OPERATING
SECTION
REPORT

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Section 8.1
ON-SITE FLOW COMPUTERS

GENERAL

Definitions

A flow computer is a device that electrically converts signals from a gas measurement system to a useful form such as flow rate. Signal inputs to flow computers can be in analog or digital form from transducers used with orifice, rotary, and turbine meters. Computer outputs vary depending on individual needs. Common outputs include analog signals proportional to flow, digital registers, and printed reports. Some flow computers also can communicate with other computers through standard communication ports, such as an RS232C port.

Industry Practices

A general-purpose computer is not intrinsically safe and may not be installed in hazardous locations. In general, such a computer is designed to be located in a weatherproof enclosure pursuant to electrical codes and in close proximity to the primary metering source. Common power inputs are 24 Vdc, 110 Vac and 240 Vac. Most systems will function properly between temperature limits of 20 to 120 degrees F; depending on the model, some systems can operate within even wider temperature ranges.

Intrinsically safe computers are designed for use in hazardous locations. Power is limited either by current barriers or by internal design. Most intrinsically safe systems are designed to operate between 0 and 140 degrees F.

Inputs to flow computers depend on the primary metering element. Inputs from an orifice meter include differential pressure, static pressure, and gas flowing temperature. Input from rotary and turbine meters are pulse signals along with static pressure and gas flowing temperature. Other inputs may, depending on the computer model, include heating value, specific gravity, mole percent carbon dioxide and nitrogen, etc.

Many computers have the capability for accepting inputs from multiple meters, calculating and reporting flow rate through each individual meter, and reporting a station total.

Flow computers can be categorized basically into three basic types: Analog computers with fixed programs, digital computers with fixed programs, and digital computers with variable programs. With the last, program changes typically are made from the keyboard.

TYPES OF FLOW COMPUTERS

Analog Flow Computers

Analog computers operate by electrically manipulating continuous electrical signals. Input information is continuous and the voltage or current is representative of a physical condition such as pressure or temperature. The computer transforms the electrical input to a physical output, such as flow rate, through signal amplification, division, summations, etc.

Digital Flow Computers

Digital computers process information by using a combination of discontinuous input signals. The analog input information is sampled at a fixed rate and converted to a fixed value through the use of an analog-to-digital converter. Once in the digital form, the computer processes the information and exercises its program in a serial manner. Output can be discrete digital values, such as contact closures and printed reports, or analog outputs, which are generated through the use of digital to analog converters. Digital flow computers also can communicate with other computers through standard communication ports, such as RS232C ports.

TYPES OF CALCULATION

Differential Head Meters (Orifice plates, nozzles, and venturi tubes)

In the United States and Canada the standard most commonly used to calculate gas flow measurement is A.G.A. Report No. 3, also referred to as ANSI/API 2530. Another major standard, International Standard Organization 5167, is used throughout Europe. Although both standards were developed from the same data, they use different equations and will provide slightly different results. Proper application of either standard will yield final results within the expected accuracy.

The basic flow formula of A.G.A. Report No. 3 is:

$$Q_h = C' \sqrt{h_w P_f} \tag{8.1.1}$$

where:

Q_h = hourly rate of flow, SCFH
C' = orifice flow constant
h_w = differential pressure, inches of water
P_f = absolute static pressure, PSIA

One of the advantages of using digital flow computers is the ability to compute and apply the C′ factor continuously. C′ consists of the following multipliers:

F_b = basic orifice factor
F_r = Reynolds number factor
Y = expansion factor
F_{pb} = pressure base factor
F_{tb} = temperature base factor
F_{tf} = flowing temperature factor
F_g = specific gravity factor
F_{pv} = supercompressibility factor
F_a = orifice thermal expansion factor
F_1 = gage location factor (only used with mercury gages)

Many of the factors that make up C′ are functions of the gas conditions and are subject to change. Flow computers are most accurate when these values are continually measured and updated for flow calculation.

