BSR/ASHRAE Standard 41.3-2022R

Public Review Draft

Standard Methods for Pressure Measurements

First Public Review (September 2025)
(Complete Draft for Full Review)

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed standard, go to the ASHRAE website at https://www.ashrae.org/technical-resources/standards-and-guidelines/public-review-drafts and access the online comment database. The draft is subject to modification until it is approved for publication by the Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE website) remains in effect. The current edition of any standard may be purchased from the ASHRAE Online Store at www.ashrae.org/bookstore or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

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(This foreword is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

FOREWORD

First published in 1989, Standard 41.3 is intended to help users select and apply suitable pressure measurement instruments. This revision of ANSI/ASHRAE Standard 41.3-2022 includes an improved method for determining when steady-state operation has been achieved for data recording, as well as changes to make it easier for higher-tier standards to adopt this standard by reference. This standard also meets ASHRAE's mandatory language requirements.

Whether pressure measurements are to be taken in a laboratory or in the field, selecting the appropriate instruments and components should be based on the required measurement accuracy or uncertainty. Once an instrument has been selected, the user might need to consult with the source regarding installation specifics, operating range limits, and calibration limits in order to obtain the expected measurement accuracy.

1. PURPOSE

This standard prescribes methods for pressure measurements under laboratory and field conditions.

2. SCOPE

This standard applies to pressure measurements under laboratory and field conditions for testing heating, ventilation, air-conditioning, and refrigeration systems and components.

3. DEFINITIONS

***accuracy*:** the degree of conformity of an indicated value to the true value.

error: the difference between the observed value of the measurand and its true value.

measurement system: the instruments, signal conditioning systems if any, and data acquisition system if any.

operating tolerance limit: the upper or lower value of an operating tolerance that is associated with a test point or a targeted set point.

***post-test uncertainty**:* an analysis to establish the uncertainty of a test result after conducting the test.

pretest uncertainty: an analysis to establish the expected uncertainty of a test result before conducting the test.

random error: the portion of the total error that varies randomly in repeated measurements of the true value throughout a test process.

***sensitivity*:** the change of output for a unit change of input.

steady-state criteria: the criteria that establish negligible change of pressure or pressure difference with time.

systematic error: the portion of the total error that remains constant in repeated measurements of the true value throughout a test process.

targeted set point: a specific set of test conditions where the required pressure or pressure difference is known and has an associated operating tolerance.

test point: a specific set of test operating conditions for recording data where the measured pressure or pressure difference is unknown and has an associated operating tolerance.

true value: the unknown, error-free value of a test result.

uncertainty: the limits of error within which the true value lies.

unit under test (UUT): equipment that is the subjected to pressure measurements.

4 CLASSIFICATIONS

4.1 Pressure Categories. The types of pressures used in this standard are listed below and shown in Figure 4-1:

a. Absolute pressure, Pa (psia)
b. Ambient pressure, Pa (psia)
c. Barometric pressure, Pa (psia)
d. Pressure difference, Pa (psid)
e. Positive gage pressure, Pa (psig)
f. Negative gage pressure or vacuum, Pa (psig)

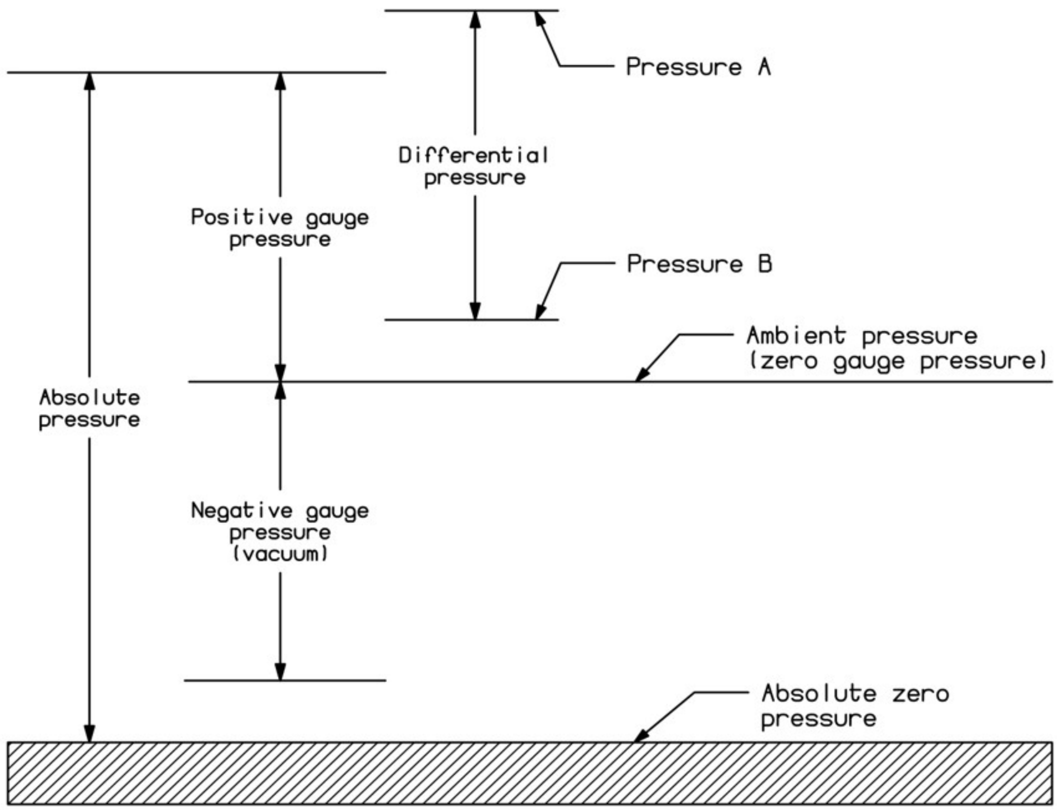

Figure 4-1: Pressure classification illustration.

4.2 Pressure Measurement Instrument Types. Pressure measurement instrument types that are within the scope of this standard include the following:

a. Pressure measuring instruments that are listed in Table 4-1.
b. Vacuum instruments that are listed in Table 4-2.
c. Pressure calibration instruments that are listed in Table 4-3.

Table 4-1: Pressure Measuring Instruments

Section	Instrument	Pressure Ranges	Output
7.1.1	Bourdon tube gage	0 to 103 kPa (15 psig) to 0 to 689 MPa (100,000 psig)	Analog indicator or digital output
7.1.2	Bellows gage	0 to 2400 kPa (350 psig)	Analog indicator or digital output
7.1.3	Diaphragm gage	0 to 69 MPa (10,000 psig)	Analog indicator or digital output
7.1.4	U-shaped manometer	0 to 7 kPa (0 to 28 in. of water)	Analog indicator or digital output
7.1.5	Inclined manometer	0 to 7 kPa (0 to 28 in. of water)	Analog indicator or digital output

7.1.6	Bonded-strain gage and deposited strain gage	Application dependent	Voltage or current
7.1.7	Piezoresistive pressure sensor	0 to 103 kPa (15 psig) to 0 to 69 MPa (10,000 psig)	Voltage or current
7.1.8	Piezoelectric pressure sensor	0 to 69 MPa (10,000 psig)	Voltage or current
7.1.9	Capacitive pressure sensor	Application dependent	Voltage or current
7.1.10	Inductive pressure sensor	Application dependent	Voltage or current
7.1.11	Linear variable differential transformer (LVDT)	Application dependent	Current
7.1.12	Vibrating element pressure sensor	Application dependent	Voltage or current

Table 4-2: Vacuum Instruments

Section	Instrument	Measurement Category
7.2.1	Micromanometer	Direct measurement
7.2.2	Hickman vacuum gage	
7.2.3	Diaphragm comparator	
7.2.4	McLeod gage	
7.2.5	Thermocouple gage	Indirect measurement – thermal conductivity
7.2.6	Pirani gage	
7.2.7	Alphatron gage	Indirect measurement – ionization
7.2.8	Molecular gage	Indirect measurement – molecular momentum

Table 4-3: Pressure Calibration Instruments

Section	Instrument Type
7.3.1	Piston gage (dead weight tester)
7.3.2	Micromanometer
7.3.3	Fortin barometer
7.3.4	Hook gage

4.3 Pressure and Pressure Difference Measurement Conditions. Pressure and pressure difference measurement test conditions that are within the scope of this standard shall be classified as one of the following types:

a. Laboratory Conditions. Laboratory pressure and pressure difference measurements under laboratory conditions are engineering development tests or tests to determine product ratings.

Informative Note: Laboratory pressure and pressure difference measurements tend to use more accurate instruments than field measurements.

b. Field Conditions. Pressure and pressure difference measurements under field conditions are tests to determine installed system pressures and pressure differences.

Informative Note: Field pressure and pressure difference measurements tend to use less accurate instruments than laboratory measurements.

5 REQUIREMENTS

5.1 Test Plan. The test plan shall be one of the following documents:

a. A document provided by the person or the organization that authorized the tests and calculations to be performed.
b. A method of test standard.
c. A rating standard.
d. A regulation or code.
e. Any combination of items a. through d.

The test plan shall specify:

a. The minimum value for the accuracy or the maximum value of measurement uncertainty of the pressure measurement system over the full range of operating conditions.
b. The values to be determined and recorded that are selected from this list: pressure, pressure difference, pretest pressure measurement uncertainty, post-test pressure measurement uncertainty, pretest pressure difference measurement uncertainty, and post-test pressure difference measurement uncertainty.
c. Any combination of test points and targeted set points to be performed together with operating tolerances.

5.2 Alternative Pressure Measurement Types and Units that shall be Reported

Table 5-1 lists the alternative pressure measurement types and units that shall be measured and reported if specified in the test plan in Section 5.1.

TABLE 5-1: Pressure measurement types and units

Pressure Categories	SI	I-P	
		Primary	Alternatives
Absolute Pressure	Pa	psia	none
Barometric Pressure	Pa	in. of mercury	psia
Ambient Pressure	Pa	in. of mercury	psia
Pressure difference	Pa	psid	in. of water [4°C (39.2°F)], in. of mercury [0°C (32°F)]
Positive Gage Pressure	Pa	psig	in. of mercury [0°C (32°F)], in. of water [4°C (39.2°F)], atmosphere
Negative Gage Pressure (Vacuum)	Pa	torr	in. of mercury [0°C (32°F)], mm of mercury [0°C (32°F)]

5.3 Accuracy or Measurement Uncertainty. A selected pressure measurement or pressure difference measurement instrument shall meet or exceed the required pressure or pressure difference measurement system accuracy or measurement uncertainty that is specified in the test plan in Section 5.1 over the full range of operating conditions**.**

5.4 Pretest Pressure or Pressure Difference Uncertainty Analysis. If required by the test plan in Section 5.1, perform an analysis to establish the expected uncertainty for each pressure or pressure difference test point prior to the conduct of that test in accordance with the pretest uncertainty analysis procedures in ASME PTC 19.1[1].

