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Standard Practice for Static Calibration of Electronic Transducer-Based Pressure Measurement Systems for Geotechnical Purposes[1]

This standard is issued under the fixed designation D 5720; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the procedure for static calibration of electronic transducer-based systems used to measure fluid pressures in laboratory or in field applications associated with geotechnical testing.

1.2 This practice is used to determine the accuracy of electronic transducer-based pressure measurement systems over the full pressure range of the system or over a specified operating pressure range within the full pressure range.

1.3 This practice may also be used to determine a relationship between pressure transducer system output and applied pressure for use in converting from one value to the other (calibration curve). This relationship for electronic pressure transducer systems is usually linear and may be reduced to the form of a calibration factor or a linear calibration equation.

1.4 The values stated in SI units are to be regarded as the standard. The inch-pound units in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ANSI/ISA Standards:*

S37.1 (R1982) Electrical Transducer Nomenclature and Terminology[2]

S37.3 (R1982) Specifications and Tests For Strain Gage Pressure Transducers[2]

S37.6 (R1982) Specifications and Tests For Potentiometric Pressure Transducers[2]

S37.10 (R1982) Specifications and Tests For Piezoelectric Pressure and Sound-pressure Transducers[2]

3. Terminology

3.1 Terms marked with "(ANSI, ISA-S37.1)" are taken directly from ANSI/ISA-S37.1 (R1982) and are included for the convenience of the user.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *absolute pressure*—pressure measured relative to zero pressure (vacuum) (ANSI, ISA-S37.1).

3.2.2 *accuracy*—ratio of the error to the full-scale output or the ratio of the error to the output, as specified, expressed in percent (ANSI, ISA-S37.1).

3.2.3 *ambient conditions*—conditions (pressure, temperature, etc.) of the medium surrounding the case of the transducer (ANSI, ISA-S37.1).

3.2.4 *best straight line*—line midway between the two parallel straight lines closest together and enclosing all output versus measurand values on a calibration curve (ANSI, ISA-S37.1).

3.2.5 *bonded*—permanently attached over the length and width of the active element (ANSI, ISA-S37.1).

3.2.6 *bourdon tube*—pressure-sensing element consisting of a twisted or curved tube of non-circular cross section that tends to be straightened by the application of internal pressure (ANSI, ISA-S37.1).

3.2.7 *calibration*—test during which known values of measurand are applied to the transducer and corresponding output readings are recorded under specified conditions (ANSI, ISA-S37.1).

3.2.8 *calibration curve*—graphical representation of the calibration record (ANSI, ISA-S37.1).

3.2.9 *calibration cycle*—application of known values of measurand, and recording of corresponding output readings, over the full (or specified portion of the) range of a transducer in an ascending and descending direction (ANSI, ISA-S37.1).

3.2.10 *calibration record*—record (for example, table or graph) of the measured relationship of the transducer output to the applied measurand over the transducer range (ANSI, ISA-S37.1).

3.2.11 *calibration traceability*—relation of a transducer calibration, through a specified step-by-step process, to an instrument or group of instruments calibrated by the National Institute of Standards and Technology (ANSI, ISA-S37.1).

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[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.95 on Information Retrieval and Data Automation.

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[2] Available from Instrument Society of America, P.O. Box 12277, Research Triangle Park, NC 27709.

3.2.12 *capsule*—pressure-sensing element consisting of two metallic diaphragms joined around their peripheries (ANSI, ISA-S37.1).

3.2.13 *diaphragm*—sensing element consisting of a thin, usually circular, plate that is deformed by pressure differential applied across the plate (ANSI, ISA-S37.1).

3.2.14 *differential pressure*—difference in pressure between two points of measurement (ANSI, ISA-S37.1).

3.2.15 *end points*—outputs at the specified upper and lower limits of the range (ANSI, ISA-S37.1).

3.2.16 *end-point line*—straight line between the end points (ANSI, ISA-S37.1).

3.2.17 *end point linearity*—linearity referred to the end-point line (ANSI, ISA-S37.1).

3.2.18 *environmental conditions*—specified external conditions (shock, vibration, temperature, etc.) to which a transducer may be exposed during shipping, storage, handling, and operation (ANSI, ISA-S37.1).

3.2.19 *error*—algebraic difference between the indicated value and the true value of the measurand (ANSI, ISA-S37.1).

3.2.20 *excitation*—external electrical voltage or current, or both, applied to a transducer for its proper operation (ANSI, ISA-S37.1).

3.2.21 *fluid*—a substance, such as a liquid or gas, that is capable of flowing and that changes its shape at a steady rate when acted upon by a force.

3.2.22 *full-scale output*—algebraic difference between the end points (ANSI, ISA-S37.1).