Pulse Output Meters

Flow computers used with pulse output meters (turbine, positive displacement, vortex shedding, etc.) utilize a different formula for the computation of flow, as follows:

$$Q_s = Q_a \times F_p \times F_t \times F_c \tag{8.1.2}$$

= corrected volume standard cubic feet

where:

$Q_a = Q_d \times MF$ (meter factor determined through calibration)

= actual volume (cubic ft)

$$Q_d = \frac{\text{pulses (meter output)}}{\text{pulses/cubic ft (meter output)}}$$

$$= \text{displaced volume (cubic ft)}$$

$$F_p = \frac{\text{gage} + \text{atmospheric pressure}}{\text{base pressure}}$$

$$= \text{pressure correction factor}$$

$$F_t = \frac{459.67 + \text{base temperature °F}}{459.67 + \text{flowing temperature °F}}$$

$$= \text{temperature correction factor}$$

$$F_c = (F_{pv})^2$$

$$= \text{square of supercompressibility factor}$$

Other Types of Meters

Other meters will use other specific formulas for the calculation of flow; these formulas must be a part of the flow computers' fixed programs. For these specific calculations use the manufacturers' equations.

OUTPUTS

Definitions

Instantaneous—Instantaneous flow data are presented in terms of a quantity per unit time. Examples of commonly used instantaneous flow rates are:

- Thousand cubic feet per hour—Mcf/h (volumetric flow rate)
- Million cubic feet per day—MMcf/d
- Cubic meters per hour—m^3/h
- Pounds per hour—lb/h (mass flow rate)
- Pounds per day—lb/d
- Dekatherms per hour—DT/h (energy flow rate)

Accumulated—Accumulated gas flow data are presented in terms of instantaneous flow rate integrated with respect to time. Units used for accumulated flows, sometimes referred to as total flow, are:

- Thousand cubic feet—Mcf (volume)
- Million cubic feet—MMcf
- Cubic Meters—m^3 (mass)
- Pounds—lb
- Dekatherms—DT (energy)

Displays

Instantaneous flow rates may be displayed on the computer's front panel. This display may take the form of an analog indicator such as a meter with a pointer, or it may take the form of a direct numeric readout by light emitting diodes or liquid crystal displays. A multiplier may be required to convert the displayed value to a meaningful number.

Accumulated flow displays also may be displayed on the computer's front panel. This display can be a direct reading electrical readout or an electro-mechanical counter. In the case of an electrical readout, memory is necessary to preserve the accumulated volume during a power failure. This electronic display may be independent of the instantaneous display or may be a time-shared display. Electro-mechanical counters retain the last reading during a power failure but are susceptible to mechanical failure. In either case, during a power failure no flow is accumulated. Accumulated flow determination requires that readings be taken at the beginning and at the end of the flow period. The difference between the two readings is the total flow.

Other data may be displayed on the computer's front panel. A common practice is to switch various parameters to a single front-panel display for time-shared viewing. Some examples of data commonly displayed are:

- Input static pressure
- Input temperature
- Input differential pressure
- Uncorrected rate of flow
- Supercompressibility factor
- Gravity factor
- Temperature factor

Digital computers generally are very versatile in that they can allow more data types to be displayed. The display of these data assists in calibration and maintenance work.

Status indicators, which offer assistance to the operator as a quick operational check, may be displayed on the computer's front panel. Generally, these displays consist of indicator lamps. Some examples are:

- Power on
- Number of meter runs in service
- Type of function displayed on numeric display
- Present alarm condition
- Alarm condition that has cleared

A printer may be an integral part of the flow computer to provide a hard copy of certain data. These data may be printed out at various times over the day, week, or month. Examples of printed data are:

- Hourly flow rate cf/h
- Daily flow rate cf/d
- Line pressures and temperatures
- Alarm conditions

Electrical Interface for Remote Use

Electrical output from analog and digital computers may represent corrected or uncorrected volumetric or mass flow. Commonly used electrical signals are 0–10 Vdc, 1–5 Vdc, 0–1 mAdc, 4–20 mAdc, and 10–50 mAdc. The flow rate represented by the maximum signal level is usually adjustable by the user. When more than one signal is offered, the maximum flow represented by each may be independent of the others. Manufacturer's specifications should be consulted to avoid electrical overloads on the output signals and concerning the maximum length of the interface cables.