5.5 Post-test Pressure or Pressure Difference Uncertainty Analysis. If required by the test plan in Section 5.1, perform an analysis to establish the pressure or pressure difference measurement uncertainty for each pressure or pressure difference test point in accordance with the post-test uncertainty analysis procedures in ASME PTC 19.1[1]. Alternatively, if specified in the test plan, the worst-case uncertainty for all test points shall be estimated and reported for each test point.

5.6 Steady-State Test Criteria. Pressure and pressure difference test data shall be recorded at steady-state conditions unless otherwise specified in the test plan in Section 5.1.

5.6.1 Steady-State Test Criteria Under Laboratory Test Conditions. If the test plan requires pressure or pressure difference test data points to be recorded at steady-state test conditions and provides the operating condition tolerance but does not specify the steady-state criteria, then determine that steady-state test conditions have been achieved using one of the following methods:

a. Apply the steady-state criteria in Section 5.6.3 if the test plan provides test points for pressure measurement.
b. Apply the steady-state criteria in Section 5.6.4 if the test plan provides test points for pressure difference measurement.
c. Apply the steady-state criteria in Section 5.6.5 if the test plan provides targeted set points for pressure measurement.
d. Apply the steady-state criteria in Section 5.6.6 if the test plan provides targeted set points for pressure difference measurement.

5.6.2 Steady-State Test Criteria Under Field Test Conditions. If the test plan requires pressure or pressure difference test data points to be recorded at steady-state test conditions and provides the operating condition tolerance but does not specify the steady-state criteria, then the methods in Section 5.6.1 are optional.

Informative Note: The steady-state methods in Section 5.6.1 are likely to be impractical under field test conditions. Under these circumstances, the user may want to select another method to determine the conditions for field test data to be recorded.

5.6.3 Steady-State Pressure Criteria for Test Points

Sample not less than 30 pressure measurements N at equal time intervals δt over a test duration Δt where Δt is in time units. Equation 5-1 states the relationship of the test duration to the number of pressure samples and the equal time intervals.

$$\Delta t = (N - 1)\delta t \tag{5-1}$$

> ***Informative Note:*** Circumstances for measurement vary, so the user should select a duration of test and the equal time intervals based upon the longest period of the observed pressure fluctuations during operation near the steady-state conditions.

Record each sampled pressure measurement P_i and the corresponding time t_i. Apply the least-squares line method to determine the slope b of the pressure data trend line using Equation 5-2.

$$b = \left\{ \frac{\left[N\left(\sum_{i=1}^{N} t_i P_i\right) - \left(\sum_{i=1}^{N} t_i\right)\left(\sum_{i=1}^{N} P_i\right)\right]}{\left[N\left(\sum_{i=1}^{N} t_i^{2}\right) - \left(\sum_{i=1}^{N} t_i\right)^{2}\right]} \right\} \quad (5\text{-}2)$$

> ***Informative Note:*** It should be noted that the units for the slope in Equation 5-2 are pressure, Pa (psia), divided by the units that the user has selected for time.

The mean of the sampled pressures $\overline{P}$ is defined by Equation 5-3.
Mnb nbjjn

$$\overline{P} = \frac{1}{N}\left[\sum_{i=1}^{N}(P_i)\right] \text{ Pa (psia)} \quad (5\text{-}3)$$

The difference between the maximum and minimum sampled values shall be less than or equal to the specified operating tolerance limit as defined in Equation 5-4 where P_L is the operating tolerance limit.

$$P_{max} - P_{min} \leq P_L \quad \text{Pa (psia)} \quad (5\text{-}4)$$

The restriction on the slope of the trend line b is defined in Equation 5-5 where Δt is the sample time interval.

$$|b \times \Delta t| \leq 0.5 \times P_L \text{ Pa (psia)} \quad (5\text{-}5)$$

$\bar{P}$, as determined by Equation 5-3, represents the steady-state mean pressure where Equations 5-4 and 5-5 are both satisfied.

> ***Informative Note:*** For further reading about methods of determining steady-state conditions, refer to Informative Appendix A – Bibliography items A1 and A2.

5.6.4 Steady-State Pressure Difference Criteria for Test Points
Sample not less than 30 pressure difference measurements N at equal time intervals δt over a test duration Δt where Δt is in time units. Equation 5-6 states the relationship of the test duration to the number of pressure difference samples and the equal time intervals.

$$\Delta t = (N-1)\delta t \quad (5\text{-}6)$$

> ***Informative Note:*** Circumstances for measurement vary, so the user should select a duration of test and the equal time intervals based upon the longest period of the observed pressure difference fluctuations during operation near the steady-state conditions.

Record each sampled pressure difference measurement ΔP_i and the corresponding time t_i. Apply the least-squares line method to determine the slope *b* of the pressure difference data trend line using Equation 5-7.

$$b = \left\{ \frac{\left[N\left(\sum_{i=1}^{N} t_i \Delta P_i\right) - \left(\sum_{i=1}^{N} t_i\right)\left(\sum_{i=1}^{N} \Delta P_i\right)\right]}{\left[N\left(\sum_{i=1}^{N} t_i^{2}\right) - \left(\sum_{i=1}^{N} t_i\right)^{2}\right]} \right\} \quad (5\text{-}7)$$

> ***Informative Note:*** It should be noted that the units for the slope in Equation 5-7 are pressure difference, Pa (psid), divided by the units that the user has selected for time.

The mean of the sampled pressure differences $\bar{P}$ is defined by Equation 5-8.

$$\overline{\Delta P} = \frac{1}{N}\left[\sum_{i=1}^{N}(\Delta P_i)\right] \text{ Pa (psid)} \tag{5-8}$$

The difference between the maximum and minimum sampled values shall be less than or equal to the specified operating tolerance limit as defined in Equation 5-9 where ΔP_L is the operating tolerance limit.

$$\Delta P_{max} - \Delta P_{min} \leq \Delta P_L \quad \text{Pa (psid)} \tag{5-9}$$

The restriction on the slope of the trend line b is defined in Equation 5-10 where Δt is the sample time interval.

$$|b \times \Delta t| \leq 0.5 \times \Delta P_L \text{ Pa (psid)} \tag{5-10}$$

$\bar{P}$, as determined by Equation 5-3, represents the steady-state mean pressure difference where Equations 5-11 and 5-12 are both satisfied.

> ***Informative Note:*** For further reading about methods of determining steady-state conditions, refer to Informative Appendix A – Bibliography items A1 and A2.

5.6.5 Steady-State Pressure Criteria for Targeted Set Points

Sample not less than 30 pressure measurements N at equal time intervals δt over a test duration Δt where Δt is in time units. Equation 5-11states the relationship of the test duration to the number of samples and the equal time intervals.

$$\Delta t = (N-1)\delta t \tag{5-11}$$

> ***Informative Note:*** Circumstances for measurement vary, so the user should select a duration of test and the equal time intervals based upon the longest period of the observed pressure fluctuations during operation near the steady-state conditions.

Record each sampled pressure measurement P_i and the corresponding time t_i. Apply the least-squares line method to determine the slope *b* of the pressure data trend line using Equation 5-12.

$$b = \left\{\frac{\left[N\left(\sum_{i=1}^{N} t_i P_i\right) - \left(\sum_{i=1}^{N} t_i\right)\left(\sum_{i=1}^{N} P_i\right)\right]}{\left[N\left(\sum_{i=1}^{N} t_i^2\right) - \left(\sum_{i=1}^{N} t_i\right)^2\right]}\right\} \tag{5-12}$$

> ***Informative Note:*** It should be noted that the units for the slope in Equation 5-12 are pressure, Pa (psia), divided by the units that the user has selected for time.

The mean of the sampled pressures $\bar{P}$ is defined by Equation 5-13.

$$\bar{P} = \frac{1}{N}\left[\sum_{i=1}^{N}(P_i)\right] \text{ Pa (psia)} \tag{5-13}$$

The difference between the maximum and minimum sampled values shall be less than or equal to the specified operating tolerance limit as defined in Equation 5-14 where P_L is the operating tolerance limit.

$$P_{max} - P_{min} \leq P_L \text{ Pa (psia)} \tag{5-14}$$

The restriction on the slope of the trend line *b* is defined in Equation 5-15 where Δt is the sample time interval.

$$|b \times \Delta t| \leq 0.5 \times \mathrm{P}_L \ \text{Pa (psia)} \tag{5-15}$$

The difference between the test condition and mean of the sampled values shall be less than or equal to half of the specified operating tolerance limit as defined in Equation 5-16 where P_{SP} is the set point pressure and P_L is the operating tolerance limit.

$$|P_{SP} - \bar{P}| \leq 0.5 \times \mathrm{P}_L \ \text{Pa (psia)} \tag{5-16}$$

$\bar{P}$, as determined by Equation 5-13, represents the steady-state mean pressures where Equations 5-14, 5-15, and 5-16 are all satisfied.

> ***Informative Note:*** For further reading about methods of determining steady-state conditions, refer to Informative Appendix A – Bibliography items A1 and A2.

5.5.6 Steady-State Pressure Difference Criteria for Targeted Set Points
Sample not less than 30 pressure difference measurements N at equal time intervals δt over a test duration Δt where Δt is in time units. Equation 5-17 states the relationship of the test duration to the number of samples and the equal time intervals.

$$\Delta t = (N - 1)\delta t \tag{5-17}$$

> ***Informative Note:*** Circumstances for measurement vary, so the user should select a duration of test and the equal time intervals based upon the longest period of the observed pressure difference fluctuations during operation near the steady-state conditions.

Record each sampled pressure difference measurement P_i and the corresponding time t_i. Apply the least-squares line method to determine the slope *b* of the pressure difference data trend line using Equation 5-18.

$$b = \left\{ \frac{\left[N\left(\sum_{i=1}^{N} t_i \Delta P_i\right) - \left(\sum_{i=1}^{N} t_i\right)\left(\sum_{i=1}^{N} \Delta P_i\right)\right]}{\left[N\left(\sum_{i=1}^{N} t_i^2\right) - \left(\sum_{i=1}^{N} t_i\right)^2\right]} \right\} \tag{5-18}$$

> ***Informative Note:*** It should be noted that the units for the slope in Equation 5-18 are pressure difference, Pa (psid), divided by the units that the user has selected for time.