3.2.23 *gage pressure*—pressure measured relative to ambient pressure (ANSI, ISA-S37.1).

3.2.24 *hermetically sealed*—manufacturing process by which a device is sealed and rendered airtight.

3.2.25 *hysteresis*—maximum difference in output, at any measurand value within the specified range, when the value is approached first with increasing and then with decreasing measurand (ANSI, ISA-S37.1).

3.2.25.1 *Discussion*—Hysteresis is expressed in percent of full-scale output, during any one calibration cycle.

3.2.26 *least-squares line*—straight line for which the sum of the squares of the residuals (deviations) is minimized (ANSI, ISA-S37.1).

3.2.27 *least squares linearity*—linearity referred to the least-squares line (ANSI, ISA-S37.1).

3.2.28 *linearity*—closeness of a calibration curve to a specified straight line (ANSI, ISA-S37.1).

3.2.28.1 *Discussion*—Linearity is expressed as the maximum deviation of any calibration point from a specified straight line, during any one calibration cycle. Linearity is expressed in percent of full-scale output.

3.2.29 *measurand*—physical quantity, property, or condition that is measured (ANSI, ISA-S37.1).

3.2.30 *measured fluid*—fluid that comes in contact with the sensing element (ANSI, ISA-S37.1).

3.2.31 *normal atmospheric pressure*—101.325 kPa (14.696 lbf/in.^{2}); equivalent to the pressure exerted by the weight of a column of mercury 760 mm (29.92 in.) high at 0°C (32°F) at a point on the earth where the acceleration of gravity is 9.8066 m/s ^{2}(32.1739 ft/s^2).

3.2.32 *operating environmental conditions*—environmental conditions during exposure to which a transducer must perform in some specified manner (ANSI, ISA-S37.1).

3.2.33 *output*—electrical or numerical quantity, produced by a transducer or measurement system, that is a function of the applied measurand.

3.2.34 *overload*—maximum magnitude of measurand that can be applied to a transducer without causing a change in performance beyond specified tolerance (ANSI, ISA-S37.1).

3.2.35 *piezoelectric*—converting a change of measurand into a change in the electrostatic charge or voltage generated by certain materials when mechanically stressed (ANSI, ISA-S37.1).

3.2.36 *piezoresistance*—converting a change of measurand into a change in resistance when mechanically stressed.

3.2.37 *potentiometric*—converting a change of measurand into a voltage-ratio change by a change in the position of a moveable contact on a resistance element across which excitation is applied (ANSI, ISA-S37.1).

3.2.38 *range*—measurand values, over which a transducer is intended to measure, specified by their upper and lower limits (ANSI, ISA-S37.1).

3.2.39 *repeatability*—ability of a transducer to reproduce output readings when the same measurand value is applied to it consecutively, under the same conditions, and in the same direction (ANSI, ISA-S37.1).

3.2.39.1 *Discussion*—Repeatability is expressed as the maximum difference between output readings; it is expressed in percent of full-scale output. Two calibration cycles are used to determine repeatability unless otherwise specified.

3.2.40 *room conditions*—ambient environmental conditions, under that transducers must commonly operate, that have been established as follows: (*a*) temperature: 25 ± 10°C (77 ± 18°F); (*b*) relative humidity: 90 % or less; and (*c*) barometric pressure: 98± 10 kPa (29 ± 3 in. Hg). Tolerances closer than shown above are frequently specified for transducer calibration and test environments (ANSI, ISA-S37.1).

3.2.41 *sealed gage pressure*—pressure measured relative to normal atmospheric pressure that is sealed within the transducer.

3.2.42 *sensing element*—that part of the transducer that responds directly to the measurand (ANSI, ISA-S37.1).

3.2.43 *static calibration*—calibration performed under room conditions and in the absence of any vibration, shock, or acceleration (unless one of these is the measurand) (ANSI, ISA-S37.1).

3.2.44 *strain gage*—converting a change of measurand into a change in resistance due to strain (ANSI, ISA-S37.1).

3.2.45 *theoretical output*—product of the applied pressure or vacuum and the ratio of full-scale output to calibrated pressure range.

3.2.46 *transducer*—device that provides a usable output in response to a specified measurand (ANSI, ISA-S37.1).

3.2.47 *transduction element*—electrical portion of a transducer in which the output originates (ANSI, ISA-S37.1).

3.2.48 *warm-up period*—period of time, starting with the application of excitation to the transducer, required to ensure that the transducer will perform within all specified tolerances (ANSI, ISA-S37.1).

4. Summary of Practice

4.1 A pressure transducer based measurement system (pressure transducer, readout system, power supply, and signal conditioner), pressure standard, and appropriate controllers, regulators, and valves are connected to pressure or vacuum sources, or both.

