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# Vacuum gauges — Calibration by direct comparison with a reference gauge

*Manomètres — Étalonnage par comparaison directe avec un manomètre de référence*

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# Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 3567 was prepared by Technical Committee ISO/TC 112, *Vacuum technology*.

This first edition of ISO 3567 cancels and replaces ISO/TS 3567:2005, of which it constitutes a technical revision.

# Introduction

The purpose of this International Standard is to establish the physical, technical and metrological conditions necessary for adequately disseminating the pressure scale in the vacuum regime by calibration with a reference gauge. It is assumed that the user will be familiar with the general procedures of vacuum generation and measurement in the vacuum ranges considered.

# Vacuum gauges — Calibration by direct comparison with a reference gauge

## 1 Scope

This International Standard specifies the physical, technical and metrological conditions to be fulfilled when calibrations of vacuum gauges are performed by direct comparison with a reference gauge. From the conditions described, the design of an apparatus that can perform vacuum gauge calibrations in an adequate manner can be deduced.

The vacuum gauges to be calibrated can be of any kind. Many types of gauges consist of several parts. Typically, these are: gauge head, cable, operational device and signal read out. This entire set is considered as the unit that has to be calibrated. Whereas, if only the gauge head (i.e. the part of the vacuum gauge directly exposed to the vacuum) is calibrated, all set-ups and conditions would have to be recorded such that the user of the calibrated gauge head would be able to perform the measurements in the same manner as during the calibration.

The reference gauge is either a calibrated gauge, traceable to a vacuum primary or national standard (normal case), with a calibration certificate according to ISO/IEC 17025, or an absolute measuring instrument (rare case), traceable to the SI units and to which a measurement uncertainty can be attributed.

This International Standard does not give guidance on how to treat special types of vacuum gauges, be they reference standards or units under calibration; it is intended that such guidance be given in other International Standards.

The pressure range for calibrations treated in this International Standard depends on the realized design of the calibration apparatus and on the type of reference gauge. The range varies in its limits from $10^{-6}$ Pa to 110 kPa.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

**3.1**
**primary standard**
measurement standard established using a primary reference measurement procedure

[SOURCE: ISO/IEC Guide 99:2007, 5.4, modified]

**3.2**
**national standard**
measurement standard recognized by national authority to serve in a state or economy as the basis for assigning quantity values to other measurement standards for the kind of quantity concerned

[SOURCE: ISO/IEC Guide 99:2007, 5.3]

**3.3**
**reference standard**
measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organization or at a given location

[SOURCE: ISO/IEC Guide 99:2007, 5.6]

NOTE In this International Standard, it is synonymous with *reference gauge*.

**3.4**
**vacuum gauge**
instrument for measuring gas or vapour pressure that is less than the prevailing atmospheric pressure

[SOURCE: ISO 3529-3:1981, 3.1.2]

NOTE 1 Some types of vacuum gauges commonly in use do not measure a pressure directly, but measure some other physical quantity which, under specific conditions, is related to pressure.

NOTE 2 For terms and definitions of the various vacuum gauges in use, see ISO 3529-3.

**3.5**
**gauge head**
part of the gauge which contains the pressure-sensitive element and which is directly connected to the vacuum system

NOTE A gauge head comprising its operational device is usually called a *transmitter*.

[SOURCE: ISO 3529-3:1981, 3.1.2.1, modified]

**3.6**
**operational device**
part of a vacuum gauge that operates the gauge head and/or delivers the signal related to pressure

**3.7**
**unit under calibration**
**UUC**
vacuum gauge to be calibrated

**3.8**
**entrance flange**
flange by which the unit under calibration or the reference gauge is connected to the calibration chamber

**3.9**
**calibration chamber**
vacuum chamber that serves as a common vacuum medium for the reference gauge and unit under calibration

**3.10**
**entrance mouth**
opening in the calibration chamber which leads to a unit under calibration, reference gauge or any other part of the calibration system

**3.11**
**calibration gas**
gas species or mixture that is used to change the pressure in the calibration chamber

**3.12**
**sorption**
taking up of a gas or vapour by a solid or liquid

**3.13**
**desorption**
liberation of gases or vapours sorbed by a material

**3.14**
**outgassing rate**
rate at which molecules and atoms desorb from a material exposed to a vacuum

**3.15**
**total pressure**
$p$
sum of pressures of all the components of a gaseous mixture

NOTE A vacuum is usually measured as the absolute pressure of gas prevalent in an enclosed chamber, expressed in pascals (Pa) or millibars (mbar): 1 mbar = 100 Pa; 1 bar = 0,1 MPa = $10^5$ Pa; 1 MPa = 1 N/mm$^2$.