The mean of the sampled pressure differences $\overline{\Delta P}$ is defined by Equation 5-19.

$$\overline{\Delta P} = \frac{1}{N}\left[\sum_{i=1}^{N}\left(\Delta P_i\right)\right] \qquad \text{Pa (psid)} \tag{5-19}$$

The difference between the maximum and minimum sampled values shall be less than or equal to the specified operating tolerance limit as defined in Equation 5-20 where $\Delta \mathrm{P}_L$ is the operating tolerance limit.

$$\Delta P_{max} - \Delta P_{min} \leq \Delta \mathrm{P}_L \ \text{Pa (psid)} \tag{5-20}$$

The restriction on the slope of the trend line *b* is defined in Equation 5-21 where Δt is the sample time interval.

$$|b \times \Delta t| \leq 0.5 \times \Delta \mathrm{P}_L \ \text{Pa (psid)} \tag{5-21}$$

The difference between the test condition and mean of the sampled values shall be less than or equal to half of the specified operating tolerance limit as defined in Equation 5-22 where ΔP_{SP} is the set point pressure and $\Delta \mathrm{P}_L$ is the operating tolerance limit.

$$|\Delta P_{SP} - \overline{\Delta P}| \leq 0.5 \times \Delta P_L \text{ Pa (psid)} \quad (5\text{-}22)$$

$\overline{\Delta P}$, as determined by Equation 5-19, represents the steady-state mean pressure difference where Equations 5-20, 5-21, and 5-22 are all satisfied.

> ***Informative Note:*** For further reading about methods of determining steady-state conditions, refer to Informative Appendix A – Bibliography items A1 and A2.

5.7 Unsteady Pressure Measurements. If required by the test plan in Section 5.1, pressure and pressure difference test data shall be recorded:

a. at operating conditions that are not steady state,
b. at the time intervals specified in the test plan,
c. within the test condition limits specified in the test plan,
d. using instrument response times specified in the test plan.

6 INSTRUMENTS

6.1 Instrumentation Requirements for All Measurements

6.1.1 Instruments and data acquisition systems shall be selected to meet the measurement system accuracy specified in the test plan in Section 5.1.

6.1.2 Measurements from the instruments shall be traceable to primary or secondary standards calibrated by the National Institute of Standards and Technology (NIST) or to the Bureau International des Poids et Mesures (BIPM) if a National Metrology Institute (NMI) other than NIST is used. In either case, the indicated corrections shall be applied to meet the uncertainty stated in subsequent sections. Instruments shall be recalibrated on regular intervals that do not exceed the intervals prescribed by the instrument manufacturer, and calibration records shall be maintained. Instruments shall be installed in accordance with the instrument manufacturer's requirements, or the manufacturer's accuracy does not apply.

Informative Note: For further reading, ISO/IEC 17025, *General Requirements for the Competence of Testing and Calibration Laboratories*[A4], defines good test laboratory practices.

7 PRESSURE MEASUREMENT AND CALIBRATION METHODS

7.1 Pressure Measurement Instruments

Pressure measurement instruments that are within the scope of this standard include the types that are described in Sections 7.1.1 through 7.1.12.

7.1.1 Bourdon Tube Gage

Bourdon tube gages feature an elastic tube closed at one end that deflects under pressure to provide a direct pressure reading on the face of the gage as shown in Figure 7-1. Variations of the elastic tube include C-shaped, helical, and spiral. The atmosphere is the reference pressure where measuring gage pressure, vacuum is the reference where measuring absolute or barometric pressure, and a separate pressure is the reference for pressure difference measurements.

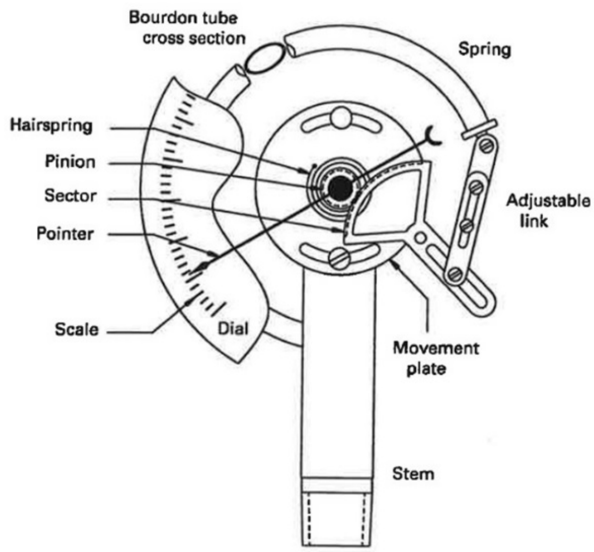

Figure 7-1 Bourdon tube gage
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7.1.2 Bellows Gage

The bellows gage uses a thin-walled convoluted pressure sensing element to provide a direct pressure reading as shown in Figure 7-2. The atmosphere is the reference pressure where measuring gage pressure, vacuum is the reference where measuring absolute or barometric pressure, and a separate pressure is the reference for pressure difference measurements.

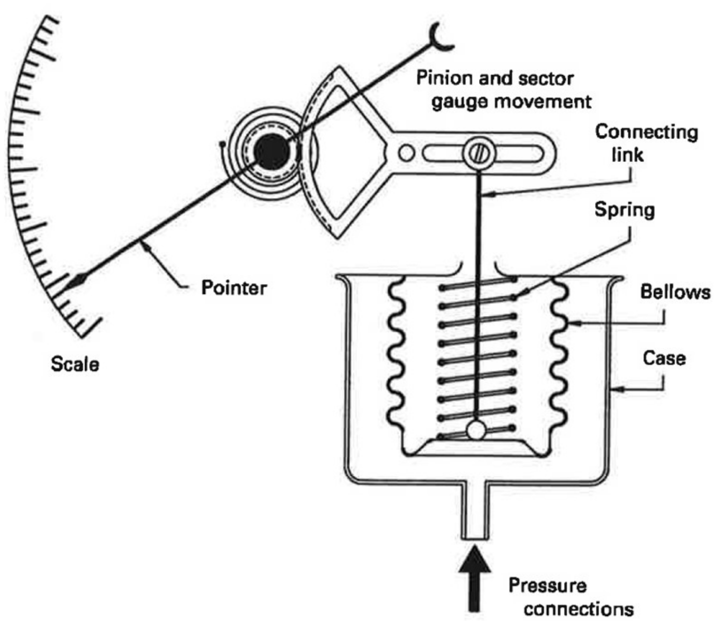

Figure 7-2 Bellows gage
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7.1.3 Diaphragm Gage

In a diaphragm gage, a flexible diaphragm or membrane, separates the sensed pressure from a reference pressure. The atmosphere is the reference pressure where measuring gage pressure, vacuum is the reference where measuring absolute or barometric pressure, and a separate pressure is the reference for pressure difference measurements. Deflection of the diaphragm is measure mechanically, as shown in Figure 7-3, or electronically using an attached strain gage or a linear variable differential transformer (LVDT) that is described in Section 7.1.11. Once known, the deflection is converted to a pressure load using plate theory.

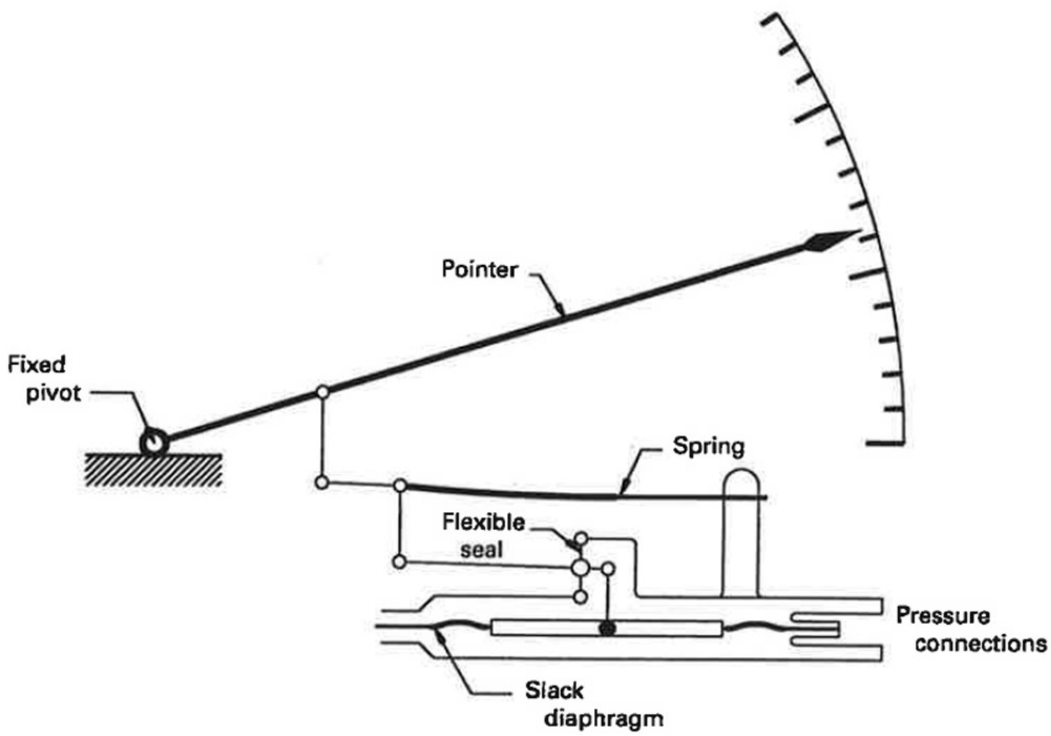

Figure 7-3 Diaphragm gage

7.1.4 U-Shaped Manometer

A mechanical U-shaped manometer with vertical legs uses a liquid specified for the instrument as the medium for static pressure or velocity pressure measurement in air ducts. U-shaped manometers that are used to measure pressure difference in accordance with Equation 7-1 in SI units or with Equation 7-2 in I-P units are configured as shown in Figure 7-4.

$$P_1 - P_2 = g[\rho_3(H_1 - H_2) + \rho_2(H_3 - H_1) - \rho_1(H_3 - H_2)] \quad (7\text{-}1)$$

where

P_1 = gas pressure upstream as shown in Figure 7-4, Pa
P_2 = gas pressure downstream as shown in Figure 7-4, Pa
g = local gravitational acceleration, m/s^2
ρ_1= gas density upstream as shown in Figure 7-4, kg/m^3