Analog and digital computers may provide electrical outputs that represent accumulated gas flow. This is done with either a dry contact closure or an open collector. In either case, each signal represents a predetermined quantity of gas. The number of accumulated pulses within a given time period multiplied by the quantity of gas per pulse equals the total accumulated flow.

The manufacturer's specification also should be consulted concerning all interface electrical loading requirements.

Digital outputs are offered by some digital on-site flow computers. These outputs can be used by telemetering terminals, teleprinters, and other display equipment. Digital outputs such as those from an RS232C port with ASCII formats are commonly used. Receiving equipment must be able to decode this signal to complete the data transfer.

Digital representation of other data may be available through the digital output port on the computer. Transfers of digital data can be made efficiently and quickly and, with the proper coding and checking, can be made error free. Digital data transfer eliminates the calibration errors associated with analog signals.

Alarm indications for external use may be available on both analog and digital computers. Normally, these will be of the dry-contact or voltage-pulse variety and can indicate different conditions within the computer.

VERIFICATION

General

Periodic checks should be made to ensure that the on-site computer is calculating correctly. Verification that the on-site computer is correct can be made if the computer output can be compared to a standard of known accuracy. After the fixed system parameters are correctly entered into the computer program, the computer output should be verified. In addition to conducting the initial verification, the responsible person should verify the computer's output periodically to ensure its accuracy.

The on-site flow calculation can be verified in the following two ways:

- **Computer System Verification**—Compare the on-site computer output to a standard by simulating input signals through the analog-to-digital (A/D) converters.
- **Computer Verification**—Compare only the on-site computer output to a standard, ignoring any error in the A/D converter by setting fixed inputs for the measurement parameters.

Calculation of a Standard

A manual calculation of the flow rate can be used as a standard to which the computer output can be compared. The precision of this manual calculation should be at least as accurate as that of the computer. Errors in the standard will occur if an incorrect variable is used as an input for the manual calculation. Examples of inputs that are required to produce acceptable manual calculation of the flow to be used as a standard are:

- Pressure
- Differential pressure or pulse frequency
- Temperature
- Specific gravity
- Supercompressibility data or factor
- Meter factor(s)
- Other data necessary to solve the applicable equation

Computer Calculation Verification Using External Input Signals

The on-site computer will scale the primary data variables (simulated transmitter signals), calculate a flow rate, and generate a value representative of the flow through the meter. A comparison between the manual flow rate calculation, as the standard, and the computer output should be made to verify that the computer is calculating flow rate correctly.

Figure 8.1.1 is an example of the configuration that might be used to spot check an on-site computer for accuracy. The test signals must be of known accuracy and stable during the test period. These values are then used in the flow equations to calculate manually the flow rate to be used as the standard. The calculated standard then is compared to the computer outputs.

The following precautions should be observed when this comparison is made:

- Values and equations used in the manual calculation must be the same as those used by the on-site computer.
- The accuracy of the input variables is limited to the manufacturer's tolerance of the calibration equipment; any differences should not be attributed automatically to the on-site computer.
- All computer outputs should be compared to the standard.
- The verification comparisons should be done at multiple points spaced throughout the normal operating range of the equipment.

