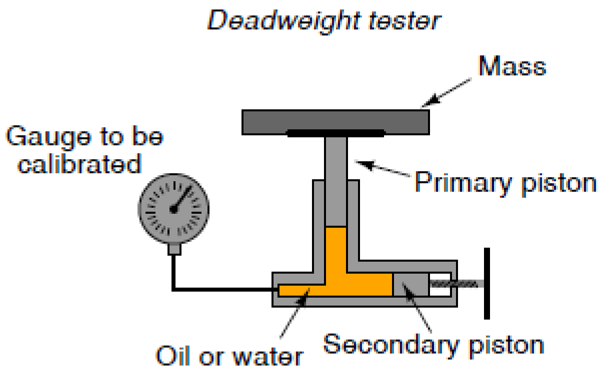
A hysteresis calibration error occurs when the instrument responds differently to an increasing input compared to a decreasing input. The only way to detect this type of error is to do an up-down calibration test, checking for instrument response at the same calibration points going down as going up.



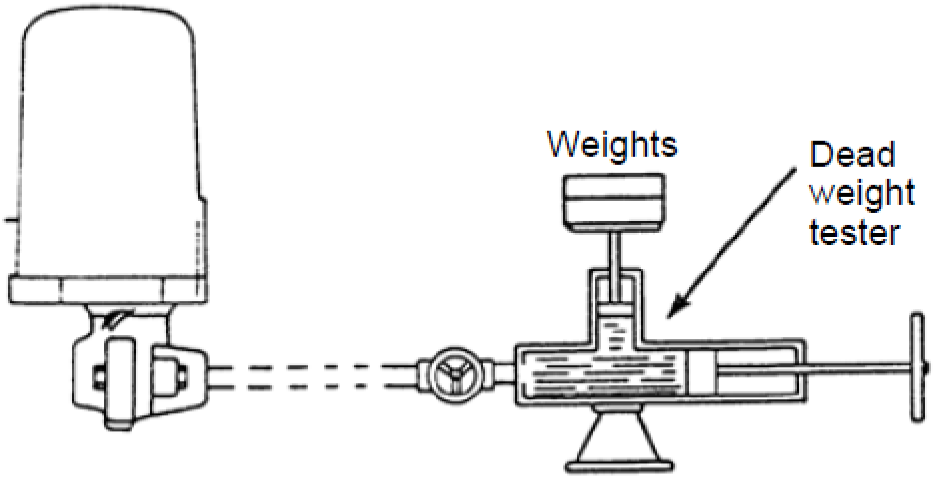
5.9.2 Calibration setup

In order to accurately calibrate a pressure instrument in a shop environment, we must create fluid pressures of known magnitude against which we compare the instrument being calibrated. As with other types of physical calibrations, our choice of standards falls into two broad categories: devices that inherently produce known pressures versus devices that accurately measure pressures created by some (other) adjustable source.

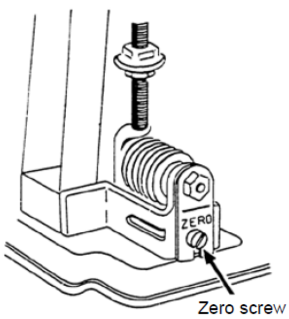
A deadweight tester (sometimes referred to as a dead-test calibrator) is an example in the former category. These devices create accurately known pressures by means of precise masses and pistons of precise area.



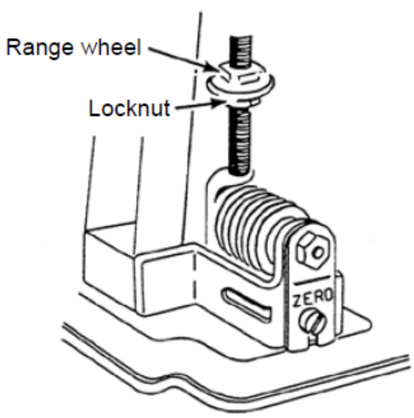
5.9.3 Calibration Procedure for pneumatic transmitter



1. With no pressure on transmitter, adjust zero screw so that output on test gauge reads 0.2 kgf/cm2 or bar, 20 kPa, or 3 psi.



2. Set calibrating pressure equal to upper limit. The output should be 1.0 kgf/cm2 or bar, 100 kPa, or 15 psi.
3. If output is incorrect, loosen locknut and adjust range wheel for correct output. Turning range wheel down increases output. Retighten locknut after each adjustment.



Repeat Steps 1 through 3 until the desired accuracy is obtained. Tighten range wheel locknut securely.

5.9.3 Calibration Procedure for electronic transmitter

5.10 **Calibration of smart transmitters.**

5.11 Questions

PART – A

Define transmitters.

Examine the principle used in pneumatic transmitter.

Illustrate the applications of temperature transmitter.

When do you call a pressure as a pneumatic pressure?

Draw the block diagram of electronic transmitter.

Write a note on different stages of transmitters.

Differentiate flow and level transmitter based on its principle of operation.

Compare 2 wire and 4 wire transmitters.

Describe the temperature transmitter and the principle used in it.

Define calibration of transmitters.

Examine about the pressure range involved in the operation of pressure transmitter.

Explain rangeablity in transmitters.

Explain Signal Pulse Modulation.

What is a smart transmitter? Why it is called so?

How smart and conventional transmitter differ from each other?

Discuss about remote adjustability in transmitter.

Draw 2 wire and 4 wire transmitters.

Write down the advantages and uses of electronic transmitter.

What is UART? Mention its uses.

Define installation of transmitters.

PART – B

Define the terms associated with industrial data transmission. (7)

Explain the principle of operation of electronic transmitter. (6)

Explain the operation of flow transmitter with suitable sketch. (13)

Explain how pressure is used in the process of transmission with neat sketch. (7)

Explain about the pressure ranges used in process of transmission and its limitations. (6)

Illustrate the features of smart and intelligent transmitter.

Briefly describe the functioning of smart and intelligent transmitter. (13) (13)

Explain the principle of operation of level type transmission with a neat sketch. (13)

Explain the working of force-balance transmitters with neat diagram. (7)

Explain the advantages and disadvantages associated with force-balance transmitters. (6)

Enumerate the types of pneumatic transmitters used in the process industry. (13)

What is a transmitter? (5)

Draw the block diagram of electronic transmitter

What are the types of transmitters used in Industrial control and explain? (8)

Describe with neat sketch the working of a square-root-extracting differential pressure transmitter. (13)

Explain with neat sketch the working of differential pressure pneumatic transmitter. (13)

Describe the different installation methods of conventional transmitters. (13)

Explain with neat sketch the construction and working of a pneumatic temperature transmitter. (13)

(i) What is calibration? (4)

(ii) Explain the different calibration methods of smart and conventional transmitters. (9)

PART – C

Sketch the functional block of smart and intelligent transmitter with communication facility and explain it. (15)

Explain the principle of Buoyancy (level and density) transmitters. (15)

Sketch the motion balance pneumatic pressure transmitter with zero adjustment and explain it. (15)

Write short notes on variable area flow transmitters. (15)

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Engineering Solutions and Training

About the Publication

ENSOLT is one of the leading design and engineering organizations in Chennai. Established in 1991, ENSOLT provides engineering consultancy and EPC services principally focused on the Oil & Gas, Power Plant and Petrochemical industries. The Company has also diversified into sectors like training and project guidance to engineering college students. ENSOLT is committed to quality knowledge transfer and training. The objective of this firm is to provide cost effective solutions to engineering glitches in the field of Electronics, Communication, Electrical and Instrumentation.

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