4.2 Pressure or vacuum is applied in predetermined intervals over the full range (or a specified portion of the full range) of the pressure measurement system.

4.3 The pressure measurement system output is compared at each pressure or vacuum interval to the applied pressure or vacuum as indicated by the pressure standard.

4.4 The error in pressure measurement system output is calculated for each pressure or vacuum interval over the calibrated range.

4.5 From error, the accuracy of the pressure measurement system is computed and a determination is made to accept or reject the pressure measurement system.

4.6 From a calibration curve, a relationship between system output and applied pressure may be determined.

5. Significance and Use

5.1 Electronic transducer-based pressure measurement systems must be subjected to static calibration under room conditions to ensure reliable conversion from system output to pressure during use in laboratory or in field applications.

5.2 Transducer-based pressure measurement systems should be calibrated before initial use and at least quarterly thereafter and after any change in the electronic or mechanical configuration of a system.

5.3 Transducer-based pressure measurement systems should also be recalibrated if a component is dropped; overloaded; if ambient test conditions change significantly; or for any other significant changes in a system.

5.4 Static calibration is not appropriate for transducerbased systems used under operating environmental conditions involving vibration, shock, or acceleration.

6. Apparatus

6.1 *Pressure Measurement Systems*—Electronic transducer-based pressure measurement systems covered in this practice may be either individual pressure transducers, as described in 6.2, with independent power supplies, signal conditioners, and readout systems or the systems may be self-contained instruments such as pressure meters or pressure monitors, as described in 6.7.3.1.

6.2 *Pressure Transducers*—Pressure transducers usually consist of a sensing element that is in contact with the measured fluid and a transduction element that modifies the signal from the sensing element to produce an output. The materials used in the sensing element must be compatible with the measured fluid. Some parts of the transducer may be hermetically sealed if those parts are sensitive to and may be exposed to moisture. Pressure connectors must be threaded with appropriate fittings to attach the transducer to standard pipe fittings, or to other appropriate leakproof fittings. The output cable must be securely fastened to the body of the transducer. A simple schematic of a generic pressure transducer is shown in Fig. 1.

6.2.1 *Sensing Elements*—A wide variety of sensing elements are used in pressure transducers. The most common elements are diaphragms, capsules, bourdon tubes, and piezoelectric crystals. The function of the sensing element is to produce a measurable response to applied pressure. The response may be sensed directly on the element or a separate sensor may be used to detect element response.

6.2.2 *Diaphragms*—Diaphragms are usually plates, disks, or wafers of stainless steel, silicon, crystal, or ceramic that deflect when subjected to pressure. Deflection of the diaphragm is detected by sensors.

6.2.2.1 *Strain-Gaged Diaphragms*—The most common diaphragm deflection sensor is the strain gage. Strain gages can be bonded to the diaphragm or imbedded in the diaphragm. Terms typically used to describe these sensors are bonded foil strain gages, bonded semiconductor strain gages, sputtered thin film strain gages, diffused semiconductor strain gages, molecularly diffused strain gages, piezoresistive strain gages, or silicon chips.

6.2.2.2 *Mechanically Linked Diaphragms*— Mechanically linked diaphragms use sensors which are physically separate from the diaphragm. A wide variety of sensors are used in this style element. Sensors may include cantilever beams or bridges, linear displacement transducers (LDT), potentiometers, or vibrating wires. Beams and bridges are typically strain-gaged sensors and terms such as semiconductor strain-gage sensing beam and sputtered strain-gage bridge are used with these devices. The LVDT, LDT, and potentiometer transducers use a rod or a rod-sweeper assembly attached to a diaphragm to sense deflection. Vibrating wire transducers use a tensioned wire that is attached to the diaphragm and deflection of the diaphragm causes a change in the frequency of vibration of the wire that is detected by electromagnetic sensors.

6.2.2.3 *Diaphragms With Noncontact Sensors*— Diaphragm deflection may be detected by noncontact sensors such as optical sensors or variable reluctance sensors.

6.2.2.4 *Capsules and Bourdon Tubes*—Capsules are commonly made of stainless steel or plastic and bourdon tubes are commonly made of bronze, copper, brass, Monel[3] metal, or stainless steel. Deflection of the capsule or bourdon tube under pressure is detected using sensors similar to those used with mechanically linked diaphragms or diaphragms with noncontact sensors as described in 6.2.2.2 and 6.2.2.3.

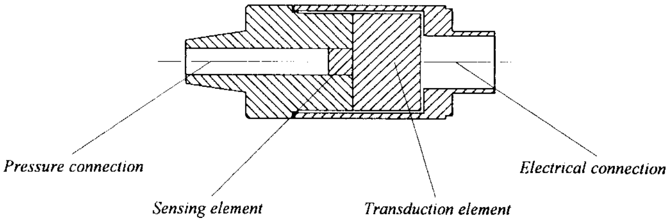

FIG. 1 Generic Pressure Transducer

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[3] Monel is a registered trademark.