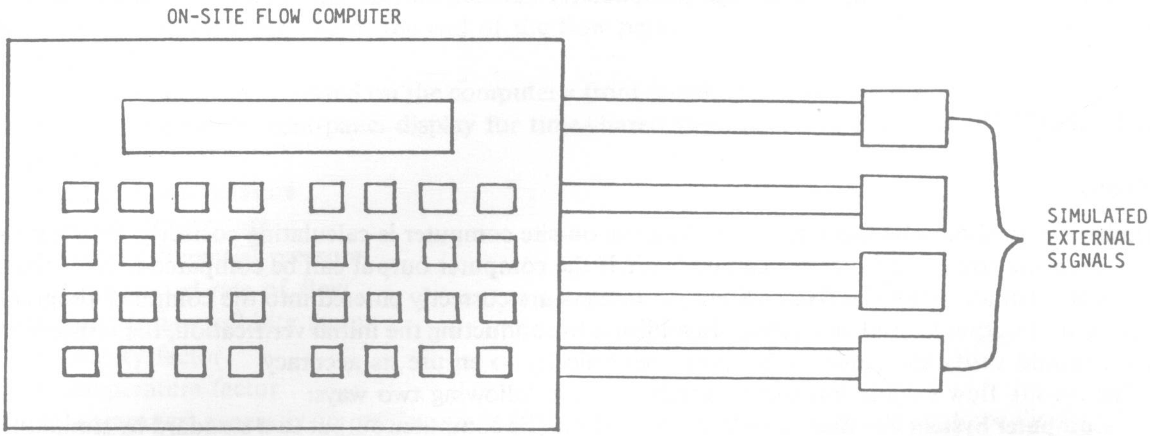

Figure 8.1.1 Computer calculation verification using external input signals.

Computer Calculation Verification Using Fixed Internal Inputs

The on-site computer will use the fixed values entered as calculating parameters to calculate a flow and generate a value representative of the flow through the meter. A comparison between the manual flow calculation, as the standard, and the computer output should be made to verify that the computer is calculating flow correctly.

The following precautions should be observed when this comparison is made:

- The values and equations used in the manual calculation must be the same as those used by the on-site computer.
- All computer outputs should be compared to the standard.

Instantaneous Comparisons Versus Accumulated

Instantaneous comparisons are much easier to make than accumulated comparisons. A single manual calculation can be used as an instantaneous standard.

A standard to be used in comparing accumulated flow over long periods of time involves the integration of the instantaneous flow with respect to time. This can introduce errors of unknown magnitude into the calculations. For verification of the on-site computer's integration circuitry, consult the manufacturer.

Section 8.2
PRESSURE AND DIFFERENTIAL-PRESSURE TRANSDUCERS AND TRANSMITTERS

GENERAL DEFINITIONS

Pressure Transducer/Transmitter—The terms transducer and transmitter frequently are used interchangeably. Strictly speaking, a transducer is a sensing element capable of transforming values of physical variables (e.g. pressure or differential pressure) into equivalent electrical signals. A transmitter takes the output from a transducer and conditions it to a standardized transmission signal that is a function only of the measured variable.

Pressure—Pressure is the force per unit area exerted by a gas, liquid, or vapor on the walls of a pipe or vessel. Commonly used units of measurement are pounds per square inch (psi), inches of water (in. H_2O), and inches of mercury (in. Hg).

Atmospheric Pressure—Barometric Pressure—Atmospheric pressure is the pressure exerted on the earth by the air surrounding it. Normally at sea level, it is equal to 14.73 psi.

Static Pressure—Gage Pressure—Gage pressure is the static pressure at any point in the system. Its value does not include atmospheric pressure. Gage pressure is denoted commonly as "psig."

Static Pressure—Absolute Pressure—Absolute pressure is the static pressure that does include atmospheric pressure at any point in a system. Typically, it is written "psia" or "in. Hg. abs.".

Differential Pressure—Differential pressure is the difference in pressure between two points in a pipe when flow exists. Differential pressure is also referred to as "Delta P," "ΔP," "DP," or "Pressure Drop" and is measured across a fixed restriction such as an orifice plate, flow tube, or venturi. Differential pressure generally is measured in inches of water column.

TRANSMITTER PERFORMANCE SPECIFICATIONS

Linearity—Linearity is the closeness to which a calibration curve approaches a straight line. It can be independent, terminal-based, or zero-based. When expressed simply as linearity, it is assumed to be independent.

Independent Linearity (Best Straight Line)—Independent linearity is expressed as the maximum deviation of a curve from a straight line that is positioned so as to minimize that deviation (Figure 8.2.1).

Zero-Based Linearity—Zero-based linearity is expressed as the maximum deviation of a curve from a straight line that is fixed at the actual output at zero percent span and positioned so as to minimize that deviation (Figure 8.2.2).

Terminal-Based Linearity (End Point)—Terminal-based linearity is expressed as the maximum deviation of a curve from a straight line that is fixed at the actual lower and upper values (Figure 8.2.3).

Hysteresis—Hysteresis is expressed as the difference between the upscale and downscale output values for the same absolute input.

Deadband—Deadband is the range through which an input signal may be varied upon reversal of direction without initiating an observable change in output signal.