ρ_2 = gas density downstream as shown in Figure 7-4, kg/m^3
ρ_3 = manometer liquid density, kg/m^3
H_1 = elevation difference number 1 as shown in Figure 7-4, m
H_2 = elevation difference number 2 shown in Figure 7-4, m
H_3 = elevation difference number 3 as shown in Figure 7-4, m

$$P_1 - P_2 = \left(\frac{g}{g_c}\right)[\rho_3(H_1 - H_2) + \rho_2(H_3 - H_1) - \rho_1(H_3 - H_2)] \quad (7\text{-}2)$$

where

P_1 = gas pressure upstream as shown in Figure 7-4, psia
P_2 = gas pressure downstream as shown in Figure 7-4, psia
g = local gravitational acceleration, ft/s^2
g_c= gravitational constant, 32.174 [(lb$_m$-ft)/(lb$_f$-s^2)]
ρ_1= gas density upstream as shown in Figure 7-4, lb$_m$/ft^3
ρ_2 = gas density downstream as shown in Figure 7-4, lb$_m$/ft^3
ρ_3 = manometer liquid density, lb$_m$/ft^3
H_1 = elevation difference number 1 as shown in Figure 7-4, ft
H_2 = elevation difference number 2 shown in Figure 7-4, ft
H_3= elevation difference number 3 as shown in Figure 7-4, ft

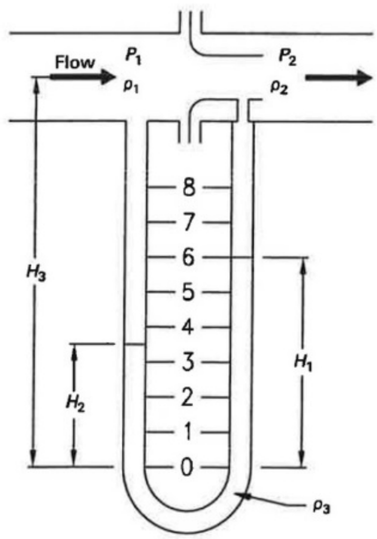

Figure 7-4 U-shaped manometer for pressure difference
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The version of the U-shaped manometer shown in Figure 7-5 is used to measure absolute pressure in accordance with Equation 7-3 in SI units or with Equation 7-4 in I-P units are configured as shown in Figure 7-5.

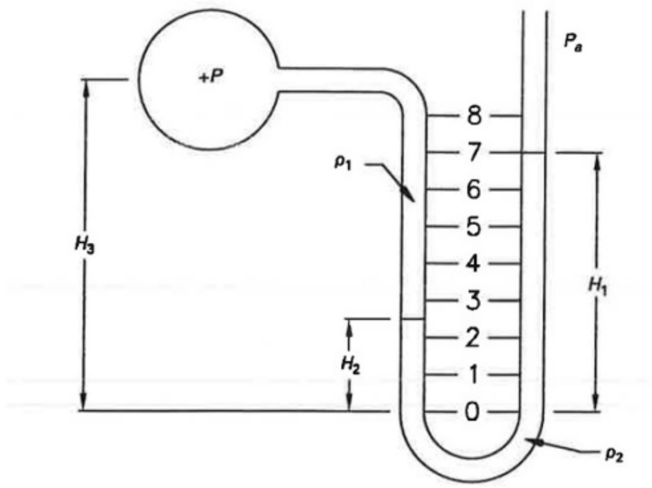

Figure 7-5 U-shaped manometer for absolute pressure
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$$P = g[\rho_2(H_1 - H_2) - \rho_1(H_3 - H_2)] + P_a \tag{7-3}$$

where

P = absolute gas pressure as shown in Figure 7-5, Pa
P_a = ambient gas pressure as shown in Figure 7-5, Pa
g = local gravitational acceleration, m/s^2
ρ_1 = gas density as shown in Figure 7-5, kg/m^3
ρ_2 = gas density as shown in Figure 7-5, kg/m^3
H_1 = elevation difference number 1 as shown in Figure 7-5, m
H_2 = elevation difference number 2 shown in Figure 7-5, m
H_3 = elevation difference number 3 as shown in Figure 7-5, m

$$P = \left(\frac{g}{g_c}\right)[\rho_2(H_1 - H_2) - \rho_1(H_3 - H_2)] + P_a \tag{7-4}$$

where

P = absolute gas pressure upstream as shown in Figure 7-5, psia
P_a = ambient gas pressure as shown in Figure 7-5, psia
g = local gravitational acceleration, ft/s^2
g_c= gravitational constant, 32.174 [(lb$_m$-ft)/(lb$_f$-s^2)]
ρ_1 = gas density as shown in Figure 7-5, kg/m^3
ρ_2 = gas density as shown in Figure 7-5, lb$_m$/ft^3
H_1 = elevation difference number 1 as shown in Figure 7-5, ft
H_2 = elevation difference number 2 shown in Figure 7-5, ft
H_3= elevation difference number 3 as shown in Figure 7-5, ft

7.1.5 Inclined Manometer An inclined manometer using a liquid specified for the instrument as the medium is made with a reservoir as shown in Figure 7-6. The slope allows the vertical height to be resolved into smaller increments. The scale accounts for the liquid density, inclination, and reservoir level shifts so that scale readings are in convenient pressure units. If P_2 is open to the atmosphere, P_1 is an absolute pressure measurement. The pressure difference $(P_1 - P_2)$ is equal to the density of the liquid ρ times the gravitational constant g times the differential liquid height h times the cosine of the angle θ as shown in Equation7-5.

$$(P_1 - P_2) = \rho g h[\cos(\theta)] \quad (7\text{-}5)$$

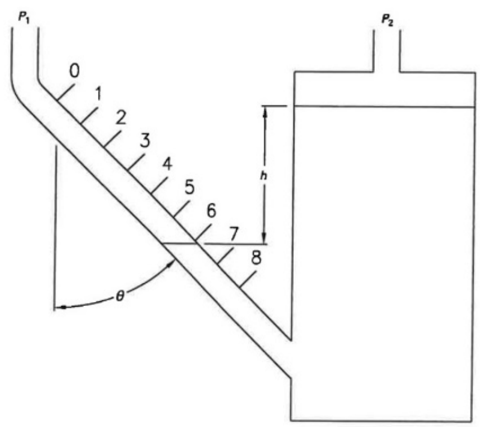

Figure 7-6 Inclined manometer
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7.1.6 Bonded Strain Gage

Strain gage technology involves the four-resister network of a Wheatstone bridge as shown in Figure 7-7. A voltage source is connected across A and C so that current will flow through each leg. If R1 and R3 increase in resistance and R2 and R4 decrease in resistance, there will be a potential difference, a signal voltage, between B and D. Figure 7-8 illustrates a bonded-strain gage installation. Alternatively, deposited thin-film elements use Wheatstone bridge circuitry deposited directly onto an elastic element by vacuum deposition or sputtering as shown in Figure 7-9.

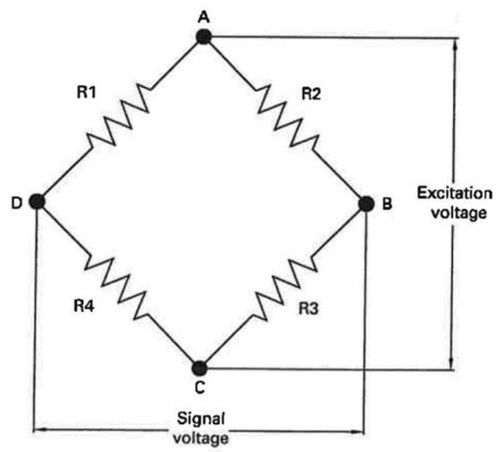

Figure 7-7 Wheatstone bridge applied to a bonded strain gage

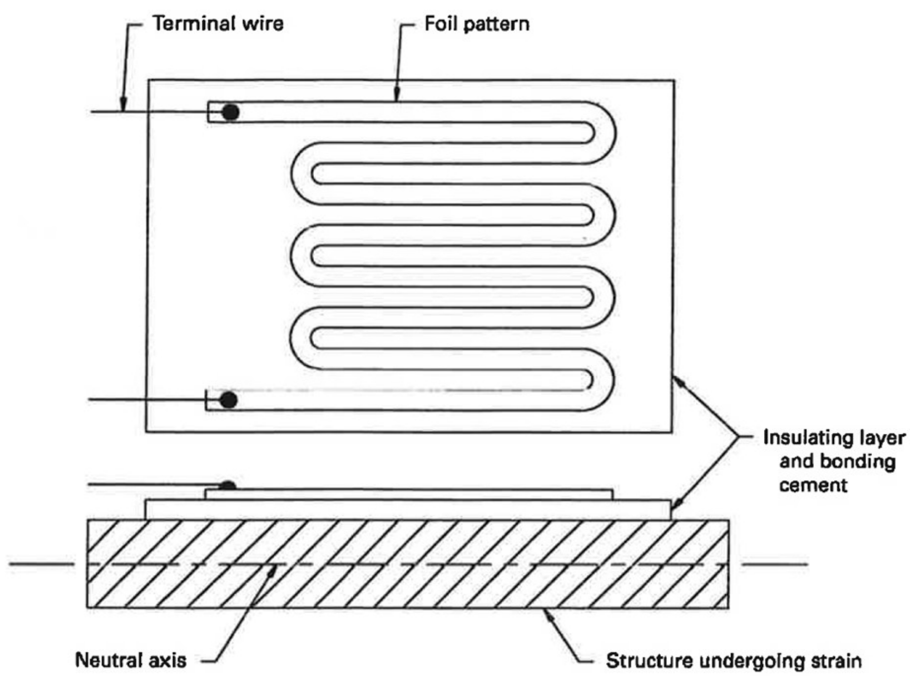

Figure 7-8 Bonded-strain gage

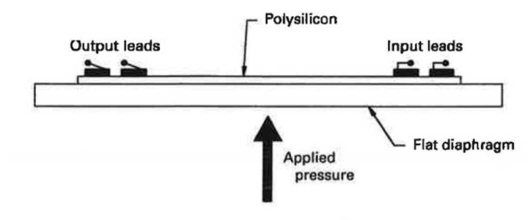

Figure 7-9 Deposited thin-film strain gage construction
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7.1.7 Piezoresistive Pressure Sensor

Piezoresistive pressure sensors are semiconductors that produce greater resistance changes than standard strain gages in response to deformation caused by pressure.

7.1.8 Piezoelectric Pressure Sensor

Pressure applied to quartz crystals creates a measurable voltage. A quartz piezoelectric gage consists of one or more quartz crystals stacked between appropriate insulators, connectors, and load-distribution plates.

7.1.9 Capacitive Pressure Sensor

A variable capacitance device consists of a diaphragm connected to conductive plates that are separated by dielectric material. Applied pressure changes the distance between the plates and creates a measurable change in capacitance.

7.1.10 Inductive Pressure Sensor

In an inductive pressure sensor, two coils are wired in opposition to form two legs of an alternating current bridge with a magnetic diaphragm placed between the two legs. Applied pressure causes the diaphragm to move toward one of the coils and away from the other, creating a measurable change in the relative inductance.

