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Vacuum technology — Vacuum gauges — Specifications, calibration and measurement uncertainties for Pirani gauges

Technique du vide — Manomètres à vide — Spécifications, étalonnage et incertitudes de mesure pour les jauges Pirani

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Foreword

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

Introduction

ISO 3567 and ISO 27893 are basic standards with no specific guidelines of a special type of vacuum gauge and are generally applicable. Detailed guidance for a specific gauge is intended to be given in separate technical specifications for the calibration of special types of gauges.

This document complements ISO 3567 and ISO 27893 when characterizing or calibrating Pirani gauges or using them as reference gauges.

Pirani gauges are widely used to measure pressures in the medium vacuum up to atmospheric pressure. The relevant parameters, calibration guidelines and uncertainties for the dissemination of the pressure scale and measurement of low and medium vacuum pressures by a Pirani gauge are described in this document.

Vacuum technology — Vacuum gauges — Specifications, calibration and measurement uncertainties for Pirani gauges

1 Scope

This document identifies parameters of Pirani gauges, their calibration procedure, and describes measurement uncertainties to be considered when operating these gauges.

This document applies to Pirani vacuum gauges operating over a pressure range of 0,01 Pa to 150 kPa.

This document complements ISO 3567 and ISO 27893 when calibrating Pirani gauges and using them as reference standards.

In addition, this document defines procedures to characterize Pirani gauges for response time and hysteresis.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 3567:2011, *Vacuum gauges — Calibration by direct comparison with a reference gauge*

ISO 27893, *Vacuum technology — Vacuum gauges — Evaluation of the uncertainties of results of calibrations by direct comparison with a reference gauge*

ISO/IEC 17025, *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.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 Definitions of components

3.1.1
thermal conductivity gauge
vacuum gauge in which the pressure is determined in relation to the transfer of thermal energy between the surfaces of two fixed elements maintained at different temperatures

Note 1 to entry: This gauge is based on the thermal conductivity of a gas being pressure dependent.

[SOURCE: ISO 3529-3:2014, 2.4.2.2, modified — Example has been deleted.]

3.1.2
Pirani gauge
thermal conductivity gauge in which the heated element is part of a Wheatstone bridge that supplies the energy to the element and by which the electrical resistance or the dissipated power of the element is being measured

Note 1 to entry: Some types of Pirani gauges have an extended upper limit of measurement range by using the heat convection inside the tube. This type is often called convection-enhanced Pirani gauge.

Note 2 to entry: See Annex A.

[SOURCE: ISO 3529-3:2014, 2.4.2.2.2, modified — Note 1 to entry has been replaced.]

3.2 Definitions of physical parameters

3.2.1
internal volume
volume of the gauge that is exposed to the vacuum system where it is attached to, counted from the connecting flange plane

3.2.2
thermal accommodation coefficient
ratio of the absolute temperature of the molecule after a hit with the heated element in a Pirani gauge and the absolute temperature of the heated element

3.2.3
long-term instability

quantity characterizing the typical change of relative measurement error $e = \frac{\Delta p}{p} = \frac{p_{\mathrm{UUC}} - p}{p}$ over time where the period needs to be specified

Note 1 to entry: Measurement errors to determine long-term instability of this gauge type are taken for nitrogen at a pressure of $p = (10 \pm 1)$ Pa (nitrogen) after a specified period. This quantity δ_t shall be a relative quantity and may be determined in two ways:

a) as the relative standard deviation of measurement error e_i obtained from at least three calibrations each being separated by the specified period

$$\delta_t = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(e_i - \overline{e}\right)^2}$$

with n being the number of calibrations i, and

$$\overline{e} = \frac{1}{n}\sum_{i=1}^{n} e_i$$

b) as the mean of absolute (non-negative) changes of measurement error Δp_i between recalibrations separated by the specified period

$$\delta_t = \frac{\sum_{i=1}^{n-1}\left|e_{i+1} - e_i\right|}{n-1}$$

and n as described above

Note 2 to entry: The formula in a) is recommended when the measurement error does not show a significant drift but random variations, and the formula in b) when the measurement error shows a systematic and monotonic drift.

Note 3 to entry: If the output signal of the gauge is not pressure (e.g. voltage or current), this signal shall be converted to pressure based on the manufacturer's specification, before the measurement error is calculated.

Note 4 to entry: Long term instability can be determined by recalibrations with a more accurate gauge or a primary standard. This often requires a transport which itself can lead to an instability of the calibrated value. For this reason, it is not reasonable to assume a linear relationship of instability with time (e.g. δ_t for a period of 2 years is not 2 times δ_t for a period of 1 year).

Note 5 to entry: If not specified otherwise, it is recommended to determine δ_t over a period of 1 year. This is usually a reasonable compromise between costs and influence of transport on the one hand and a possible drift and lowest possible measurement uncertainty on the other hand.

EXAMPLE If δ_t was determined to 6,5 % according to the formula in b), where the period of recalibration was 1 year, the report will be "δ_t = 6,5 % for a period of one year".