**3.16**
**residual pressure**
lowest pressure that can be reached in the calibration chamber, typically after 24 h of pumping

NOTE The residual pressure depends, among others things, on the bake-out condition of the calibration chamber.

**3.17**
**base pressure**
pressure in the calibration chamber that exists either before gas is admitted into the calibration chamber for calibration, or later, after the gas inlet valve has been turned off for some time

NOTE The base pressure can be higher than the residual pressure, but cannot be lower.

## 4 Symbols and abbreviated terms

| | |
|---|---|
| $D$ | diameter of cylinder, expressed in millimetres (mm) |
| $e$ | error of reading |
| $p$ | total vacuum pressure, expressed in pascals (Pa) or millibar (mbar) |
| $p_0$ | base pressure, expressed in pascals (Pa) or millibar (mbar) |
| $p_{cal}$ | calibration pressure, expressed in pascals (Pa) or millibar (mbar) |
| $p_{ind}$ | indicated pressure, expressed in pascals (Pa) or millibar (mbar) |
| $p_{res}$ | residual pressure, expressed in pascals (Pa) or millibar (mbar) |
| $Q_{out}$ | outgassing rate, expressed in pascal litres per second (Pa · L/s), pascal cubic metres per second (Pa · m$^3$/s) or millibar litres per second (mbar · L/s) |
| $q_{v,eff}$ | effective volume flow rate of the pump — effective litres per second (L/s) or cubic metres per second (m$^3$/s) volume flow rate into pump |
| $S$ | sensitivity (coefficient) (Pa$^{-1}$) |
| $u$ | standard uncertainty |
| $U$ | expanded uncertainty |
| CF | correction factor |
| UUC | unit under calibration |

## 5 General principle

The UUC is connected to the same calibration chamber as the reference gauge.

Calibration of a vacuum gauge — the UUC — by comparison with a reference gauge is done by exposing the entrance flange of the UUC and that of the reference gauge to the same density and velocity distribution of calibration gas molecules. The same density and velocity distribution of these molecules means the same pressure at the two locations, but not vice versa. Since there are many types of vacuum gauge that do not measure pressure — but instead, for example, gas density or the impingement rate of gas molecules — the above requisite is both necessary and more stringent than only calling for equal pressures at the two entrance flanges.

The gas density (pressure) in the calibration chamber can be varied and the gauge readings of the UUC compared with the pressures indicated by the reference gauge.

From this general principle, the requirements (see Clause 6) for the design of the calibration apparatus are deduced.

## 6 Requirements

### 6.1 Design of calibration chamber

The chamber shall be designed to ensure that the distribution of gas in the measuring volume is sufficiently uniform in space and stable in time.

In addition, the material of the calibration chamber shall be chosen such that the residual pressure, $p_{\mathrm{res}}$, determined by the effective pumping speed, $q_{\mathrm{v,eff}}$ (effective volume flow rate into pump), and the total outgassing rate in the calibration chamber, $Q_{\mathrm{out}}$ (absence of leaks), is low enough to perform the calibrations, as expressed by Formula (1) (see also 6.3):

$$p_{\mathrm{res}} = \frac{Q_{\mathrm{out}}}{q_{\mathrm{v,eff}}} \tag{1}$$

In detail, the calibration chamber shall be designed and operated as follows. However, design criteria a) to e) may be disregarded when the minimum pressures to be realized in the vacuum chamber are larger than 100 Pa and only static pressures (see 7.1) are established. Independent of pressure, criteria b) to d) may be disregarded when only static pressures are established.

a) The calibration chamber shall have a volume of at least 20 times the total volume of all the gauges and associated pipe work connecting the chamber and the gauges (e.g. elbows shall be considered as part of the gauge volume).

b) The shape of the calibration chamber (see Figure 1) shall be cylinder-symmetrical to at least one axis. A sphere is ideal, but two symmetrical domes, each a part of a sphere and attached to one another, or cylinders, are equally possible. Where a cylinder is used, its overall length shall be within one and two times its diameter, and domed ends are recommended.

c) The centre of the cross-sectional area of the pumping outlet and the gas inlet (if applicable) shall lie on the same cylindrical axis of symmetry of the calibration chamber. The gas inlet may be positioned between the pump outlet and pump system (see 6.3), in which case there is no need to have the gas inlet on the axis of symmetry.

d) All entrance mouths and their respective flanges to which either the UUCs or the reference gauges are to be connected shall be on a common equatorial plane, perpendicular to the cylindrical axis of symmetry chosen for the pumping outlet.