7.1.11 Linear Variable Differential Transformer (LVDT)

An LVDT is an electromechanical pressure sensor that produces an electrical output in response to the movement of the core. As shown schematically in Figure 7-10, three coils are equally spaced on a cylindrical coil form. A rod-shaped magnetic core positioned axially inside this coil assembly provides a path for magnetic flux, linking the coils. Where the primary coil is energized, AC voltages are induced into the two secondary coils. Where the core moves toward one of the secondary coils, the induced voltage in that secondary coil increases while the induced voltage in the other secondary coil decreases.

> ***Informative Note:*** An LVDT is used to measure the elastic displacement of an elastic element such as a Bourdon tube, a diaphragm, or a bellows.

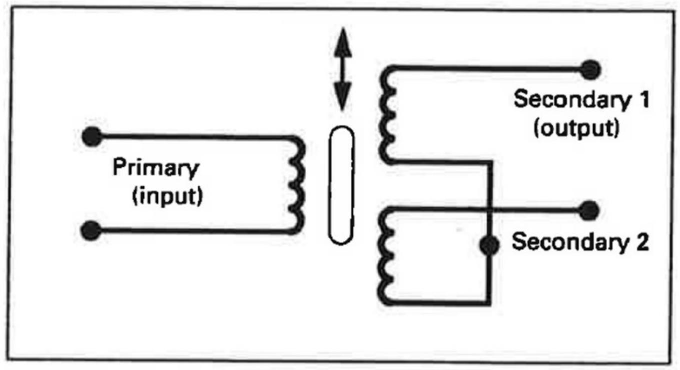

Figure 7-10 Schematic of an LVDT.
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7.1.12 Vibrating Element Pressure Sensor

Figure 7-11 is a schematic of a pressure transducer with a vibrating element. A steel wire connected to a diaphragm is excited to vibrate at its natural frequency by a magnetic driver and a pickup coil. Pressure applied to the diaphragm changes the tension in the wire changing its natural frequency by a measurable amount.

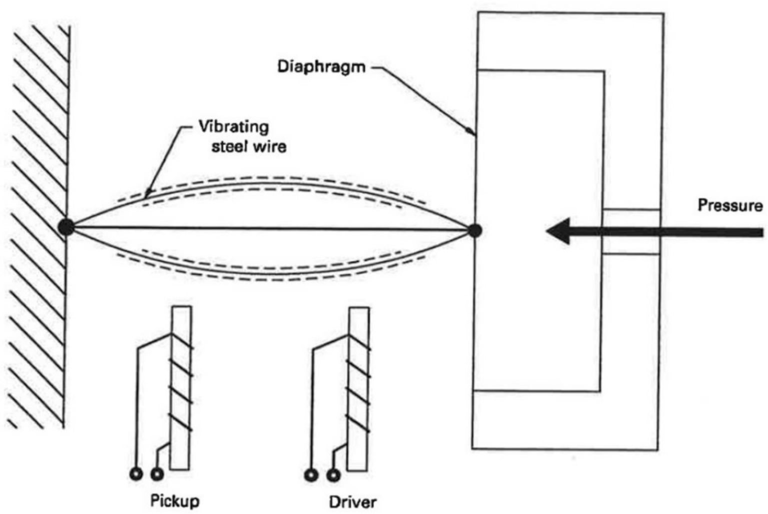

Figure 7-11 Schematic of a pressure transducer with a vibrating element.
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7.2 Vacuum Instruments

Vacuum instruments that are within the scope of this standard include, but are not limited to, the instruments that are described in Sections 7.2.1 through 7.2.8.

7.2.1 Micromanometer

A micromanometer is a precision device for measuring small pressure differences or absolute pressures. This device consists of an inclined tube with a vertically movable well as shown in Figure 7-12. The tube is not graduated but is provided with a fixed index. The well is moved up or down using a micrometer screw and is connected to the inclined tube indication with a flexible hose. In operation, the instrument is first zeroed by adjusting the height of the well independently of the micrometer so that the meniscus in the inclined tube coincides with the index where the micrometer reads zero. With a pressure difference applied between the well and the upper end of the inclined tube, the meniscus moves away from the index. The meniscus is adjusted back to coincidence by raising the well with the micrometer screw. The micromanometer reading then measures the pressure difference in terms of head of the manometer liquid.

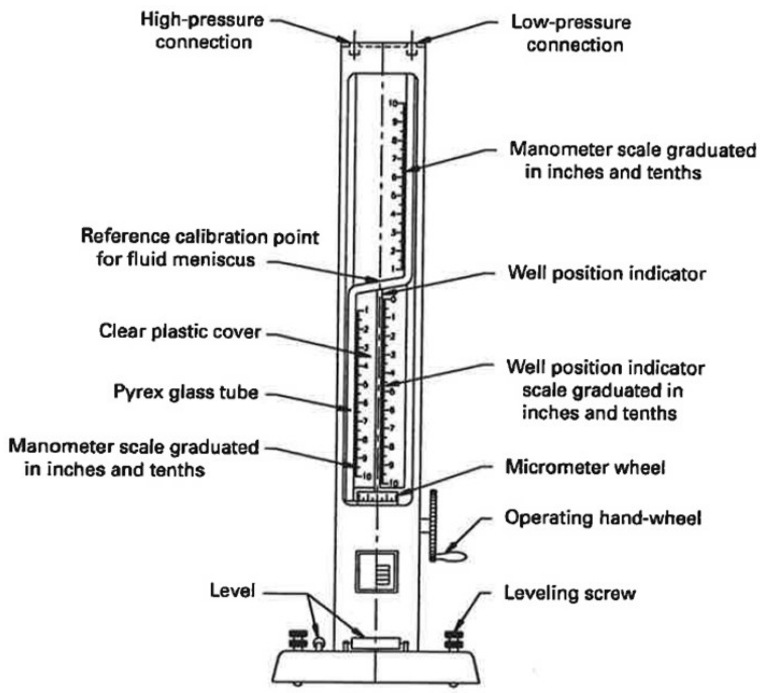

Figure 7-12 Schematic of a micromanometer
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7.2.2 Hickman Vacuum Gage

The Hickman vacuum gage uses butyl phthalate, a liquid with a vapor pressure less than mercury and a density that is 5% greater than water density.

7.2.3 Diaphragm Comparator

A diaphragm comparator is a modified version of the diaphragm pressure gage that permits the measurement of pressure differentials with a sensitivity of 0.1 Pa (0.00075 torr). The reference pressure, a high vacuum or atmospheric pressure, is applied to one side of the diaphragm and the unknown higher pressure is applied to the other side of the diaphragm. The diaphragm forms one plate of an electrical capacitor. An adjustable direct-current (DC) voltage is applied to bring the diaphragm back to its original position by electrostatic attraction. The balance point is indicated by a capacitive bridge circuit. The value of the balancing DC voltage, read from a potentiometer, is the measure of pressure difference.

7.2.4 McLeod Gage

A McLeod gage is used to compress a volume of rarefied gas into a much smaller volume. The pressure of the original sample is calculated from the dimensions of the apparatus and a pressure difference reading. The compression is assumed to be isothermal because of the time involved and the large surface-to-volume ratio.

Combining these two methods of use allows one instrument to be used for higher and lower pressures.

Condensable components in the original gas sample will be partially compressed and will not contribute to the measured gas volume. A cold trap between the gage and the system is required to prevent mercury contamination of the system by mercury vapor from the gage at low pressures.

7.2.5 Thermocouple Gage

In a thermocouple gage, resistance wire is electrically heated within a metal or glass envelope. A thermocouple is resistance-welded to the midpoint of the heater wire. An auxiliary microammeter is used to measure the current produced by the voltage at the thermocouple terminals.

> ***Informative Note:*** The reading depends upon the gas composition. For gases including air, the thermal conductivity through the gas is constant at pressures above 130 Pa (0.975 torr), but the thermal conductivity decreases as the pressure decreases down to approximately 1.3 Pa (0.00975 torr). As a result, the useful range for a thermocouple gage is from 1.3 Pa to 130 Pa (0.00975 to 0.975 torr).

7.2.6 Pirani Gage

The operation of a Pirani gage is the same as the operation of a thermocouple gage and has the same useful range: from 1.3 Pa to 130 Pa (0.00975 to 1 torr). In a Pirani gage, the resistance of the heating element is measured by a bridge circuit that includes an identical sealed-off Pirani gage to compensate for variable ambient temperatures and variable supply voltages.

7.2.7 Alphatron Gage

The alphatron ionization gage measures gas pressures from 0.01 Pa (0.00075 torr) up to atmospheric pressure. This gage uses a small quantity of radium as an alpha source. The alpha particles emitted from this source ionize the gas. The positive ions are accelerated by an electric field to a negatively charged collector probe. The accumulated positive charge on this probe causes an electric current flow that is measured by an electrometer amplifier. This output of this amplifier operates a microammeter or a strip-chart recorder. At pressures below 130 Pa (0.975 torr), the angular deflection of the dial indicator is proportional to pressure.

7.2.7 Molecular Gage

The operation of a molecular gage depends on the transfer of molecular momentum transmitted from a moving surface to another moving surface in close proximity.

7.3 Pressure Calibration Instruments

Pressure calibration instruments that are within the scope of this standard include, but are not limited to, the instruments described in Sections 7.3.1 through 7.3.4.

Pressure standards are categorized as (a) primary standards, (b) secondary standards, and (c) working standards. Primary and secondary standards are used as interlaboratory standards and transfer standards and have direct traceability to the NIST. By definition, a primary pressure measurement standard is a pressure-measuring instrument that can reduce pressure measurement into measurements of mass, length, temperature, and gravity. Examples include piston gages and manometers. In contrast, a secondary standard is an instrument that must be calibrated to relate the output directly to pressure. The output from a secondary standard can be sensed mechanically or electrically using principles of resistance, capacitance, or inductance. Working standards are devices that are used to measure, test, or examine developmental or production items to determine compliance with specifications. Uncertainty of the pressure measurement at the point of use shall include the errors accumulated and propagated in the transfer of the measurement along a calibration chain.

7.3.1 Piston Gage (Deadweight Tester)

The piston gage, shown schematically in Figure 18, is a calibration device that measures pressure in terms of applied force per unit area. The piston gage is an accurate calibrating instrument for pressure from roughly 69 kPa to 68.9 MPa (0.01 psi to 10,000 psig) in steps as small as 0.01% of range with a calibration accuracy of 0.01% to 0.5% of the reading.