Repeatability—Repeatability is expressed as the closeness of agreement among a number of consecutive output measurements for the same absolute input when approached from the same direction.

Converter—A converter is a device designed to perform a specific instrument signal conversion, such as changing a 3–15 psi instrument air signal to a 4–20 mA electronic signal:

- P/I converters (pressure to current) change pneumatic instrument signals to current signals.
- I/P converters (current to pressure) change current signals to pneumatic signals.

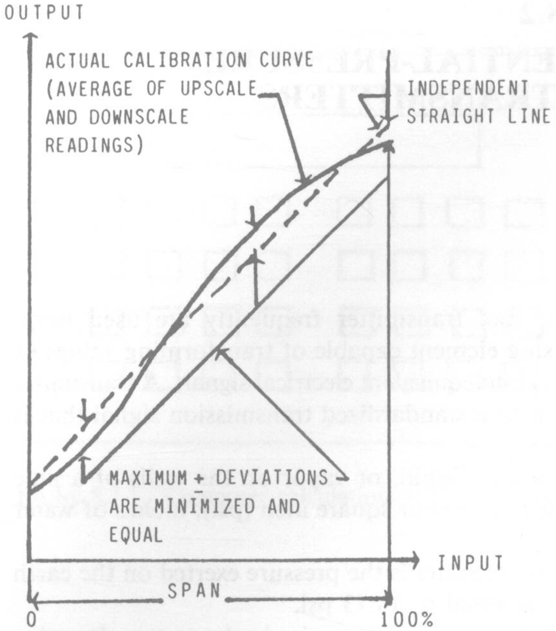

Figure 8.2.1 Independent linearity.

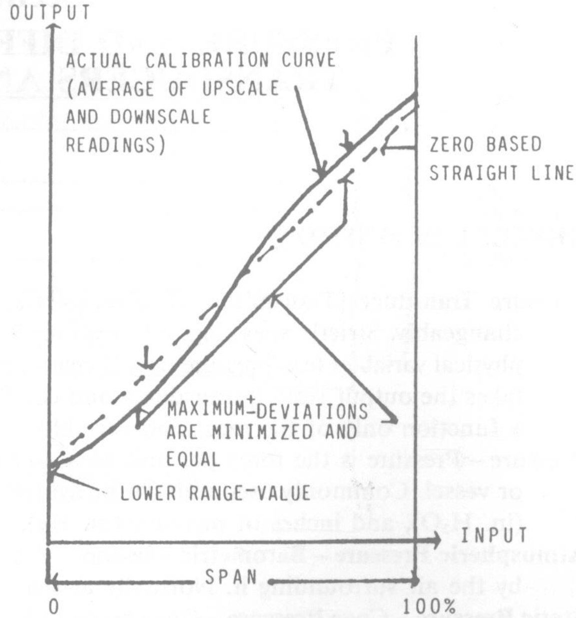

Figure 8.2.2 Zero-based linearity.

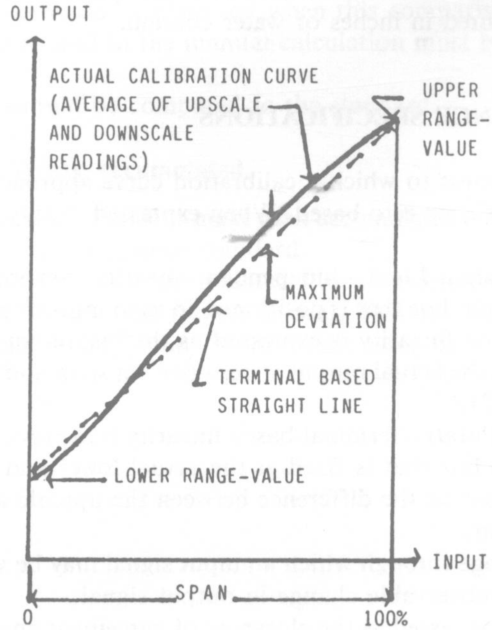

Figure 8.2.3 Terminal-based linearity.

- I/I converters (current to current) change current signals from one value to another, i.e. 4–20 mA to 10–50 mA.