   Where a cylinder is used, it is recommended that this equatorial plane separate the cylinder into two halves of equal length. Where a cylinder with a length of (3/2)$D$ in relation to its diameter is used (suitable

for pump speed measurements), the gauges may be placed at one third of the length ($D$/2) above the bottom flange.

e) Temperature differences between arbitrary points across the calibration chamber shall be less than 1 K. Points closer than 5 cm from the entrance mouth to a heated vacuum gauge head (e.g. ionization gauge) may be disregarded.

f) The spatial [see e)] mean temperature of the calibration chamber shall be (23 ± 3) °C during calibration, while the mean temperature should not change by more than 1 K.

If the design criteria a) to e) are not fulfilled, the possible correction owing to unequal molecular density and velocity distribution at the entrance flanges of the reference gauge and UUC (see 7.3) shall be measured and the uncertainty of the correction term estimated.

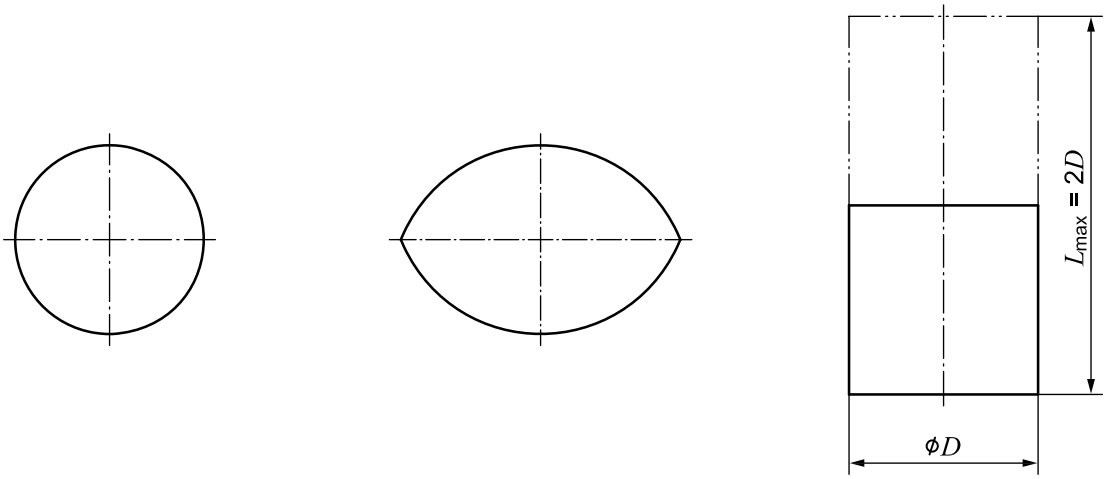



**Figure 1 — Examples of possible calibration chamber shapes**

## 6.2 Plumbing of gauges to calibration chamber

**6.2.1** In order to minimize unbalanced molecular (pressure) distribution from sorption, gauge pumping and outgassing etc., the tubing connecting the calibration chamber and the gauges shall be as short as possible and shall have a diameter of at least the open area of the entrance flange of the gauge. In cases where the UUC or the reference gauge imposes a significant heat load [see 6.1 e)] on the calibration chamber, the tube length may be increased to reduce thermal conductance.

**6.2.2** Care shall be taken to ensure that the simultaneous operation of the reference gauges and UUC does not result in any significant mutual influence of their respective readings in steady operation. An influence on the order of the uncertainty of the base pressure is acceptable.

NOTE The mutual influence can be checked by observing the reading of a gauge when switching another gauge off and on.

**6.2.3** No significant ambient air flow cooling or heating of the UUC or reference gauge shall be present. A protective cover could be necessary.

## 6.3 Vacuum and gas inlet system

**6.3.1** The base pressure, $p_0$, in the calibration chamber shall be less than one tenth of the lowest pressure, $p_{cal}$, realized for a calibration, as determined by the reference gauge. The vacuum pump and its tubing to the calibration chamber shall be sized accordingly.