A piston gage calibrator consists of a hydraulic system that statically balances the forces on an accurately machined piston in a close-fitting cylinder with known cross-section dimensions. A valve applies the same hydraulic pressure to the piston and the pressure gage to be calibrated. Weights applied to the top of the piston oppose the fluid force, that is applied to lift the piston weight combination in the cylinder. Where the piston and weights are supported by the hydraulic fluid, the pressure applied is

$$P = F/A \tag{7-6}$$

where

P = calibrating pressure
F = total force of the piston-weight mass
A = piston cross-sectional area

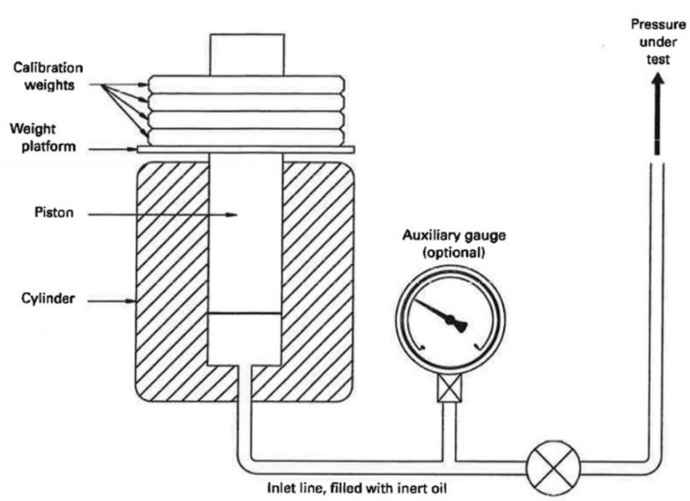

Figure 7-13 Schematic of a simple piston gage.
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7.3.2 Micromanometer

A micromanometer is a precision device for measuring small pressure differences or absolute pressures. This device consists of an inclined tube with a vertically movable well as shown in Figure 7-15. The tube is not graduated but is provided with a fixed index. The well is moved up or down using a micrometer screw and is connected to the inclined tube indication with a flexible hose. In operation, the instrument is first zeroed by adjusting the height of the well independently of the micrometer so that the meniscus in the inclined tube coincides with the index where the micrometer reads zero. With a pressure difference applied between the well and the upper end of the inclined tube, the meniscus moves away from the index. The meniscus is adjusted back to coincidence by raising the well with the micrometer screw. The micromanometer reading then measures the pressure difference in terms of head of the manometer liquid.

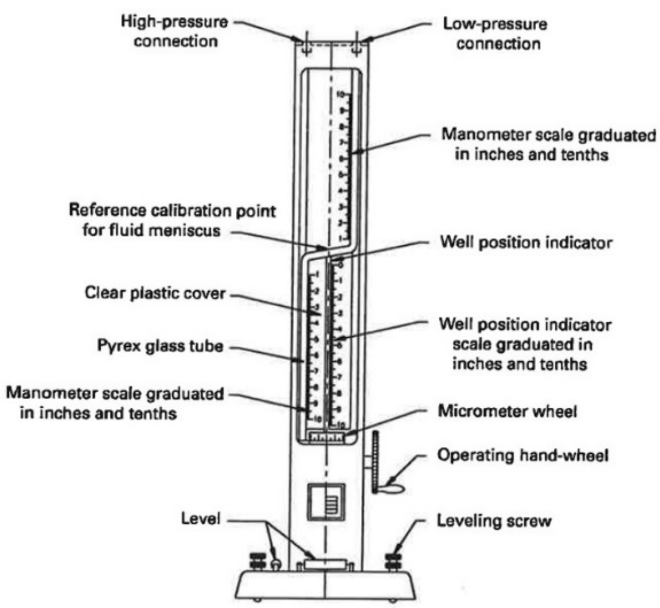

Figure 7-14 Schematic of a Micromanometer.
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7.3.3 Fortin Barometer

The Fortin barometer, illustrated in Figure 7-15, is an absolute-pressure mercury manometer specifically designed for measuring atmospheric pressure. It consists of a vertical glass tube sealed at the upper end and with its lower end immersed in a cistern of mercury. The upper end of the tube is evacuated and the surface of the cistern is exposed to atmospheric pressure, that causes the mercury to rise in the tube to a height corresponding to the atmospheric pressure. The level of the mercury meniscus in the tube is measured by a Vernier index moveable relative to a fixed graduated scale.

The mercury in the cistern is adjusted to a fixed reference point of ivory by means of a displacer screw operating against the flexible bottom of the cistern. The tip of the ivory point corresponds to the zero of the reading scale. Readings shall be corrected for nonstandard temperature, gravity, and capillary depression, that shall be computed. Readings shall be corrected for instrument imperfections that are detected during comparisons with calibrated standards.

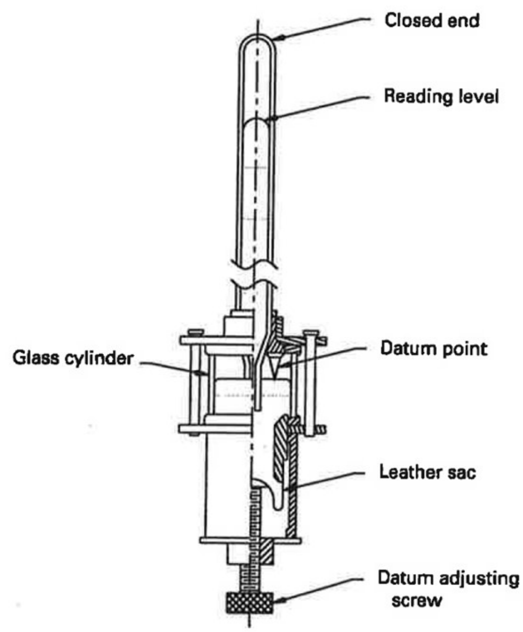

Figure 7-15 Fortin barometer.
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7.3.4 Hook Gage

The Hook gage is an air pressure measurement and calibration device that is capable of measuring positive and negative air pressures. The Hook gage consists of a central column, two connected wells that are filled with water, and depth micrometers fitted with hooks to discern water depth. Setup of the gage is achieved by leveling the base to level the wells, filling the wells with water, and zeroing out the micrometers with the hooks contacting the water surface to form a dimple. Pressure readings are taken by applying pressure to the pressure or vacuum side well, and adding the readings of each micrometer together to determine how much of the water column has been displaced. Readings need to be corrected for the density change of water with temperature.

8 UNCERTAINTY ANALYSIS

8.1 Post-test Uncertainty Analysis. A post-test analysis of the measurement system uncertainty, performed in accordance with ASME PTC 19.1[1], shall accompany each pressure measurement and pressure difference measurement if specified in the test plan in Section 5.1. Where two pressure measuring instruments are used to measure a pressure difference, the individual instrument accuracies shall be included in the pressure difference measurement uncertainty estimate.

Informative Note: Informative Appendices B and C contain examples of pressure measurement uncertainty calculations.)

8.2 Method to Express Uncertainty. All assumptions, parameters, and calculations used in estimating uncertainty shall be clearly documented prior to expressing any uncertainty values. Uncertainty shall be expressed as:

$$v = \bar{X}_m \pm U_{\bar{X}}\ (P\%) \tag{8-1}$$

where:

v = the variable that is a measurement or a calculated result
$\bar{X}_m$ = the best estimate of the true value
$U_{\bar{X}}$ = the uncertainty estimate for the variable
P = the confidence level, %

Informative Note: For example, pressure = 2.538 psia ± 0.013 psia; 95%, states that the best value for pressure is believed to be 2.538 psia with a 95% probability that the true value lies within ±0.013 psia of this value.

9 TEST REPORT

If the test plan in Section 5.1 defines the test report requirements, the test report requirements in the test plan supersede the test requirements in Section 9. Otherwise, Section 9 specifies the test report requirements using the pressure units in Table 5-1.

9.1 Test Identification

a. Date, place, and time
b. Operator identification

9.2 Unit Under Test Description

a. Model number and serial number.

9.3 Instrument Description

a. Model number, serial number and location within the UUT.

b. Operating range.

c. Instrument accuracy based on specifications or calibration.

d. Documentational evidence of calibration in accordance with Section 6.

9.4 Measurement System Description

a. Description, model number, and serial number.
b. Operating range.
c. Documentational evidence of instrument calibrations.

9.5 Test Results. If specified in the test plan in Section 5.1, report the following test results in the units specified in Table 5-1.

a. Pressure
b. Pretest uncertainty estimate for the pressure measurement.
c. Post-test uncertainty estimate for the pressure measurement.
d. Pressure difference.
e. Pretest uncertainty estimate for the pressure difference measurement.
f. Post-test uncertainty estimate for the pressure difference measurement.

10. REFERENCES

1. ANSI/ASME PTC 19.1-2018, *Test Uncertainty*, ASME, New York, NY.
2. ANSI/ANSI PTC 19.2-2010 (R2020), *Pressure Measurement,* ASME, New York, NY.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX A
BIBLIOGRAPHY

A1. Kelley, Jeffrey D., and Hedengren, John D., “A Steady-State Detection (SSD) Algorithm to Detect Non-Stationary Drifts in Processes,” BYU Scholars Archive, 2013.
A2. Miller, Steven J., “The Method of Least Squares,” Brown University, 2006.
A3. ASME B40.100-2013, *Pressure Gages and Gage Attachments*, ASME, New York, NY.
A4. ISO/IEC 17025:2017, *General Requirements for the Competence of Testing and Calibration Laboratories*, Geneva, Switzerland: International Electrotechnical Commission.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX B
PRESSURE TRANSDUCER UNCERTAINTY EXAMPLE

B1. In this example, an absolute pressure transducer with an operating range of 0-3447 kPa (0-500 psia) is used to measure the pressure of a gas, so the Full Scale (FS) of the instrument is 3447 kPa (500 psia). The corresponding pressure transducer voltage output range is from 0 to 5 VDC. The calibration temperature is 21.1 °C (70 °F). This uncertainty example uses ASME PTC 19.1[1] to establish a framework for estimating the systematic standard uncertainty, b_r, of pressure measurement where the result, *R,* is a function of independent parameters. For this example, $b_r = \Delta P$ and, $R = P$.