INDUSTRY STANDARDS AND PRACTICES

It is essential that pressure and temperature transmitters conform to certain standards as to pressure, temperature, and electrical ratings. Some of the more common standards are:

- National Electrical Manufacturers Association (NEMA), which establishes requirements for weatherproof electronics housings
- National Electrical Code (NEC) and Canadian Standards Association (CSA) Class I, Group D, Division 1 and 2, which establish requirements for equipment used in hazardous areas where natural gas is present
- Instrument Society of America (ISA), which defines letter designations for thermocouple sensor types, i.e. Type K—chromel/alumel
- American Society of Mechanical Engineers (ASME) E-220-72 and American National Standards Institute (ANSI) MC96.1, which define the relationship between thermoelectric current and temperature

Detailed information concerning any of these standards may be obtained by consulting the applicable documents.

In addition to the foregoing industry standards and practices, there are also certain general practices that are followed in the design and construction of pressure transducers and transmitters. Three of these, to which conformance should be expected, are: output grounding (+, −, or floating), process connection capability, and dimensional compatibility.

PERFORMANCE SPECIFICATIONS

An essential consideration in the selection of pressure transducers and transmitters is performance. Overall accuracy—including the effects of ambient temperature, overpressure, static pressure, input impedance, sensor lead resistance effect, vibration, mounting position, power supply, load variations, electromagnetic interference, lightening protection, radio-frequency interference, and speed of response—should be examined. Long term stability also should be considered.

Accuracy

For the transducer, accuracy is the measure of how closely the output conforms to the true pressure; for the transmitter, accuracy is the measure of how closely the output conforms to the transducer's output. Accuracy statements should include the effects of hysteresis, linearity, repeatability, and stability expressed as a percent of maximum calibrated span or percent of reading.

Ambient Temperature Effects

Variation in ambient temperatures can cause a corresponding variation in the pressure transmitter's zero and span outputs. The zero effect is expressed as a percent of calibrated span.

The span effect should be combined with the zero effect according to the root sum square (RSS) method of error analysis:

$$\text{Total error} = \sqrt{(\text{Zero Effect})^2 + (\text{Span Effect})^2}$$

Typical presentations of temperature effect specifications are:

- No specifications
- ±a%/°F
- ±a%/X°F
- ±a% from Y°F to Z°F
- ±a% FS/°F
  (This specification can be misleading in that often it is based on a reference temperature between Y and Z with the stated percent applying to half the span.)
- ±a% zero error/X°F at maximum span
  +b% total error including span and zero/X°F at maximum span
  ±c% zero error/X°F at minimum span
  ±d% zero error including span and zero/X°F at calibrated span
  (This specification is the worst-case effect and can be applied to any span of X°F within the temperature limits.)

Overpressure Effects

When a pressure transmitter is subjected to a pressure in excess of its calibrated span, either a temporary or a permanent effect may take place.

Temporary Overpressure Effect—Moderate overpressure of a pressure transmitter or, in the case of differential pressure transmitter, sequencing a 3-valve manifold incorrectly so that one side of the transmitter sees full line pressure can have a temporary effect on transmitter performance. Ideally, this effect is confined to a zero shift, which can be corrected simply by rezeroing the transmitter. However, transmitters whose design incorporates the use of mechanical stops may hang up in the overpressured position.

Permanent Overpressure Effect—Overpressure greater than the manufacturer's recommended limits at some point will result in permanent damage to the pressure transmitter. This damage could be evidenced by erratic output, performance outside of specifications, or complete failure. To insure against permanent overpressure effects, adhere to the manufacturer's guidelines.

Static Pressure Effects

Static pressure has an effect on both the span and zero of differential pressure transmitters. The zero effect can be corrected by simply rezeroing at line pressure. Span effects may be corrected by recalibrating at line pressure or by using manufacturer's information when available.

Vibration Effect

Since vibration is almost always present in a piping system, its effect on pressure transmitters should be considered. Vibration-effect specifications should state the magnitude, frequency, and plane of vibration as a percent of calibrated span per "g" up to X Hz for each axis.

Power-Supply Effect

The effect of power-supply variations—both dc voltage level and ripple—on the transmitter performance should be considered.