6.2.2.5 *Piezoelectric Crystals*—Piezoelectric crystals are made from quartz, tourmaline, or ceramic. Deformation of the crystal under pressure causes a piezoelectric effect in the crystal which produces a measurable voltage.

6.2.3 *Transduction Elements*—Common transduction elements include amplifiers, signal conditioners, Wheatstone bridges, demodulators, power regulators, power supplies, and signal converters. In many transducers these elements are miniaturized solid-state electronic circuits.

6.3 *Pressure or Vacuum Sources*—Filtered pressure or vacuum sources capable of delivering and maintaining pressure or vacuum to the upper and lower limits of the pressure measurement systems range. A fluid medium similar to the one that the measurement system will contact in the laboratory or field application must be used for calibration. Pressure or vacuum sources should be continuously variable over the full range of the measurement system. To minimize risk of system overload, the maximum pressure or vacuum produced by the sources should be regulated or otherwise controlled so that the applied pressure or vacuum does not exceed 125 % of the upper limit or lower limit of the measurement systems range.

6.4 *Readout Systems*—Electronic devices that accept the output signal from a signal conditioner, bridge balance, or the transduction element of a transducer and converts it into an analog or digital display of the output signal. Digital or analog voltmeters, ammeters, or multimeters; strip-chart recorders; dataloggers; oscilloscopes; computers; or similar devices may be used to provide a visual display of the output signal. The accuracy of the readout system should be at least ±0.1 % of the maximum output signal.

6.5 *Signal Conditioners*—Electronic devices that make the output signal from a transduction element compatible with a readout system. It may also provide excitation for a transducer. A signal conditioner may or may not be needed to make the transduction element output compatible with the readout system.

6.6 *Power Supplies*—Electronic devices used to furnish excitation to a transducer (normally direct-current (d-c) power). Power supplies may include batteries or line-powered, electronically regulated, power supplies. The accuracy of the power supply output should be ±0.1 % of the maximum output.

6.7 *Pressure Standards*:

6.7.1 Pressure standards should have a pressure range equal to or greater than 125 % of the upper limit or lower limit of the measurement system range.

6.7.2 *Primary Pressure Standards*—Highly accurate pressure measurement devices. Primary pressure standards are commonly accurate to within ±0.01 to ±0.05 % of the pressure reading. Primary pressure standards may include deadweight testers, deadweight piston gages, or precision mercury manometers. Primary pressure standards used with this practice must be accompanied by a certificate of calibration and a certificate of traceability to the National Institute of Standards and Technology. These certificates must be *current*.

NOTE 1—For normal laboratory use, *current* means calibration and certification has occurred within a period of 12 to 60 months prior to the date-of-use where the appropriate time interval depends on the frequency of use. See manufacturer's recommendations for frequency of recalibration and recertification.

6.7.3 *Secondary Pressure Standards*—Pressure measurement devices that are less accurate than primary pressure standards. Secondary pressure standards used with this practice must be calibrated utilizing a primary pressure standard which meets the requirements in 6.7.1 and 6.7.2. Secondary pressure standards may include pressure meters, pressure monitors, or pressure test gages.

6.7.3.1 *Pressure Meters or Pressure Monitors*—Self-contained electronic pressure measurement systems containing pressure transducer, power supply, signal conditioner, and readout system. Commonly accurate to within ±0.05 to ±0.1 % of full-scale output.

6.7.3.2 *Pressure Test Gages*—Mechanical pressure measurement devices such as bourdon tube pressure test gages. Commonly accurate to within ±0.1 to ±0.5 % of full span.

6.8 *Thermometer*—A thermometer accurate to 1°C (2°F).

6.9 *Barometer*—A barometer accurate to 0.3 kPa (0.1 in. Hg).

6.10 *Hygrometer*—A hygrometer accurate to 3 % relative humidity.

7. Hazards

7.1 *Safety Hazards*:

7.1.1 This practice may involve hazardous materials, operations, and equipment.

7.1.2 Verify that all electrical wiring is properly connected.

7.1.3 Carefully examine the pressure transducer body for burrs and sharp edges.

7.1.4 This practice may involve the use of high air pressure. Appropriate precautions must be taken.

7.1.5 Verify that all pressurized lines, fittings, and connections are properly connected.

7.2 *Technical Precautions*:

7.2.1 Use the same power cables for calibrating the pressure measurement system and for performing a test. A different cable length will change the resistance of the circuit and will result in a change in calibration.

