Metrology Society of Australia
MSA Test Method 1 - 2008
Calibration of Pressure Calibrators, Indicators and Transducers

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1. Introduction:

This Test Method describes test procedures for the calibration of pressure calibrators, indicators, transducers and transmitters. It is intended that this document be referenced instead of in-house developed test methods.

This document has been prepared in consultation with members of the Metrology Society of Australia (MSA) – Pressure Measurement Technical Group representing people from manufacturers, laboratories and users of calibration services. It is to be used in conjunction with ISO/IEC 17025, General and Supplementary Requirements for Calibration Laboratories.

2. Scope:

This document deals with electro-mechanical pressure instruments for measuring gauge pressure, absolute pressure, vacuum or differential pressure which have a digital readout or an electrical output, but does not include mechanical pressure gauges with a dial and pointer indication. Refer instead to MSA Test Method 2, Calibration of Pressure Gauges. The pressure instruments are divided here into three main types. The test procedures will vary slightly for each of them.

Pressure Calibrators – with a digital readout, usually manufactured with an accuracy tolerance less than 0.1% of reading and designed for calibrating other instruments. They often have other electrical measurement or output ranges and may include a pressure controlling mechanism.

Pressure Indicators – with a digital readout, usually manufactured with an accuracy tolerance greater than 0.1% of full scale and designed often for direct measurement. Can include transducers with a digital output. Eg RS232.

Pressure Transducers – usually manufactured with an accuracy greater than 0.1% of full scale and designed often for direct measurement but with an electrical output (including transmitters). Eg. 0/10 V or 4/20 mA.

3. Desired Outcomes of the Calibration:

3.1 To Reduce Reading Errors:

While focus on the quality of measurement and rigorous uncertainty estimation is important. The aim is to avoid problems for the user due to inaccurate measurements. Adjustments that will reduce reading errors should be done where possible, unless the user requests otherwise.

3.2 Measurement Quality:

To provide measurement results of high quality and low uncertainty. The user of the instrument should be able to realise the instrument's best performance if desired.

3.3 Traceability:

To provide traceability to national standards of pressure.

3.4 Inform:

To alert the user to any aspects of the instrument's performance that may impact on its subsequent use.

4. Accuracy Specifications:

Reference shall be made to the manufacturer's one year accuracy specification for each tested range unless the user agrees to conformance to another accuracy specification.
Manufacturer's accuracy specifications can often be obtained from the manufacturer's web site, user manuals, product brochures or from the user. The accuracy specification represents the maximum allowance for non-linearity, hysteresis, repeatability, and drift over the year, assuming regular use of an available zero function for gauge and differential instruments.

Compliance to the accuracy specification requires the measurement results to fall within the specification limits by an amount at least equivalent to the measurement uncertainty.

5. Reference Equipment:

Reference equipment shall be certified by an accredited laboratory and be traceable to national or international standards.
The uncertainty of the reference instrument at the 95% confidence level shall be less than or equal to half the test instrument accuracy specification at any point tested.

6. Calibration Test Procedure:

6.1 Test Design:

The test shall be designed to operate the instrument with a repeatable set of test conditions in such a manner that the measured performance is a good indication of the best performance possible.
Where possible the test should emulate the conditions of use and be guided by what the user requires. Without knowledge of the way the user wants the test instrument to be tested, the following procedure shall be followed.

6.2 Test Environment:

The instrument shall be brought into an environment conditioned to a temperature between 18 and 22 ^{0}C (preferably 20 ^{0}C) and controlled to within $\pm 1^0$C or better for calibrators during testing and to within $\pm 2^0$C or better for other instruments. A minimum of 4 hours for calibrators and 1 hour for indicators and transducers shall be provided before testing occurs to allow most instruments to come to thermal equilibrium near room temperature. Extra allowance should be made if the instrument was initially at a very different temperature (eg during transportation where the temperature goes above 30°C or below 10°C) or if it has a very high thermal mass. Be guided by the manufacturer's literature on warm up.