Lowest uncertainties due to the base pressure effect can be achieved if the value of the base pressure is below the resolution limit of the UUC and/or reference gauge. It is strongly recommended that a base pressure lower than the resolution limit of the UUC and/or reference gauge be established, if this resolution limit is greater than or equal to 1 mPa.

NOTE Where a low residual pressure and base pressure in the calibration chamber is required, it could be necessary to provide heating to the chamber to accelerate the removal of sorbed gases or vapours from the chamber walls.

**6.3.2** A throughput pumping system that discharges the pumped gas continuously into the atmosphere is recommended. If no throughput pump is used, it shall be ensured that the effective pumping speed remains stable throughout the calibration procedure.

**6.3.3** Any significant back streaming of oil into the vacuum chamber shall be excluded.

**6.3.4** The base pressure and residual pressure should be monitored using an extra gauge.

**6.3.5** The gas inlet may be provided either by admitting gas into the tubing between the calibration chamber and pump system or separately on the axis of symmetry of the calibration chamber. If the latter option is chosen, the inlet shall be designed such that each gas molecule coming from the gas inlet has to make at least one hit with a wall of the calibration chamber or a baffle before it can enter the entrance mouth of the UUC or reference gauge.

NOTE A valve reducing the effective pumping speed could help to reduce gas consumption. A corresponding rise of residual pressure has to be considered as a trade-off.

## 6.4 Calibration gas

For the calibration gas, nitrogen 99,9 % pure or better is recommended. Other gases of the same purity, even well-defined gas mixtures, may also be used for calibration. At pressures below 100 Pa the gases shall not stick significantly to the surface (sorption). Vapours shall not condense under calibration chamber conditions.

If the gas purity is relevant for the uncertainty budget, the possibility has to be considered that the reservoir gas purity might not be present in the calibration chamber, due to desorbing gases between the gas reservoir and (including) the calibration chamber.

## 6.5 Thermometers and ambient conditions

Thermometers with an overall expanded uncertainty ($k = 2$) of less than or equal to 0,5 K shall be used. The temperature of the calibration chamber shall be measured by means of thermometers in good thermal contact with the chamber. The ambient temperature around the UUC and the reference gauge shall be determined by means of thermometers suitably positioned and protected from radiation.

The ambient temperature shall be (23 ± 3) °C and should not change by more than 1 K during the calibration. If a change of more than 1 K is unavoidable, special care shall be taken so that the uncertainty contributions due to temperature drift are correctly evaluated.

The ambient condition addressed by 6.2.3 also has to be considered. In addition, the ambient air flow and/or thermal radiation in the calibration room shall be such that the temperature condition according to 6.1 e) can be fulfilled.

### 6.6 Reference gauge

The reference gauge shall be either a calibrated gauge (normal case), traceable to a vacuum primary or national standard, or an absolute measuring instrument (rare case), traceable to SI units and to which a measurement uncertainty can be attributed. In the first case, the reference gauge shall have a calibration certificate according to ISO/IEC 17025:2005, 5.10.

It is recommended that the reference gauge have a lower or equal resolution limit and a lower or equal measurement uncertainty than the UUC, when either would be calibrated at a primary standard.

The reference gauge should be calibrated, in accordance with this International Standard, for the type of gas that will be used for the calibration. If the reading of the reference gauge depends on the gas species, it shall be calibrated for the type of gas that will be used for the calibration.

## 7 Calibration

### 7.1 Procedure

**7.1.1** When operating the gauges, follow the manufacturer's instructions closely, unless otherwise specified (for example by the customer). If, in later use, a set routine is followed when taking a pressure reading, repeat this routine for the calibration. Always use the reference gauge according to the manufacturer's instructions and/or the information given in the calibration certificate.

**7.1.2** After complete installation of the UUC and reference gauge(s), and when the whole calibration system has been readied, pump down the calibration chamber. A bake-out could be necessary in order to reach a base pressure consistent with the requirement of 6.3.1.

**7.1.3** The gauges should be switched on when the pressure in the calibration chamber has reached the operating conditions of the respective gauge (after bake-out during cool-down phase). Allow the gauges and their operational device to warm up and stabilize. The stabilization time depends on the type of gauges and the uncertainty required.