7.2.2 It is recommended that serial numbers be used for control purposes for all system components. Use a marking pen rather than a scribe to mark on the transducer body or on other sensitive system components. If sensitive components must be marked, use extreme care.

7.2.3 Pressure transducers must be stored in suitable boxes or cases when not in use.

7.2.4 Primary and secondary pressure standards are sensitive instruments and must be carefully stored, transported, and operated. Refer to the manufacturer's recommendations for proper care and operation of these devices.

7.2.5 Calibrate pressure transducers and measurement systems under the same ambient conditions and at the same physical orientation they will experience in the laboratory or field application.

7.2.6 Transducers or measurement systems used to measure pore fluid pressure must produce minimal volume change during changes in pressure. Some transducers or systems with diaphragm, capsule, or bourdon tube sensing elements may cause larger than acceptable volume changes and should not be used for pore fluid pressure measurement applications.

8. Calibration and Standardization

8.1 Verify that the pressure standard has current certificates of calibration and traceability. If the certificates are not current, have the pressure standard calibrated before performing this practice.

8.2 Verify that the readout system used has a current calibration. If the calibration is not current, have the readout system calibrated before performing this practice.

9. Ambient Conditions

9.1 Temperature change is very critical when deadweight testers or deadweight piston gages are used as the pressure standard. To avoid piston area variations during calibration, the room temperature should not vary more than ±1°C (±2°F).

9.2 Allow all electronic equipment to warm up in accordance with the manufacturer's recommendations or for at least 30 min before use to ensure stability.

9.3 Place the pressure measurement system, pressure standard, and all other pertinent equipment in the environment in which they are to be calibrated for at least 24 h prior to the time of calibration.

10. Preparation for Calibration

10.1 All data are to be recorded on a data sheet. An example data sheet is shown as Fig. X1.1. Any data sheet may be used as long as the data sheet contains all required data.

10.2 Visually inspect the pressure transducer or pressure measurement system for mechanical defects, poor finish, and improper identification.

10.3 Visually inspect all electrical connectors.

10.4 Locate and record information relating to the pressure transducer or measurement system including manufacturer, serial number, range, and full-scale output.

10.5 Locate and record information relating to the pressure standard including manufacturer, serial number, type, mechanism style, medium, range, and accuracy.

10.6 Determine and record the pressure range to be calibrated and the required accuracy.

10.7 Determine and record the calibration method (type of calibration) to be performed. Three calibration methods (gage pressure, absolute pressure, and differential pressure) are common and the method chosen depends on the design and intended use of the transducer or measurement system. Calibration equipment requirements and setups are different for each method. Consult manufacturers recommendations for proper equipment and setup requirements.

10.7.1 *Gage Pressure Calibration*—Gage pressure calibration means that during calibration the transducer or measurement system is measuring applied pressure relative to ambient (atmospheric) pressure and a pressure source is usually all that is required.

10.7.2 *Absolute Pressure Calibration*— Absolute pressure calibration means that during calibration the transducer or measurement system is measuring applied pressure relative to a vacuum and a vacuum source is needed in addition to a pressure source.

NOTE 2—Vacuum is used in this practice as negative pressure relative to standard atmospheric pressure. This practice will give the relation between pressure/vacuum and electrical output from the sensor but not necessarily absolute zero.

10.7.3 *Differential Pressure Calibration*— Differential pressure calibration means that during calibration the transducer or measurement system is measuring the difference between two independent sources. The sources may be two applied pressures, two applied vacuums, or an applied pressure and an applied vacuum.

10.8 Connect the transduction element of the transducer or measurement system to any required excitation source, power supply, signal conditioner, or readout system, or combination therefore. Follow the manufacturer's recommendations for excitation levels and proper electrical connections.

10.9 Connect the transducer or measurement system, pressure standard, and any required controllers, regulators, or valves, or combination therefore, to the pressure or vacuum sources, or both. Secure all components with the force or torque recommended by the manufacturers.

10.10 Check for leaks. Check all connections between the pressure and vacuum sources, pressure standard, transducer or measurement system, and any required regulators, valves, controllers, and fittings for leaks prior to continuing this practice.

10.11 Turn on all electronic components and allow adequate time for the equipment to warm up. The manufacturer's recommendations should be followed or a minimum of 30 min should be allowed.

10.12 Determine the transducer or measurement system output with no pressure or vacuum on the system. If appropriate for the transducer or measurement system being calibrated, adjust the zero reading.

10.13 Exercise the sensing element by increasing (or decreasing) the pressure (or vacuum) to the upper (or lower) limit of the transducer or measurement system range. Hold this pressure (or vacuum) on the transducer or measurement system for several minutes to allow all components to equilibrate under the applied pressure (or vacuum). If appropriate for the transducer or measurement system being calibrated, adjust the span.