Take care to avoid the following:

- Draughty air, especially for low pressure instruments and where dead weight testers are used.
- Sun light and sources of thermal radiation.
- Stacking instruments
- Electro-magnetic effects from nearby equipment.
- Electrical output leads near PC's, power cables and transformers.
- Vibrations.

6.3 Instrument Set Up:

6.3.1 Faults:

The instrument shall be powered up and a check made that it operates. Visually check the instrument for faults, such as display or power supply problems, hand pump, valving or connection faults. Inform the user of faults that will affect the results and that may require repair. Seek approval for repair work before proceeding.

6.3.2 Settings:

It is possible to optimise some calibrators for testing. Select the highest possible resolution and set any damping to a minimum. The resolution can sometimes be affected by the selection of a particular pressure unit.
Select an SI unit for testing the device and try to avoid manometric units such as metres of water to avoid confusion through conversion factors unless specifically requested.

6.3.3 Power Supply and Warm Up:

Instruments can be affected by low battery level or if a charger is in use. Before testing the re-chargeable batteries should be recharged or the dry cells should be replaced if low in charge. Testing shall not continue with display of a low battery signal. The manufacturer's specified warm up time, if one is available is useful to obtain. Without specific instruction, a minimum of 60 minutes for calibrators, and a minimum of 15 minutes for indicators and transducers shall be provided. Some instruments need to have the automatic time off setting disabled to enable warm up and testing. A test should also be performed to determine if the output is affected by operating the unit with or without the charger connected.

6.4 Test Fluid:

The test fluid used must be compatible with the instrument. Some instruments are marked with warnings if a particular fluid is required. Some, for example require clean dry gas due to the electronics in the transducer being unprotected or to avoid inaccuracies with liquid use. Some have small internal tubing which can easily become blocked with liquid contamination. If poor repeatability is observed, then clearing these tubes may be necessary to obtain best performance. Be guided by the manufacturer's specifications. Generally pressures ranges less than 1000 kPa or with resolutions less than 0.1 kPa are better tested on a dry gas due to improved sensitivity and reduced head errors and therefore reduced measurement uncertainty. Inspection of the pressure port often provides a guide as to what fluid has been in use.
If the instrument is marked "Oil Free" or "For Oxygen" then it must be treated so.
The laboratory shall have procedures for the safe handling of instruments for use on oxygen where contamination with oil can present substantial risk to the end user.

6.5 Head Consideration:

The pressure head P_h, of fluid is given by:

$$P_h = (\rho_F - \rho_A)gh$$

Where ρ_F is the test fluid density, ρ_A is the air density, g is gravity and h is the difference in height between the reference level of the test instrument and that of the standard. The term is often significant with low pressure instruments tested on liquid as well as high pressure tests performed on gas.
For gases, the density is dependent upon the pressure. The fluid density is;

$$\rho_F = \frac{G_c P}{(273.15 + t)}$$

where G_c is 3.48 x 10^{-3} for air and 3.37 x 10^{-3} for nitrogen in $kg.m^{-3}.K.Pa^{-1}$. P is the absolute gas pressure in Pa. t is the gas temperature in °C
A useful approximation to the formulae above for gauge pressure testing with nitrogen at 20°C, where h is in mm and P is the test pressure is:

$$P_h = 1.12x10^{-07}hP$$

Pressures generated by a reference instrument need to be evaluated at the test instrument chosen reference level. Commonly, this level is chosen to be the connection port of the test instrument.
If the chosen reference level is known to affect the measurement results, the chosen level shall be indicated on the report.

6.6. Exercising and Zeroing:

Before testing, the instrument shall be pressurised to full scale to exercise the transducer and check for leaks. Exercising will often cause a change in the zero reading and the instrument shall be re-zeroed after providing sufficient settling time if zeroing is possible.
It is recommended that low range instruments being tested with a fluid be disconnected at the instrument reference level to ensure there are no small head pressures on the inlet before zeroing.
Connecting instruments in a horizontal orientation where possible helps to avoid zero errors.
It may be necessary to zero the device during testing. It is desirable to give measurement results unaffected by zero drift so as to report the instrument's best performance.