Certain types of gauges will require "degassing" at certain pressures, which should be done during this stabilization period.

If there are gauge heads kept under vacuum by an isolation valve, this shall be opened only when the pressure in the calibration chamber has dropped below the expected value of pressure in the gauge head and/or full scale of the gauge.

**7.1.4** Complete the pump-down until a base pressure $p_0$ consistent with 6.3.1 has been reached. Before starting the calibration, record the base pressure and all zero readings of the gauges. This record could become obsolete in the case of calibrations made in a decreasing sequence and, because of this, calibration should be performed in a rising pressure sequence. If calibrations in decreasing sequence are also to be performed, note that the base pressure and its uncertainty could play a significant role.

Measure base pressure $p_0$ in the same condition of the vacuum system as during the calibration, e.g. the valves corresponding to the UUC and reference gauge in the open position.

**7.1.5** Establish the first calibration pressure either statically or by stationary equilibrium, as follows.

a) **Static method**

*Static* means that the valve to the pump system is closed and gas is admitted into the calibration chamber until the required pressure value is reached (for target pressure points, see Annex B).

1) Make another record of the base pressure $p_0$ after closing the valve to the pump system and before gas admission if different from that recorded according to 7.1.4.

2) If the pressure rise due to outgassing and desorption in the calibration chamber exceeds one tenth of the lowest calibration pressure 5 min after closing the valve, use the stationary equilibrium method instead.

3) The target value of pressure shall be hit within a certain range agreed with the customer. If no range has been specified, the realized pressure value shall be within ± 5 % of the agreed target pressure value.

b) **Stationary equilibrium method**

The valve to the pump system remains fully open or is partly closed. Gas is admitted into the calibration chamber until the required value is reached.

1) The target value of pressure shall be hit within a certain range agreed with the customer. If no range has been specified, the realized pressure value shall be within ± 5 % of the agreed target pressure value.

2) The pressure indicated by the gauges shall be stable over time so that it does not change by more than 0,5 % within 2,5 min. As an example, if the specified stability in time cannot be reached, the records can be taken in the following order: reference gauge, then UUC, then reference gauge, with about equal time intervals between. For the comparison with the UUC, the mean of the two reference gauge readings shall be taken. Especially at pressures below 1 mPa it may be difficult to observe a change of 0,5 % within 2,5 min, since the resolution of the gauge is too poor. In this case, it is sufficient to obtain a pressure stability where the change of pressure is below the resolution of the UUC.

3) Make another record of the base pressure $p_0$ before gas admission, when the valve to the pump system has been partly closed, if different from that recorded according to 7.1.4.

In both methods a) and b), the records of the reference gauge and UUC shall be taken at coincident times or as closely spaced in time as possible.

**7.1.6** The following information shall be recorded both before and during calibration:

— identification of the reference gauge(s) and UUCs, including the type of gauge, manufacturer and the serial number of the gauge heads and their relevant operational devices;

— date of calibration;

— ambient temperature;

— temperature of the calibration chamber;

— calibration gas;

— base pressures [see 7.1.5, a) 1) and b) 3)];

— details of the gauge settings, including the settings of the relevant operational devices;

— relevant details of the installation of the gauges (orientation of the gauge head, position on the calibration chamber and, as appropriate, the type of tube used for the gauge head, type of flange, etc.);

— name of the calibration engineer;

— table of results, including reference gauge readings and UUC readings.

If only the gauge head is calibrated, it shall be ensured that all set-ups and conditions are recorded such that the user of the calibrated gauge head will be able to perform the measurements in the same manner as during the calibration.

**7.1.7** After completion of the measurements at the final target pressure, pump the system down to check that no leak, significant adsorption, contamination of the walls or failure of the pump system, etc. occurred during the calibration. The system is required to reach the base pressure or 1/1 000 of the final calibration pressure

within 10 min, if this can be expected from the pumping speed and the total chamber volume. If, unexpectedly, the system needs longer than 10 min, the calibration system shall be reconditioned (e.g. leak test, pump test, purging, bake-out) and the calibration repeated.

## 7.2 Evaluation of measurements

From the measurement records, the following shall be generated for each calibration pressure list:

— calibration pressure as mean of reference gauge readings corrected according to the calibration certificate and according to other necessary corrections for the conditions during the calibration;

— indicated UUC readings (and possibly mean values from repeat measurements) corrected by zero readings, etc.;

— quantity to be determined by the calibration (error of reading, correction factor, sensitivity coefficient, for example, in volts/pascals, etc.);

— the uncertainty of the measurand at the time of calibration determined in accordance with 7.3.

