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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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An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

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

Introduction

The purpose of this Technical Specification 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 Technical Specification lays down 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 can be deduced how to design an apparatus that can perform vacuum gauge calibrations in an adequate manner.

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 whole set is considered as the unit that has to be calibrated. Whereas, if only the gauge head (i.e. that 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 absolutely measuring instrument (rare case), traceable to the SI units and to which a measurement uncertainty can be attributed.

This Technical Specification does not give guidance on how to treat special types of vacuum gauges, be they reference standards or units under calibration, and it is intended that such guidance be given in other technical specifications.

The pressure range for calibrations treated in this Technical Specification depends on the realised 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 17025:2005, *General requirements for the competence of testing and calibration laboratories*

ISO/IEC Guide to the expression of uncertainty in measurement (GUM), BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1st edition 1993, corrected and reprinted in 1995

3 Terms and definitions

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

3.1
primary standard
standard designated or widely acknowledged as having the highest metrological qualities and whose value is accepted without reference to other standards of the same quantity in the same range

3.2
national standard
standard recognized by a national decision to serve, in a country, as a basis for assigning values to other standards of the quantity concerned

3.3
reference standard
standard generally having the highest metrological quality available at a given location or in a given organization, from which measurements made there are derived

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

NOTE 1 Some types of vacuum gauge 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 a vacuum gauge exposed to the vacuum whose pressure has to be measured

NOTE Gauge heads that include their operational device are usually called *transmitters*.

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
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 has been valved 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)

S_{eff} effective pumping speed — effective litres per second (L/s) or cubic metres per second (m^3/s) volume flow rate into pump

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.

The idea of the calibration of a vacuum gauge (UUC) by comparison with a reference gauge is to expose the entrance flange of the UUC and entrance flange of the reference gauge to the same density and velocity distribution of the calibration gas molecules. The same density and velocity distribution of the calibration gas molecules also 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 can be compared with the pressures indicated by the reference gauge.

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

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_{res}, determined by the effective pumping speed, S_{eff} (effective volume flow rate into pump), and the total outgassing rate in the calibration chamber, q_{out} (absence of leaks), is low enough to perform the calibrations. See Equation (1) and 6.3.

$$p_{\text{res}} = \frac{q_{\text{out}}}{S_{\text{eff}}} \qquad (1)$$

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 realised in the vacuum chamber are larger than 100 Pa and static pressures only (see 7.1) are established.

a) The calibration chamber shall have a volume of at least twenty times the total volume of all the gauges and associated plumbing connected to it.

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 on 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 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.

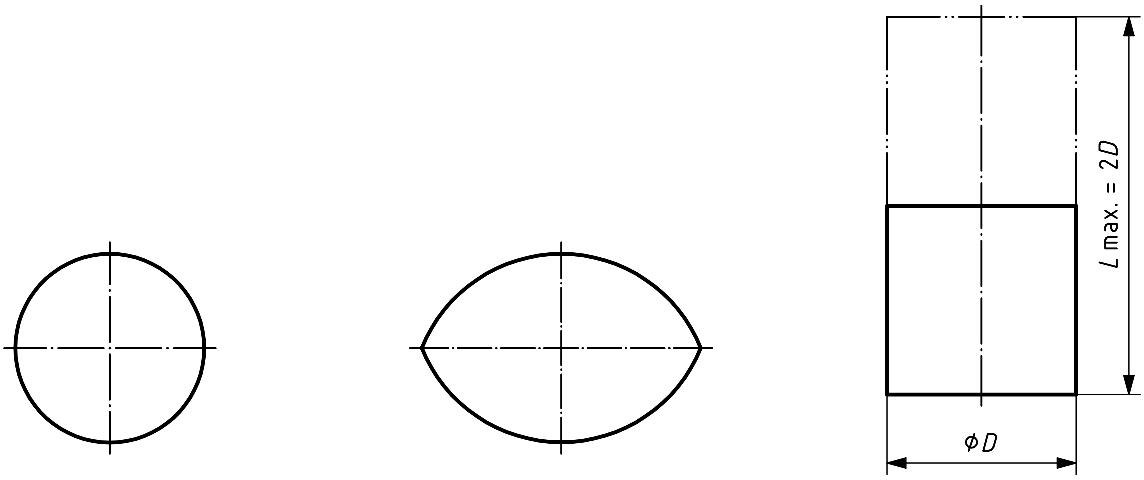
d) All entrance mouths and their respective flanges to which either the UUCs or the reference gauges are to be connected shall be on a common equatorial plane, perpendicular to the cylindrical axis of symmetry chosen for the pumping outlet.

   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 $3/2D$ in relation to its diameter is used (suitable for pump speed measurements), the gauges may be placed at 1/3rd 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 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 calibrations, 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.



a) b) c)

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.

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}, realised 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 equal to or higher than 1 mPa.

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