6.7 Repeatability Evaluation:

Repeatability shall be determined for the purpose of measurement uncertainty evaluation and ensuring good stability. Repeatability shall be determined for a low and a high pressure point with additional points being necessary with changes in resolution. For pressure points in between, repeatability can be interpolated from the maximum and minimum points tested.
A simplified method described here provides an estimation which is appropriate to instruments for which a satisfactory evaluation has to be performed in a time efficient manner.
This method requires the instrument to be pressurised to the test point 3 times and the readings recorded. Zero should not be adjusted during the assessment. The estimate for the standard uncertainty u_{Rep} may then be taken as:

u_{Rep} = (Max reading – Min reading)/√3.

If the instrument analysis warrants a better estimate, then a greater sample size and the usual statistical evaluation may be used.
If non-repeatability would cause the instrument to not comply with the accuracy specification, then agreement from the user shall be obtained to proceed with testing.

6.8 Settling Time:

A suitable settling time shall be selected before testing begins.
Some instruments require more than 30 seconds before a test point reading has stabilised. This makes calibration very slow and raises the question about what settling time is reasonable.
It is reasonable to set some limit to the settling time and increase the uncertainty allowance for repeatability to cover any further settling of the output.
A common settling time for pressure indicators would be 10 to 15 seconds and for calibrators, which tend to have a finer resolution, 20 to 30 seconds would be more common. A reasonable limit for settling time is 40 seconds unless the user advises otherwise.

6.9. Test Point Selection:

As a minimum, calibrators shall be tested at 10 points including zero and indicators or transducers tested at 7 points. Test points are to be spread over the range and shall include zero and a point within 5% of full scale. Tests should be done in SI units where possible.
Agreement from the user is required if not all of the pressure ranges can be tested or a range can be partially tested only.
Differential gauge pressure ranges may be tested with the negative port open to atmosphere.

6.9.1 Vacuum Ranges:
Many instruments have a vacuum or compound capability. Points shall be selected in the vacuum range if the instrument is designed with this capability unless agreed to by the user. A separate test for the vacuum side of a compound range is only necessary when requested. The greater the pressure range the less points required on vacuum. As it is not easy to develop a full vacuum, it is acceptable to apply something less such as -95 kPa unless requested otherwise.

6.9.2 Absolute Ranges:
Testing of an instrument with an absolute pressure range requires either a reference instrument with absolute pressure capability or a gauge pressure reference used in conjunction with a certified barometer.

6.9.3 Analogue Instruments:
Analogue instruments, not based on microprocessor technology, may have selectable units which represent separately adjustable ranges. In this case a full test should be performed on the SI unit and at least a single point at full scale should be included for each other unit. If the user agrees to having only one specific range tested, the instrument shall be labelled accordingly. Eg "kPa range tested only". Conversely, instruments that have digital conversion factors stored in memory require only one range to be tested.

6.9.4 Electrical Ranges:
Many pressure calibrators have electrical measurement and output ranges. Agreement from the user shall be obtained to determine if the electrical ranges should be tested or not. The method for testing of electrical ranges is not covered within this document.

6.10 Test Point Sequence:

6.10.1 As Found Test:
One set of readings shall be taken as found, on rising pressure only, and before adjustment. Assessment shall be made as to whether adjustments to calibration shall occur. See the section on adjustment below.

6.10.2 As Left Test:
Two sets of readings shall be taken with rising and falling pressures. Vacuum test points on a compound gauge range may be tested after the positive pressure test.