NOTE 3—Initial calibration of new transducers or measurement systems may require more exercise cycles to properly break in the sensing element. Follow the manufacturer's recommendations for all initial calibrations.

10.14 For some transducers or measurement systems given 10.12 and 10.13 may need to be repeated until stable readings are obtained at both the upper and lower limits of the range.

11. Calibration Procedure

11.1 Read and record the ambient temperature, relative humidity, and atmospheric pressure. The temperature, relative humidity, and atmospheric pressure should be within the limits defined in 3.2.40 (*room conditions*).

11.2 With zero pressure or vacuum on the transducer or measurement system, determine and record the transducer or measurement system output on a data sheet as output.

NOTE 4—For a gage pressure calibration this point will correspond to zero gage pressure. For an absolute pressure calibration this point will correspond to atmospheric pressure. For a *differential pressure* calibration this point will correspond to zero differential pressure.

11.3 Perform two or more complete calibration cycles consecutively. Each cycle consists of pressure increments up to the upper limit of the calibrated range followed by pressure decrements down to the lower limit of the calibrated range. Each cycle must consist of enough calibrations points to adequately define linearity, hysteresis, and repeatability. Obtain a minimum of five calibration points, at equally spaced intervals across the calibrated range, in each cycle. In general, the calibration cycle should simulate the pressure or vacuum sequence that will be applied during the actual test application.

NOTE 5—Five calibration points are considered the minimum acceptable for adequate calibration. ANSI/ISA-S37.3 (R1982) requires at least eleven calibration points.

11.4 Determine or calculate and record the values of applied pressure/vacuum and theoretical output for each pressure or vacuum interval.

11.5 Raise or lower the pressure or vacuum on the system in the appropriate intervals as determined in 11.4 to obtain the desired value of applied pressure/vacuum as indicated by the pressure standard. Determine and record the corresponding transducer or measurement system output on the data sheet as output.

11.6 Repeat 11.5 for the full calibrated range.

11.7 Repeat 11.5 and 11.6 for each calibration cycle.

11.8 Release the system pressure or vacuum to ambient (atmospheric) pressure.

11.9 Read and record the ambient temperature, relative humidity, and atmospheric pressure.

11.10 Calculate and record linearity error, hysteresis error, and repeatability error for each pressure or vacuum interval.

11.11 Select and record the maximum error from the errors calculated in 11.10 for each type of error. These values are the largest single deviation (either positive or negative) from zero.

11.12 Calculate and record linearity accuracy, hysteresis accuracy, and repeatability accuracy in percent of full-scale output using the maximum errors selected in 11.11.

11.13 Evaluate the accuracies obtained in 11.12. If the values of accuracy exceed the required accuracy, 11.1 through 11.12 are to be repeated. If the pressure transducer or measurement system still does not meet the specified accuracies, it may be rejected for use or the calibrated range may be limited to those pressure or vacuum intervals where the transducer meets the specified requirements.

11.14 Values of applied pressure/vacuum and output may be used to compute a calibration factor or calibration equation to convert between transducer or measurement system output and applied pressure or vacuum. Possible methods to obtain a factor or equation include use of the end-point line, the best straight line, or the least-squares line. The method using the least-squares line is illustrated in the appendix.

12. Calculation

12.1 Determine theoretical output for each interval as follows:

$$\begin{aligned} theoretical\ output &= applied\ pressure\ (or\ vacuum) \\ &\quad \times [full-scale\ output/calibrated\ pressure\ range] \end{aligned} \tag{1}$$

12.2 Determine the pressure transducer or measurement system errors for each pressure or vacuum interval using the following expressions:

12.2.1 For any calibration point:

$$linearity\ error = theoretical\ output - output \tag{2}$$

12.2.2 For any calibration cycle:

$$\begin{aligned} hystersis\ error &= output\ (pressure\ increasing) \\ &\quad - output\ (pressure\ decreasing) \end{aligned} \tag{3}$$

12.2.3 For consecutive calibration cycles:

$$\begin{aligned} repeatability\ error &= output\ (pressure\ increasing,\ first\ cycle) \\ &\quad - output\ (pressure\ increasing,\ second\ cycle) \end{aligned} \tag{4}$$

12.3 Determine the accuracy for each type of error using the following expression:

$$accuracy = (maximum\ error/full-scale\ output) \times 100 \tag{5}$$

13. Report and Records

13.1 The report is to consist of a completed and checked data sheet and any calculations required to determine a calibration factor or calibration equation.

13.2 All calculations are to show a check mark.

13.3 Permanent, continuous records including calibration data sheets and reports must be kept for each transducer or measurement system as long as that transducer or measurement system is in use in a laboratory or field application.