Sometimes, a single measurand as a mean over a larger pressure range can be determined such as the effective accommodation coefficient of a spinning rotor gauge, ion gauge constant or ion gauge sensitivity.

## 7.3 Measurement uncertainty

The standard uncertainty, $u$, of the quantity determined by the calibration, e.g. error of reading, correction factor, sensitivity coefficient, shall be calculated in accordance with ISO/IEC Guide 98-3. The following uncertainty contributions can be significant.

a) Uncertainty of base pressure due to inaccuracy of measurement and drift in time.

NOTE For the static method, the drift in time can be estimated from the pressure rise after closing the valve to the pump. For the stationary equilibrium method, the drift in time can be estimated by observing the base pressure before gas admission over 30 min in the same position of the pump valve as during the first calibration point.

b) Uncertainty of calibration pressure due to non-equal density and velocity distribution of gas molecules at the entrance flange of UUC and reference gauge(s). If the design criteria of 6.1 to 6.3 are met, the standard uncertainty (relative) of these effects may be estimated to $u = 0{,}3$ % for pressures $p_{\mathrm{cal}}$ below 100 Pa and $u = 0{,}1$ % for pressures $p_{\mathrm{cal}}$ greater than or equal to 100 Pa, even if the design criteria of 6.1 are not met.

NOTE This uncertainty includes non-equal density and velocity distribution of gas molecules due to several effects: specific flow conditions by rarefied gas flow through the vacuum system — including the effect of a partly closed (and therefore not cylinder-symmetrical to the chamber axis) valve to the pump, see Note to 6.3.5 — temperature gradients and drifts in time, sorption, desorption, outgassing, pumping speed of gauges, and small leaks. For the last five of these effects, it is assumed that all is state of the art: meaning that all components are cleaned and baked out according to the level of required base pressure, the pumping speed of the gauge is less than 1/100 of the effective pumping speed, $S_{\mathrm{eff}}$, on the chamber, and leak testing has been performed. Lower uncertainties may be estimated, if the laboratory has carefully evaluated the effects mentioned above (e.g. comparing measurements at different ports by changing the gauges, measurement of spatial temperature distribution and temporal temperature drift).

c) Uncertainty of calibration pressure due to drift in time.

NOTE This can be estimated by observing the reading of the reference gauge in a time interval typical of that needed to perform the measurements at a given target pressure.

d) Measurement uncertainty of the reference gauge. In addition to the uncertainty value given in the calibration certificate, the following can also contribute to this uncertainty: long-term instability of the gauge, its resolution scatter, scatter of indicated values, inaccuracy of offset measurement, offset drift, effect of ambient conditions, different temperatures of the calibration chamber at use as the reference standard and when it was calibrated, temperature drift and possible mutual influences of the gauges.

e) Uncertainty of indicated reading of the UUC owing to resolution scatter, scatter of indicated values, inaccuracy of offset measurement, offset drift, drift of temperature during calibration and possible mutual influences of the gauges.

f) Uncertainty owing to impurities in the calibration gas.

g) Repeatability of the measurements.

It is common practice to state in the calibration certificate the expanded uncertainty $U = ku$, where $k = 2$. For a normal distribution, this is equal to a 95 % confidence interval.

## 8 Calibration certificate

The calibration certificate shall be generated according to ISO 17025. In addition, especially for vacuum gauge calibrations according to this International Standard, the following shall be included in the certification:

— identification of the reference gauge(s) and UUCs, including type of gauge, manufacturer and serial number for gauge heads and their relevant operational devices;

— ambient temperature, including its variation and uncertainty during the calibration;

— temperature of the calibration chamber, including its variation and uncertainty during the calibration;

— calibration gas;

— base pressures [see 7.1.5, a) 1) and b) 3)];

— details of the gauge settings, including the settings of the relevant operational devices;

— relevant details of the installation of the gauges (orientation of the gauge head, position on the calibration chamber and, as appropriate, the type of tube used for the gauge head, type of flange, etc.);

— relevant details of environmental conditions (atmospheric pressure, humidity, etc.);

— the mathematical model of the quantity determined by the calibration.

If a single quantity is not determined by the calibration, the information given in Table 1 shall be generated from the measurement records for each calibration pressure list.