6.11 'On Nominal' or 'Off Nominal':

Observation of each test point may be performed in several ways. 'Off nominal' testing means applying an arbitrary pressure near the test point and taking a test instrument reading. 'On Nominal' testing means the applied pressure is adjusted to be very close to the test point value (within $1/8^{th}$ of the resolution) and a test instrument reading taken. A third method is possible where the applied pressure is adjusted until the test instrument achieves the desired value and the reference instrument value is read. The method chosen will effect the measurement uncertainty.

7. Adjustment:

The instrument shall be adjusted if results do not conform to the accuracy specification in section 4, where possible and unless requested by the user otherwise.
Care shall be taken to follow manufacturer's instructions for adjustment.
Some instruments cannot be adjusted, or can only be adjusted with specific cabling and software. In this instance, agreement from the user shall be obtained as to whether the report can be issued stating compliance to a lesser specification or whether repair or adjustment elsewhere is required.
If compliance to a lesser specification, other than the manufacturer's one year accuracy specification is accepted by the user, a label shall be applied to the instrument indicating the lesser accuracy level achieved.

8. Estimation of Uncertainty:

Uncertainty estimation is a subject on its own covered well in other texts. Reference can be made to *Assessment of Uncertainties of Measurement* by RR Cook available from NATA or to the ISO *Guide to the expression of uncertainty in measurement*.
However the following principal terms to include in an uncertainty estimation are:

- **Repeatability:**

Covered above, u_{Rep} = (Max-Min)/√3

- **Resolution:**

Assume rectangular distribution half range = ½ resolution. u_{Res} = 0.5Resolution/√3. Doubled if testing 'off nominal', and the corrections are rounded to the nearest instrument resolution only.

- **Reference Instrument:**

Depends on the reference used. Refer to the certificate for the reference standard and consider environmental conditions such as gravity for dead weight testers and temperature.

- **Reference Instrument Drift:**

The calibration of the standard used is an 'on the day' analysis and consideration needs to be given to the expected drift since the last calibration. The manufacturer may specify a drift expectation and history may provide further information. An estimate is better than no allowance at all.

- **Head:**

Head uncertainty relates to uncertainty in reference height, gravity and fluid density. Height measurement is usually the principal element.

- **Electrical Output Test Instruments:**

Uncertainty in the measurement of electrical outputs can be obtained from the electrical instrument calibration certificates. Allowance may be required for using it at a temperature different from that when it was certified and for drift.

9. Reporting the Results:

The report shall include the following:

1. Test report number.
2. Serial numbers.
3. Description of the instrument.
4. Table of results including the nominal pressure of each test point, as found readings, as left mean readings and corrections for both rising and falling pressure and the measurement uncertainty. Average readings for both rising and falling may be reported for barometers. See notes for transducers below.
5. Measurement uncertainty shall be reported at the 95% confidence level in the same units as the results. It shall be reported at each test point for calibrators. A calculation at full scale only may be reported for other instruments.
6. The accuracy specification calculated at each pressure in the same units as the results is recommended.
7. A statement detailing whether the instrument was adjusted and how.
8. A statement of compliance to this test method. The compliance statement shall include a description of the accuracy specification to which it conforms.
9. The reference instrument identification and report number.
10. Room temperature and tolerance.
11. Position of the instrument during testing.
12. Settling time
13. Warm up time
14. Test medium
15. Reference level chosen for testing
16. Conversion factors used if not SI units.
17. Any other information important to the performance of the instrument.

9.1 Table of results – Transducers

The results table for transducers with electrical outputs shall be similar to indicators, except that the readings and uncertainty are expressed in units of electrical output. Eg Volts or milliamps. Readings alone without the corrections may be reported for raw transducers with a voltage output. Some users may require an equation that defines a best straight line fit or even a more complex curve fit by regression. The results table shall still be provided unless requested by the user otherwise.

10 Removable Modules:

Many calibrators have externally connected pressure modules. It is important to make a distinction with these remote modules. Some require calibration data to be stored in the base instrument and therefore the calibration is only valid when the module is used with a particular base unit. In this case the base unit shall be identified on the report.