Load Effect

Load effect, like power-supply effect, should be considered. A usable load-range plot of supply voltage (Vdc) versus load resistance (ohms) is the accepted method.

Mounting-Position Effect

The mounting position may have an effect on zero; the effect can be calibrated out.

Effect of Radio Frequency Interference (RFI) and Electromagnetic Interference (EMI)

Radio transmitters and high voltage power lines in close proximity to a pressure transmitter may affect output. Pressure transmitters should be designed to minimize or eliminate RFI and EMI effects by shielding.

Input Impedance

The internal impedance should be small compared with the external impedance when measurement of the internal voltage is desired.

Functional Specifications

Functional specifications are as important as performance specifications. What are the environmental operating limits and power requirements? Can the device be used in hazardous locations? These, and many other questions, should be considered in selecting equipment.

Range and Span

Pressure transmitter operating ranges can be flexible enough to allow a wide range of calibrated spans. However, the relationship between maximum and minimum spans (turn down) should be such as to give acceptable errors at the minimum span. Specifically, effects on transmitter zero, if expressed as a percent of upper range limit (URL), are directly proportioned to the turndown of the transmitter.

Power Requirements

The choice of power supply will depend on the total requirements of the system. Manufacturer's specifications giving power supply requirements for the equipment under consideration are readily available; they should be consulted.

Hazardous Locations

All electronic pressure transmitters used in hazardous locations must be approved by a recognized agency such as, but not limited to, Underwriters Laboratories Inc., Factory Mutual Engineering Corp., or Canadian Standards Association.

Temperature Limits

Electronic pressure transmitters/transducers have definite ambient temperature limits above or below which service life and performance can be affected. Temperatures outside the manufacturer's recommended range will have an adverse effect on the device's life and can result in performance outside specifications or even failure.

Elevation and Suppression

The term *elevation and suppression* concerns the ability of a pressure transmitter to be calibrated at other than zero-based spans (−10 to +10 inches of water, 25 to 50 psi, etc.). The term *suppression* is used when zero is below the calibrated span while the term *elevation* is used when zero is above the calibrated span. Elevation and suppression can be expressed mathematically as:

$$\%\ \text{Elevation or Suppression} = \frac{\text{Lower Calibrated Value} \times 100}{\text{Span}}$$

Example: A pressure transmitter calibrated from 50 to 75 inches of water would have a suppression of

$$\frac{50}{25} \times 100 = 200\%$$

In selecting a transmitter, consideration must be given to its elevation or suppression capabilities if a span other than zero based is required.

Pressure Limits

Pressure transmitters also have definite pressure limits above or below which service life and performance can be affected. Excessive pressure will adversely affect life, while pressures below recommended minimums will affect performance. Maximum operating-pressure limits also must be considered to insure safety in the event of an extreme pressure condition.

Damping

Where damping is required, a pressure transmitter should be adjustable; ideally it should be continuously adjustable.

TRANSMITTER TYPES

There are various technologies used in pressure-transmitter design. The following are the most common:

Variable Capacitance

Variable-capacitance sensing depends on the position of a diaphragm placed between two capacitor plates that generate a signal directly proportional to the change in capacitance.

Strain Gage

In a strain gage transmitter, the pressure deforms the sensing element (strain gage), and a signal proportional to the change in resistance is generated. The strain gage itself may be a film deposited on a backing, foil or wire bonded to a backing, or a silicon crystal semiconductor.

Force Balance

In a force balance pressure transmitter, the pressure input is balanced through a series of mechanical linkages by an opposing force proportional to the pressure; the face is generated by a magnetic coil.

Resonant Wire

The sensing module of a resonant- or vibrating-wire transmitter contains a wire whose tension is varied by changes in pressure. The natural frequency of a wire under tension is a function of the amount of tension applied; the greater the tension the higher the frequency. By measuring the frequency, a signal proportional to the pressure can be obtained.

INSTALLATION

The accuracy of a pressure measurement depends to a great extent on the proper installation of the transmitter and the impulse piping. Care should be taken to minimize the environmental effects.

Impulse Piping

Impulse piping — the piping between the process and the transmitter — should be kept as short as possible.