TABLE B-1. Pressure Transducer Characteristics

Parameter	Description	Value	Accuracies
A_{FS}	Full scale accuracy	± 0.11 %	± 3.79 kPa (± 55 psia)
NL	Full scale non-linearity	± 0.1 %	± 3.44 kPa (± 50 psia)
H	Full scale hysteresis	± 0.05 %	± 1.72 kPa (± 25 psia)
NR	Full scale non-repeatability	± 0.02 %	± 6.90 kPa (± 10 psia)
Z_S	Full scale zero shift	± 0.036 %FS/°C ± 0.02 %FS/°F	Dependent on Temperature
S_S	Full scale span shift	± 0.027 %FS/°C ± 0.015 %FS/°F	Dependent on Temperature

The pressure transducer output voltage, V_{DC}, is related to the absolute pressure of the gas, P, in Equation B-1.

$$P = V_{DC} \times \frac{FS}{V_{range}} \tag{B-1}$$

The uncertainty in the pressure reading, ΔP, is found by applying the ASME PTC 19.1-2018[1] method as shown in Equation B-2.

$$\Delta P = \pm\left[\left(\Delta V_{DC}\frac{\partial P}{\partial V_{DC}}\right)^2 + \left(\Delta A_{FS}\frac{\partial P}{\partial A_{FS}}\right)^2 + \left(\Delta NL\frac{\partial P}{\partial NL}\right)^2 + \left(\Delta H\frac{\partial P}{\partial H}\right)^2 + \left(\Delta NR\frac{\partial P}{\partial NR}\right)^2 + \left(\Delta Z_S\frac{\partial P}{\partial Z_S}\right)^2 + \left(\Delta S_S\frac{\partial P}{\partial S_S}\right)^2\right]^{1/2} \tag{B-2}$$

The sensitivity of the pressure measurement with respect the to the voltage can be found through partial differentiation of Equation B-1 to obtain Equation B-3.

$$\frac{\partial P}{\partial V_{DC}} = \frac{FS}{V_{range}} \tag{B-3}$$

The sensitivities of parameters A_{FS}, NL, H, NR can be approximated to be 1, and the listed accuracy applied, so the terms in Equation B-2 that are shown in Equation B-4

$$\left(\Delta A_{FS}\frac{\partial P}{\partial A_{FS}}\right)^2 + \left(\Delta NL\frac{\partial P}{\partial NL}\right)^2 + \left(\Delta H\frac{\partial P}{\partial H}\right)^2 + \left(\Delta NR\frac{\partial P}{\partial NR}\right)^2 \tag{B-4}$$

reduce to Equations B-5 to B-8.

$$\Delta A_{FS}\frac{\partial P}{\partial A_{FS}} = \Delta A_{FS} = A_{FS} \times FS = listed\ accuracy \tag{B-5}$$

$$\Delta NL\frac{\partial P}{\partial A_{FS}} = \Delta NL = NL \times FS = listed\ accuracy \tag{B-6}$$

$$\Delta H\frac{\partial P}{\partial A_{FS}} = \Delta H = H \times FS = listed\ accuracy \tag{B-7}$$

$$\Delta NR\frac{\partial P}{\partial A_{FS}} = \Delta NR = NR \times FS = listed\ accuracy \tag{B-8}$$

Contributions from the zero and span terms in Equation B-2 are dependent on the temperature and are related by the chain rule analytically and are evaluated numerically.

For the zero term, the chain rule is shown in Equation B-9.

$$\Delta Z_S\frac{\partial P}{\partial Z_S} = \Delta Z_S\frac{\partial P}{\partial T}\frac{\partial T}{\partial Z_S} \tag{B-9}$$

Where numerically,

$$\Delta Z_S\frac{\partial T}{\partial Z_S} = \Delta Z_S\frac{\Delta T}{\Delta Z_S} = \Delta T \tag{B-10}$$

and,

$$\frac{\partial P}{\partial T} = Z_s \times FS \tag{B-11}$$

so that,

$$\Delta Z_S\frac{\partial P}{\partial Z_S} = \Delta T \times Z_s \times F \tag{B-12}$$

And similarly, the span term reduces to Equation B-13.

$$\Delta S_S\frac{\partial P}{\partial S_S} = \Delta T \times S_s \times FS \tag{B-13}$$

Consequently, Equation B-2 reduces of Equation B-14 where *T* is the temperature at which the measurement was taken where ΔV_{DC} is dependent on the accuracy of the voltage reader or data acquisition system.

$$\Delta P = \pm\left[\left(\Delta V_{DC} \times \frac{FS}{V_{range}}\right)^2 + (A_{FS} \times FS)^2 + (NL \times FS)^2 + (H \times FS)^2 + (NR \times FS)^2 + (\Delta T \times Z_s \times FS)^2 + (\Delta T \times S_s \times FS)^2\right]^{1/2} \tag{B-14}$$

Applying the specifics for this example in SI units:

$$\Delta P = \pm\left[\left(\Delta V_{DC} \times \frac{3447000}{5}\right)^2 + (3790)^2 + (3480)^2 + (1720)^2 + (690)^2 + (0.00036 \times 3447000 \times (T - 21.1))^2 + (0.00027 \times 3447000 \times (T - 21.1))^2\right]^{1/2} \text{Pa} \quad \text{(B-15)}$$

$$\Delta P = \pm\left[\begin{matrix}(\Delta V_{DC} \times 689400)^2 + 29909000 + \left(1241 \times (T - 21.1)\right)^2 \\ +(930.7 \times (T - 21.1))^2\end{matrix}\right]^{1/2} \text{Pa} \quad \text{(B-16)}$$

Applying the specifics for this example in IP units:

$$\Delta P = \pm\left[\left(\Delta V_{DC} \times \frac{500}{5}\right)^2 + (0.55)^2 + (0.5)^2 + (0.25)^2 + (0.1)^2 + (0.0002 \times 500 \times (T - 70))^2 + (0.00015 \times 500 \times (T - 70))^2\right]^{1/2} \text{psia} \quad \text{(B-17)}$$

$$\Delta P = \pm\left[\begin{matrix}(\Delta V_{DC} \times 100)^2 + 0.625 + \left((0.1 \times (T - 70)\right)^2 \\ +(0.075 \times (T - 70))^2\end{matrix}\right]^{1/2} \text{psia} \quad \text{(B-18)}$$

B2. TEST CASE 1

B2.1 Instrument Application 1

The pressure transducer in Section B1 is combined with a data acquisition to measure a refrigerant compressor discharge pressure at 100 °C (212 °F). A reading of 3103 kPa (450 psia) is recorded as 4.5 V.

TABLE B-2. Data Acquisition System Characteristics

Parameter	Description	Value	Accuracies
N/A	Input Range	25 mV/V	N/A
N/A	Offset Error	± 0.05 %	± 0.0125 mV/V
V_R	Voltage Reading	4.5 V	N/A
N/A	Gain Error	± 0.05 %	± 0.05625 mV
T_c	Calibration Temperature	21.1 °C (70 °F)	N/A
D_O	Offset Drift	0.3 µV/(V°C) 0.167 µV/(V°F)	Dependent on temperature
T	Measurement Temperature	100 °C (212 °F)	N/A
D_T	Temperature Drift	To be Determined	Dependent on Temperature

The pressure transducer output voltage (V_{DC}) is related to the offset error, gain error, and offset drift as shown in Equation B-19,

$$\Delta V_{DC} = \pm[(\Delta Offset\ error\ )^2 + (\Delta Gain\ error\ )^2 + (Temperature\ Drift)^2\ ]^{1/2} \qquad \text{(B-19)}$$

where the temperature drift is expressed in SI units in Equation B-20 and is IP units in B-21.

$$D_T = V_R \times D_O \times (T - T_c) = 4.5 \times (3 \times 10^{-7}) \times (100 - 21.1) = 0.000107\ V \qquad \text{(B-20)}$$
$$D_T = V_R \times D_O \times (T - T_F) = 4.5 \times (1.67 \times 10^{-7}) \times (212 - 70) = 0.000107\ V \qquad \text{(B-21)}$$

Substituting values into Equation B-19 yields the result for ΔV_{DC} in Equation B-22 in both SI and IP units.

$$\Delta V_{DC} = \pm[(0.0000125\ )^2 + (0.00225)^2 + (0.000107)^2\ ]^{1/2} = \pm 0.00225\ V \qquad \text{(B-22)}$$

Substituting the value of ΔV_{DC} in Equation B-4 and other values in Table B-1 into Equation B-16 yields the uncertainty for Instrument Application 1 in Equations B-23 and B-24 in SI units.

$$\Delta P = \pm \begin{bmatrix} (0.00225 \times 689400\ )^2 + 29909000 + \left(1241 \times (100 - 21.1)\right)^2 \\ +(930.7 \times (100 - 21.1))^2 \end{bmatrix}^{1/2} \text{Pa} \qquad \text{(B-23)}$$

$$\Delta P = \pm\ 122.52\ \text{ kPa} \qquad \text{(B-24)}$$

Substituting the value of ΔV_{DC} in Equation B-22 and other values in Table B-1 into Equation B-18 yields the uncertainty for Instrument Application 1 in Equations B-25 and B-26 in IP units.

$$\Delta P = \pm \begin{bmatrix} \left(0.00225 \times \frac{500}{5}\right)^2 + 0.625 + \left(0.1 \times (212 - 70)\right)^2 \\ +(0.075 \times (212 - 70))^2 \end{bmatrix}^{1/2} \text{psia} \qquad \text{(B-25)}$$

$$\Delta P = \pm\ 17.77\ \text{ psia} \qquad \text{(B-26)}$$

Equation B-27 expresses the uncertainty results for Instrument Application 1 in both SI and IP units.

$$P = 3103 \pm 122.52\ kPa\ (450 \pm 17.77\ psia)\ (95\%) \qquad \text{(B-27)}$$

B2.2 Instrument Application 2: Analog Comparison

An analog precision gas pressure gage is used to measure the same discharge pressure. The gage has a pressure range is 0-3447 kPa (0-500 psia) and a resolution of 13.47 kPa (2 psia) between scale markers. The scale markers are close enough together so that the user can discern 6.89 kPa (1 psia) in between scale marks. Consequently, there is a resolution uncertainty of 6.89 kPa (1 psia). The dial gage has a stated accuracy of 3% in the last quarter of the span.