It is strongly recommended that an equation be provided by which it is possible to calculate the true pressure from the gauge output and the data given in the certificate.

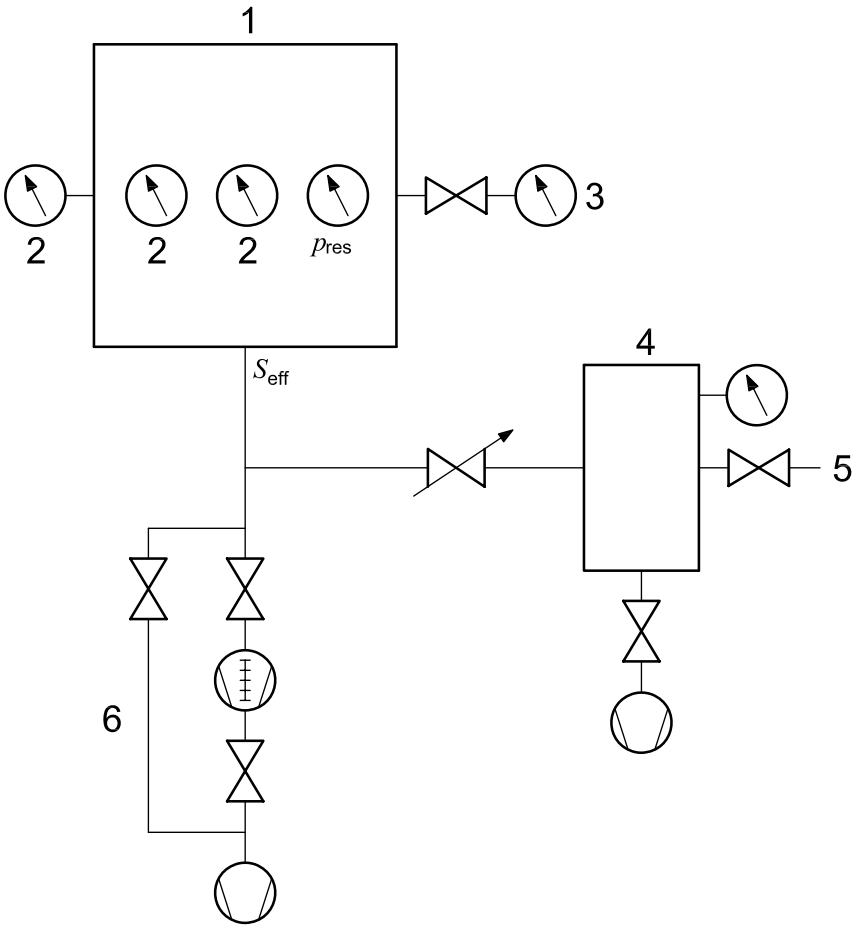
**Table 1 — Example table of results for calibration certificate**

| $p_{cal}$ | $p_{ind}$ **etc.** | $e$ **or** CF **or** $S$ **etc.** | $U\ (k = 2)$ |
|---|---|---|---|
| The calibration pressure as the mean of reference gauge readings corrected according to the calibration certificate and according to other necessary corrections for the conditions during the calibration. | The indicated UUC readings (eventually mean values of repeat measurements) corrected for offset, etc. | The quantity to be determined by the calibration (e.g. error of reading $e$, correction factor CF, sensitivity coefficients in volts/pascals). | The expanded (absolute or relative) uncertainty of the quantity in the previous column at the time of calibration determined in accordance with 7.3. |
| If, for simplicity, it is agreed by the customer and the calibration laboratory that only one uncertainty value is to be given in a whole range, this value shall represent the largest possible uncertainty value in the range. | | | |

Sometimes, a single quantity as a mean over a larger pressure range is determined (e.g. effective accommodation coefficient of a spinning rotor gauge, ion gauge coefficient, ion gauge sensitivity coefficient). In this case, the uncertainty of this quantity shall be given.

# Annex A
(informative)

## Example of possible calibration system set-up




**Key**

1 calibration chamber
2 UUC
3 reference gauge
4 buffer volume[a]
5 from gas reservoir
6 by-pass

[a] For better stability of pressure in front of the leak valve and therefore constant flow rate.