13.4 Permanent, continuous records including certificates of calibration and traceability must be kept for each pressure standard as long as that pressure standard is used for calibration of transducers or measurement systems.

14. Keywords

14.1 calibration; electronic equipment; instrumentation; manometer; pressure gage; pressure-measuring instrument; pressure standard; pressure transducer; sensor

APPENDIX

(Nonmandatory Information)

X1. RELATIONSHIP BETWEEN PRESSURE AND SYSTEM OUTPUT USING THE LEAST-SQUARES LINE

X1.1 Obtain a least-squares line to represent the calibration for a electronic transducer-based pressure measurement system as follows:

X1.1.1 Perform a least-squares linear regression analysis on the calibration point data where values of applied pressure/vacuum from the pressure standard are (*x*) and system output is (*y*).

X1.1.2 Compute the correlation coefficient. A correlation coefficient of +1 indicates a strong positive correlation and −1 indicates a strong negative correlation.

X1.1.3 Compute the intercept (*b*) and the slope (*m*) to get the equation $y = m\,x + b$. The equation can be plotted as shown in Fig. X1.1.

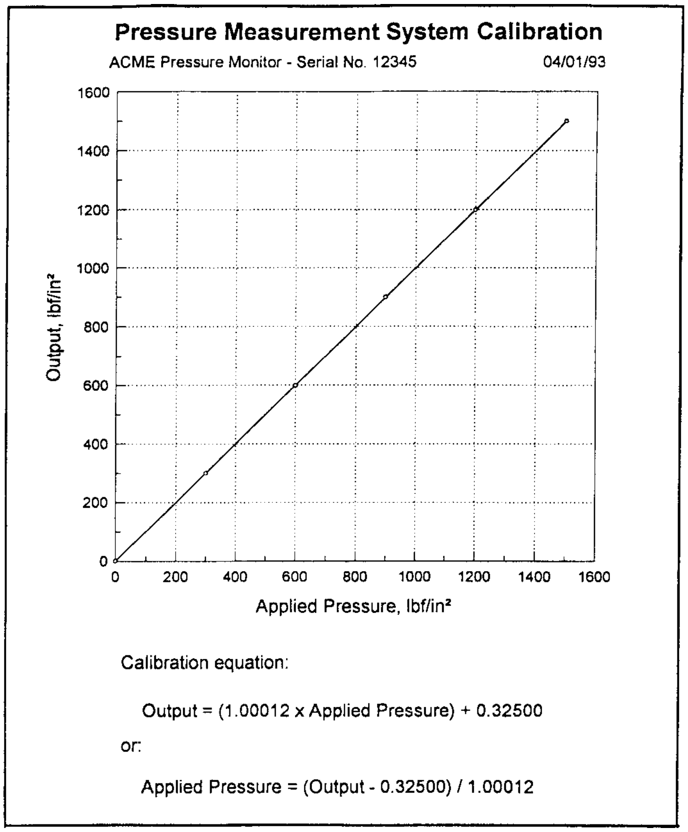
X1.1.4 Rearrange the linear regression equation:

$$y = m\,x + b \qquad \text{(X1.1)}$$

into the form:

$$x = \frac{y - b}{m} \qquad \text{(X1.2)}$$

X1.1.5 Use Eq X1.2 to compute an unknown pressure (*x*) from a known system output (*y*). Substitute the known output for (*y*) and the slope (*m*) and intercept (*b*) from the least-squares linear regression equation. Solve for the unknown pressure (*x*) using Eq X1.2. See the example on Fig. X1.1, Fig. X1.2, and Fig. X1.3.



Pressure Measurement System Calibration

ACME Pressure Monitor - Serial No. 12345 04/01/93

Calibration equation:

Output = (1.00012 x Applied Pressure) + 0.32500

or:

Applied Pressure = (Output - 0.32500) / 1.00012

FIG. X1.1 Example Least-Squares Line Plot

Pressure Measurement System Calibration

For Systems Based On Electronic Pressure Transducers

Electronic Transducer / Pressure Meter

Manufacture : ACME Pressure Monitor

Serial Number : 12345

Pressure Range : 0 to 1500 (lbf/in^2)

Calibrated Pressure Range : 0 to 1500 (lbf/in^2)

Full Scale Output - FSO : 1500 (lbf/in^2)

Units

Pressure

(Pa)(kPa)(MPa)(mm Hg)(bar)

[✓ lbf/in^2])(lbf/ft^2)(in Hg)(in H2O)

Electrical

(mV) (V) (mA)

Calibration type

Gage [✓] Absolute [ ]

Differential [ ] Other [ ]