However, some modules hold the calibration data in the module itself and their output is independent of the base unit. The report in this case does not need to reference the base unit calibrator.

11 In Conclusion:

Some calibrators have re-calibration dates programmed in. Where possible update them if it is known what re-calibration interval the user requires.

A calibration label shall be applied identifying the laboratory, the report number and date of test. If an external pressure module is related to a base unit as described above, a label should be applied to both items.

After disconnecting the instrument, drain test fluid from pressure ports.

12. Summary of Key Points:

The following is a summary of the key points for this test procedure and is intended to provide a useful quick reference only. For a more complete understanding, refer to the wording given in the detail above. It may be helpful for determining compliance during a laboratory quality system assessment.

Main instrument types:

Calibrators: designed mainly for calibrating other instruments
Indicators: designed mainly for direct measurement
Transducers: designed mainly for direct measurement but with an electrical output

Accuracy specification:

Reference shall be made to the manufacturer's one year accuracy specification for each tested range unless the user agrees to conformance to another accuracy specification.

Reference Equipment:

The uncertainty of the reference instrument at the 95% confidence level shall be less than or equal to half the test instrument accuracy specification at any point tested.

Test Environment:

18 to 23 ^{0}C (preferably 20 ^{0}C) and controlled to within $\pm 1^0$C.
Condition calibrators for 4 hours and indicators and transducers for 1 hour.

Instrument Set Up:

Test in SI units where possible
Powered up warm up shall be a minimum of 60 minutes for calibrators and 15 minutes for indicators and transducers.
Exercise instrument to full scale and back.
Zeroing to be done before and during testing with the instrument vented to atmosphere.

Test Points:

Calibrators to be tested at a minimum of 10 points including zero.
Indicators and transducers to be tested at a minimum of 7 points including zero.
Points spread over the range to within 5% of full scale including vacuum, absolute and electrical ranges unless agreed to by the user otherwise.
Two sets of readings shall be taken with rising and falling pressures.
An "As Found" test before calibration adjustment is to be done.

Adjustment:

Compliance to the accuracy specification requires the measurement results to fall within the specification limits by an amount at least equivalent to the measurement uncertainty.
Agreement from the user is required if compliance to a lesser accuracy specification can be met only.

Uncertainty Estimation:

Measurement uncertainty calculations are required with a contribution from resolution, repeatability, reference instrument uncertainty and drift and reference instrument electrical output uncertainty when relevant.

Reporting The Results:

Refer to 9. Reporting the results, above.

Labels:

A calibration label is to be applied and a label indicating any limitations to the ranges tested or the accuracy achieved.

13 Definitions:

Absolute pressure: Pressure that is relative to full vacuum such as that measured by a barometer. (see gauge pressure)

Corrections: The value to be added to a test instrument reading to indicate the true pressure. Correction = (reference pressure – average reading). They are opposite in sign to reading errors.

Differential Pressure: Pressure that is measured relatively between the high and low side of a sensor.

Full scale: The top end of a measured pressure range.

Gauge pressure: Pressure that is relative to atmospheric pressure (see absolute pressure)

Hysteresis: The difference in readings obtained from a test on falling instead of rising pressures.

Manufacturer's Accuracy Specification: Refers to the limits that the manufacturer expects the corrections applied to pressure readings (reading errors) to fall within, usually over a limited time period, such as one year. This usually includes effects from non-linearity, repeatability, hysteresis and drift.

Non-linearity: The degree to which pressure readings deviate away from a straight line between bottom and full scale.

Range: The span between bottom and full scale of measured values.

Reading error: The difference between the indicated reading and the true pressure. They are opposite in sign to corrections.

Resolution: The minimum increment on a digital display, sometimes referred to as a count.

Repeatability: The variation in readings at a given test point observed during the time of testing.

Drift: The variation in readings at a given test point observed over a period of time after calibration.

Settling time: The time period required after a stable pressure is applied to an instrument before the output has stabilised well enough for a reading to be taken.