**Figure A.1 — Calibration installation**

# Annex B
(informative)

# Problems in practice

## B.1 Zero settings

Some types of gauge have a zero setting. The gauge reading should be set at zero in accordance with the manufacturer's instructions when the calibration chamber is at base pressure. If the base pressure is above the resolution limit of the UUC or reference gauge, this has to be considered.

The zero setting should be re-checked when other settings (range, gain, etc.) are changed and at the end of the calibration.

NOTE Where the calibration range covers more than a decade it could prove necessary to check the zero setting again when the decade is changed during the calibration.

Some types of gauges have an atmosphere setting. The gauge should be set when the chamber and/or the gauge head is at atmospheric pressure, in accordance with the manufacturer's instructions.

## B.2 Calibration gas purity

The gas purity in the calibration chamber can be checked by use of a residual gas analyser. This should be switched off during calibration.

## B.3 Target pressure points

In general, the target pressure points are agreed upon by the customer and the calibration laboratory. If nothing has been specified, at least three target points are considered for an UUC; normally three target points per decade of reading — spaced about equally on a logarithmic scale (e.g. 1,2 and 5 or 2, 5, and 9) — are measured.

## B.4 Repeat measurements

In general, repeat measurements are a compromise between accuracy and the costs of calibration, and are therefore subject to agreement between customer and calibration laboratory.

A measurement can only be considered as a repeat measurement when the calibration system has returned to the base pressure in between individual measurements [either between individual complete series or between individual calibration (target) points].

If only one measurement has been made, the calibration laboratory needs a procedure for estimating the repeatability of the calibration result. For example, it is possible to perform several repeat calibrations once for the same type of gauges as the UUC, estimate a standard uncertainty from the scatter (repeatability) of results from these measurements, and apply this standard uncertainty to calculate the total uncertainty for the result of the single measurement.

## B.5 Achieving a low base pressure

To achieve a stable low residual pressure in the calibration chamber, it could be necessary to bake the chamber first.

It is recommended that dry nitrogen be used to vent the chamber to atmospheric pressure.

When not in use, the calibration chamber should be kept under vacuum.

## B.6 Contamination

A contaminated gauge head will contaminate the calibration equipment. Careful cleaning and drying of the gauge head is recommended before installation on the calibration system.

If cleaning is performed, the customer has to be informed before, since the calibration constant may be altered by this procedure.

Some vacuum gauge types have hot surfaces. In a dirty system, the hot surface could be oxidized or oil vapours could decompose to form a crust. This crust will alter the characteristics of the gauge and can make calibration difficult.

## B.7 Temperature effects

In order to consider the temperature effects of the gauges, refer to the manufacturer's manual, textbooks, or Reference [6] in the Bibliography.

## B.8 Vibrational effects

Some vacuum gauges may be sensitive to vibration. Check the manufacturer's manual to see if the conditions are met by the calibration system. Damping elements between vibrating pumps and the calibration chamber can help to reduce the vibration amplitudes sufficiently.

## B.9 Gauge handling and mutual interferences

Low-pressure, high-accuracy gauges (where the upper limit of the measuring range is below atmospheric pressure) can change their calibration value if they are let up to atmosphere. These gauges should be fitted with an isolation valve, which is closed whenever the gauge pressure exceeds the upper limit.

When installing vacuum gauges with strong permanent magnets [e.g. cold-cathode (Penning-type) gauge heads], care should be taken to avoid any magnetic interaction with other gauges (especially an ion gauge or another cold cathode gauge).

In the case of ionization gauges, a direct path from charged particles from one gauge to the other is to be avoided.

## B.10 Reference gauges

The use of at least two independent reference gauges is recommended in order to detect any malfunction of the reference gauges by comparing their measurement results. If the results are not consistent within their measurement uncertainties, the reference gauges should be recalibrated. Gauge heads using the same operational device are not completely independent. It could be sufficient to use gauges with overlapping measuring ranges and compare their measurement results in the common range.

## B.11 Recalibration cycles

As a rough guideline, reference gauges used on clean vacuum systems should be calibrated every 12 months. Under harsher conditions, the recalibration period should be reduced to 6 months or even shorter periods.

When sufficient data on the long term stability are available, the calibration period for reference gauges of high accuracy, kept permanently pumped on the calibration apparatus, can be extended to 2 years (with increased uncertainty due to long-term instability).

For more information on selecting the optimum intervening period between calibrations, see ISO 10012-1[4].

# Bibliography

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