Performed By : A. Tester

Date : 4/1/93

Computed By : B. A. Compu II

Date : 4/1/93

Checked By : I. M. Checker

Date : 4/1/93

Calibration Data

Applied Pressure / Vacuum (lbf/in^2) (1)	Theoretical Output (lbf/in^2) (2)	Output - Trial 1: Pressure Increasing (lbf/in^2) (3)	Output - Trial 1: Pressure Decreasing (lbf/in^2) (4)	Output - Trial 2: Pressure Increasing (lbf/in^2) (5)	Output - Trial 2: Pressure Decreasing (lbf/in^2) (6)
(a) 0.0	0.0	0.0	0.0	0.0	0.0
(b) 299.7	299.7	300.2	300.4	300.3	300.4
(c) 599.4	599.4	599.9	600.0	600.0	600.1
(d) 899.1	899.1	899.4	899.5	899.5	899.6
(e) 1198.8	1198.8	1199.2	1199.3	1199.3	1199.3
(f) 1498.5	1498.5	1498.7	—	1498.8	—
(g)					
(h)					
(i)					
(j)					

Ambient Conditions

Start of Calibration

Temperature 70 °C [✓ °F]

Atmospheric Pressure 28.5 (in Hg)

Relative humidity 53 %

End of Calibration

Temperature 70 °C [✓ °F]

Atmospheric Pressure 28.5 (in Hg)

Relative humidity 55 %

Visual Inspection

Finish	[✓] ok	[ ] not ok
Nameplate	[✓] ok	[ ] not ok
Electrical Connection	[✓] ok	[ ] not ok
Pressure Connection	[✓] ok	[ ] not ok

Error Computations

Theoretical Output (2)	Linearity Error (2) - (3)	Linearity Error (2) - (4)	Linearity Error (2) - (5)	Linearity Error (2) - (6)	Hysteresis Error (3) - (4)	Hysteresis Error (5) - (6)	Repeatability Error (3) - (5)	Repeatability Error (4) - (6)
(a) 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(b) 299.7	−0.5	−0.7	−0.6	−0.7	−0.2	−0.1	−0.1	0.0
(c) 599.4	−0.5	−0.6	−0.6	−0.7	−0.1	−0.1	−0.1	−0.1
(d) 899.1	−0.3	−0.4	−0.4	−0.5	−0.1	−0.1	−0.1	−0.1
(e) 1198.8	−0.4	−0.5	−0.5	−0.5	−0.1	0.0	−0.1	0.0
(f) 1498.5	−0.2	—	−0.3	—	—	—	−0.1	—
(g)								
(h)								
(i)								
(j)								
Maximum Error				−0.7	−0.2		−0.1	

	Linearity		Hysteresis		Repeatability	
Accuracy (using maximum error) - (% FSO)	−0.05%	Accept : [✓]	−0.01 %	Accept : [✓]	−0.01 %	Accept : [✓]
Required accuracy - (% FSO)	± 0.05 %	Reject : [ ]	±0.05 %	Reject : [ ]	±0.05 %	Reject : [ ]

Pressure Standard

Manufacture : ABC Gauge Co.

Serial Number : A135B

Type	Mechanism style		Medium
Primary [✓]	Dead Weight [✓]	Manometer [ ]	Hydraulic [ ]
Secondary [ ]	Digital Pressure Meter [ ]	Pressure Test Gage [ ]	Pneumatic [✓]

Range : 0 to 2000 (lbf/in^2)

Accuracy : ± 0.02 % of reading

Results

FIG. X1.2 Example Calibration Data Sheet

PRESSURE MEASUREMENT SYSTEM CALIBRATION

ACME PRESSURE MONITOR - SERIAL NO. 12345 04 / 01 / 93

	TRIAL 1		TRIAL 2	
	OUTPUT		OUTPUT	
APPLIED PRESSURE (lbf / in^2) (2)	PRESSURE INCREASING (lbf / in^2) (3)	PRESSURE DECREASING (lbf / in^2) (4)	PRESSURE INCREASING (lbf / in^2) (5)	PRESSURE DECREASING (lbf / in^2) (6)
0.0	0.0	0.0	0.0	0.0
299.7	300.2	300.4	300.3	300.4
599.4	599.9	600.0	600.0	600.1
899.1	899.4	899.5	899.5	899.6
1198.8	1199.2	1199.3	1199.3	1199.3
1498.5	1498.7	-	1498.8	-

Regression analysis: $y = mx + b$

Number of observations = 22

Correlation coefficient = 1.00000

Slope, m = 1.00012 (lbf / in^2) / (lbf / in^2)

Intercept, b = 0.32500 (lbf / in^2)

Calibration equation : Output = (1.00012 x Applied pressure) + 0.32500

FIG. X1.3 Calculations for Least-Squares Line

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