Standard method for converting resolution uncertainty to systematic uncertainty is

$$Systematic\ uncertainty = \frac{Resolution\ uncetainty}{\sqrt{3}} \qquad \text{B-28}$$

where,

$$\Delta P = \pm(Span\ error^2 + Systematic\ uncertainty^2)^{\frac{1}{2}} \qquad \text{B-29}$$

Applying values,

$$\Delta P = \pm\left((0.03 \times 3447000)^2 + \left(\frac{6890}{\sqrt{3}}\right)^2\right)^{\frac{1}{2}} = 103 \text{ kPa} \quad \text{B-30}$$

$$\Delta P = \pm\left((0.03 \times 500)^2 + \left(\frac{1}{\sqrt{3}}\right)^2\right)^{\frac{1}{2}} = 15 \text{ psia} \quad \text{B-31}$$

$$P = 3103 \pm 103\, kPa\; (450 \pm 15\, psia) \quad \text{B-32}$$

B3. TEST CASE 2

B3.1 Instrument Application 3

The pressure transducer in Section B1 and the data acquisition system in Section B3.1 are used to measure the pressure in an exhaust plenum. The air is at 35 °C (95 °F) and the measured pressure is 105 kPa (15.2 psia).

$$D_T = V_R \times D_O(T - T_c) = 4.5 \times (3 \times 10^{-7})(35 - 21.1) = 0.0000188\, V \quad \text{B-33}$$

$$\Delta V_{DC} = [(0.0000125\,)^2 + (0.00225)^2 + (0.0000188)^2\,]^{1/2} = 0.00225\, V \quad \text{B-34}$$

$$\Delta P = [(0.00225 \times 689400\,)^2 + 29909 + (1241 \times (35 - 21.1))^2 + (930.7 \times (35 - 21.1)^2\,]^{1/2} Pa = 22.30\, kPa \quad \text{B-35}$$

$$\Delta P = [(0.00225 \times 100\,)^2 + 0.625 + (0.1 \times (95 - 70))^2 + (0.075 \times (95 - 70))^2\,]^{1/2}\, psia = 3.23\, psia \quad \text{B-36}$$

$$P = 105 \pm 22.30\, kPa\; (15.2 \pm 3.23\, psia) \quad \text{B-37}$$

B3.2 Instrument Application 4 –Analog Comparison

An analog precision gas pressure gage is used to measure the same airflow. The gage goes from 0-138 kPa (0-20 psia) and has a resolution of 1.38 kPa (0.2 $psia$) between scale markers. For the instrument the scale markers are close enough together so that the user can discern 0.69 kPa (0.1 $psia$) inbetween scale marks or a resolution uncertainty of 0.69 kPa (0.1 $psia$). The dial gage has a stated accuracy of 2% in the last quarter of the span.

$$\Delta P = \left((0.02 \times 1380)^2 + \left(\frac{690}{\sqrt{3}}\right)^2\right)^{\frac{1}{2}} = 2.79\, kPa \quad \text{B-38}$$

$$\Delta P = \left((0.02 \times 20)^2 + \left(\frac{0.1}{\sqrt{3}}\right)^2\right)^{\frac{1}{2}} = 0.404\, psia \quad \text{B-39}$$

$$P = 105 \pm 32.79\, kPa\; (15.2 \pm 0.404\, psia) \quad \text{B-40}$$

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX C
FLUID FLOW PRESSURE MEASUREMENT BASICS

There are three components to a pressure reading in dynamic systems: static pressure, dynamic (velocity), and total pressure. Static pressure is the pressure that the fluid exerts on the container, dynamic pressure is the pressure that results from the momentum of the moving fluid, and total pressure is the sum of the static pressure and dynamic pressure. Total pressure can be read directly by slowing the velocity to zero locally or globally. Dynamic pressure can be measured by inserting a bluff body to reduce the local velocity to zero and subtracting off the static pressure. If static pressure is desired, care must be taken not interfere with the fluid flow or components of the dynamic pressure will be added to the static measurement. A static measurement is considered accurate if the flow path geometry has not changed in cross section or direction of flow and the attachment point is a clean hole in the wall of the container, free of burrs and intrusion into the flow stream.

Where making a pressure measurement, the user should follow the instrument manufacturer’s application guidelines or general engineering best practices to obtain correct values.

Where correlating the results of two independent tests, the user must consider differences in flow geometries before drawing any conclusions. For example, given the same mass flow rate a static pressure measurement of two tubes where one is twice the diameter will read differently. The larger diameter tube will have more of the dynamic component converted to static than the smaller diameter tube. Also, if one measurement has a straight section of 6 or more diameters before or after the measurement and the other is taken close to a valve with changing flow path the result will be a difference in the measured value that is not easily compensated.

Figure C-1 shows an example of Pitot-static tube construction and the tubing connections to manometers or a pressure difference transducer to obtain both dynamic pressure and static pressures that are used to determine air velocities at a single measurement point. Pitot-static tubes shall be aligned within ±10 degrees of the airflow direction, and any misalignment shall be included in the uncertainty estimate.

FIGURE C-1: An example of Pitot-static tube construction and connections

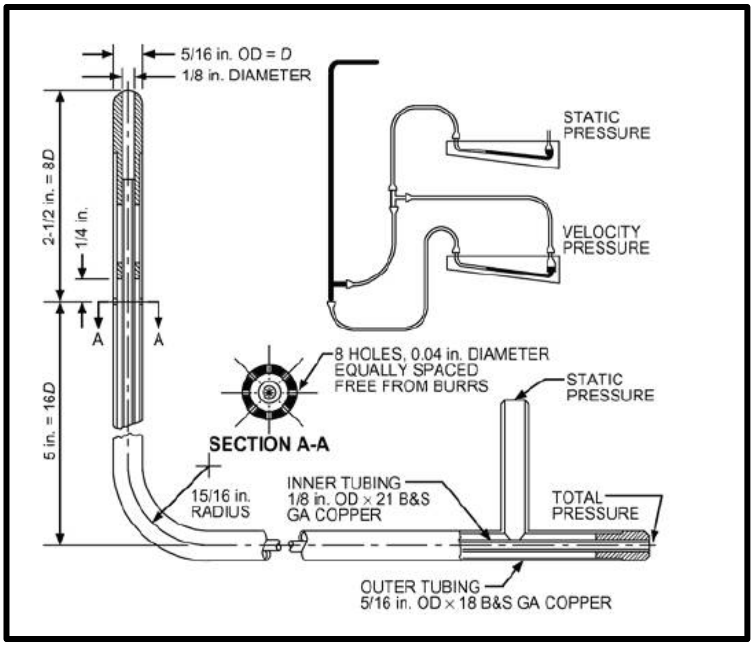
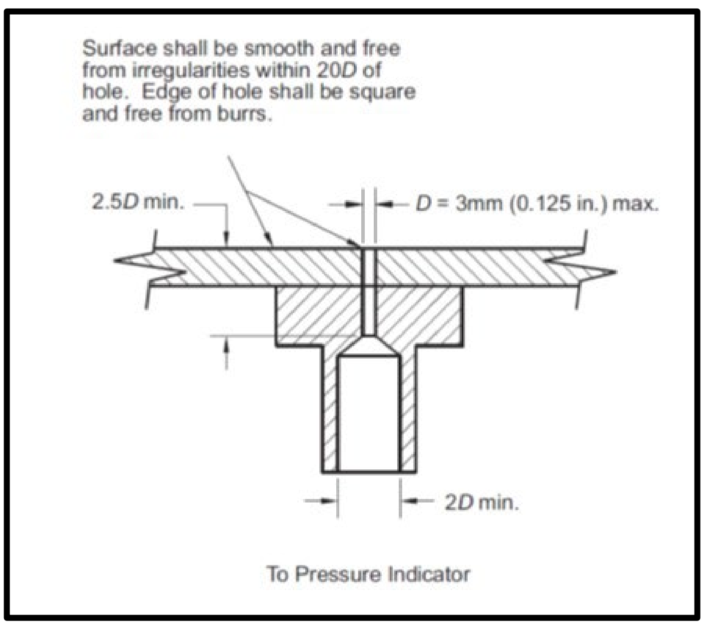


Figure C-2 shows the construction requirements for a static pressure tap on an air duct.

FIGURE C-2: Static pressure tap construction requirements



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INFORMATIVE APPENDIX D: PRESSURE COMPENSATION REQUIRED FOR AN ELEVATION DIFFERENCE

D1. Pressure Compensation Required for an Elevation Difference. Liquid in a connecting tube between the source of pressure and the measurement point creates a measurement error if the two points are not at the same elevation. Pressure measurements made above the source of pressure will be less than the source of pressure by a constant amount, while pressure measurements made below the source of pressure will be greater than the source of pressure by a constant amount. Apply Equation D-1 in SI units or Equation C-2 in I-P units to determine the value needed to compensate for this error.
In SI units:

$$P_c = \rho_l g \Delta y \quad \text{(D-1)}$$

where

P_c = pressure compensation, Pa
ρ_l = liquid density, kg/m^3
g = local gravitation constant, m/s^2
Δy = elevation difference between the measurement point and the source of pressure, m

In I-P units:

$$P_c = \rho_l \left(\frac{g}{g_c}\right) \Delta y \quad \text{(D-2)}$$

where

P_c = compensation pressure, psia
ρ_l = liquid density, lb_m/ft^3
g = local gravitational acceleration, ft/s^2
g_c = gravitational constant, 32.174 [$(lb_m \cdot ft)/(lb_f \cdot s^2)$]
Δy = elevation difference between the measurement point and the source of pressure, ft

Refrigerants will create a liquid column if the tubing ambient temperature is less than the saturation temperature of the fluid being measured even if the pressure is being measured on gas within the system.

D2. Example. Compressor discharge pressure in an R410a system is measured by a pressure transducer that is elevated 1.27 m (50 in.) above the source of pressure. The refrigerant saturation temperature is 41.2 ºC (107ºF) and the ambient temperature is 35 ºC (95ºF). The refrigerant liquid density is 944 kg/m^3 (59 lb_m/ft^3).
Applying Equation D-2 results in a pressure compensation of 12 kPa (1.7 psia). Section D1 states that pressure measurements made above the source of pressure will be less than the source pressure. If, for example, the measured pressure reading is 2.515 MPa (350 psig), the pressure at the source is 2.526 MPa (351.7 psig).

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INFORMATIVE APPENDIX E: PRESSURE MEASUREMENT VOLUME

Pressure measurement is always an invasive measurement. The pressure measuring element adds volume to the system being monitored as does any inter-connecting conduits from the system to the transducer. The increase in volume can reduce the pressure of a compressible fluid system in proportion to increase in volume. For example, if the pressure measurement instrumentation increases the volume by 1% there will be a 1% reduction in the pressure measured if additional fluid is not added into the system.

A particularly severe error can occur where the system contains two phases of a fluid. If the additional volume has a saturation temperature that is below the ambient temperature seen by the measurement system, then the volume will be filled with gas. In the event that the saturation temperature of the fluid is above the ambient temperature seen by the measurement system then the volume will be filled with liquid. For example, a pressure transducer connected to the gas service port of a heat pump will be filled with gas in the cooling mode but filled with liquid in the heating mode. This effectively changes the charge between cooling and heating.

To determine if the volume has an effect on the system being measured a test needs to be conducted with and without the transducers attached. Observe other measurements such as temperatures, performance, heat transfer, etc., in both cases to make sure the effect of the measurement volume added is truly insignificant. If the amount of fluid required by the system is determined then attempt to set the fluid quantity in the case where the instrument volume contains only gas.