3.2.4
response time
τ
time that elapses when the Pirani gauge is exposed to a sudden pressure change of nitrogen between 1 kPa to 100 Pa (up or down to be specified), until the Pirani shows 90 % of the pressure change difference

Note 1 to entry: See Figure 1.

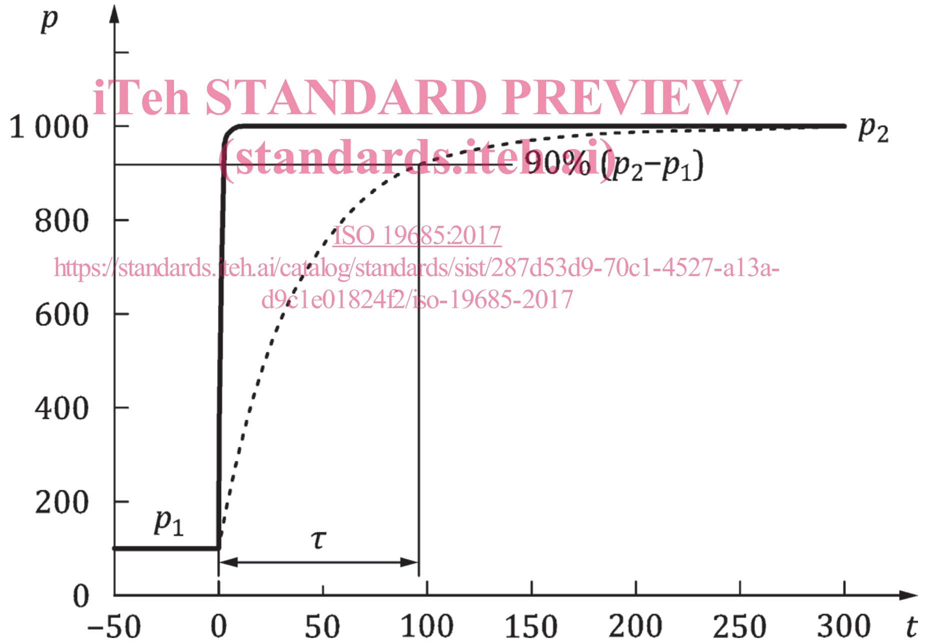

Figure 1 — Illustration to explain definition of response time τ

3.2.5
hysteresis
relative difference of indication of a Pirani gauge when exposed to the same pressure in a rising and decreasing sequence

4 Symbols and abbreviated terms

Symbol	Designation	Unit
e	Relative measurement error	1 or in %
p	Pressure, traceable to SI	Pa
Δp	Measurement error (measured pressure p_{UUC} minus reference pressure p)	Pa
p_{UUC}	Measured pressure by unit under calibration (UUC)	Pa
δ_t	Long-term instability as defined in 3.2.3	1 or in %
τ	Response time	ms
UUC	Unit under calibration	

5 Principle of Pirani gauge

The Pirani gauge is one type of a thermal conductivity vacuum gauge. In the Pirani gauge, gas molecules conduct heat away from a heated element to a surrounding wall that is usually at room temperature (see Figure A.1). In a certain pressure range, the heat taken away by the molecules is proportional to molecular density and hence pressure. The corresponding temperature change of the heated element, which is often a filament, causes a change in resistance. The resistance is part of a Wheatstone type bridge circuit that supplies the energy to the element and by which the electrical resistance or the dissipated power of the element is being measured. The bridge circuit may keep constant either the temperature of the heated element, or the heating power, or voltage or current. The linear measurement range is highest, when the temperature is kept constant. More detailed information is given in Reference [1].

The heat conductivity is strongly dependent on the gas species. It depends on the degrees of freedom of the molecule, its mass and the thermal accommodation coefficient of the molecule with the surface of the material of the heated element[2]. Therefore, also the signal measured by the Pirani gauge is strongly gas dependent. The thermal accommodation coefficient is significantly affected by impurities on the surface, which makes the Pirani gauges sensitive to contamination by vacuum processes. Coverage of the heated element caused by such processes also changes the lower measurement limit and, due to the change of filament diameter, the sensitivity.

At higher pressures, in the viscous flow regime, the heat conductivity through the gas becomes pressure independent. The lighter the gas molecule, the lower the pressure this occurs. This limits the useful measuring range of the Pirani gauge. Convection is still causing some heat dissipation from the heated element, but the sensitivity of the Pirani gauge is very small in this regime.

The lower measurement limit and resolution of the Pirani gauge is determined by the heat conductivity to the mechanical support structure of the heated element and radiation. For this reason, ambient temperature changes do affect the sensitivity of the gauge significantly below 10^{-1} Pa.

The wall temperature of the gauge head may also be influenced by the heated elements itself. At higher pressures > 1 kPa, more heating power for the heated element is needed to keep the temperature constant than at lower pressures and, as a consequence, the surrounding wall is heated up. This again reduces the heating power and may cause hysteresis.

NOTE In recent years, another type of thermal conductivity gauge was commercialized. The heated element (filament) is not operated at a constant temperature, but is cyclically heated up to a defined temperature threshold by an increasing voltage ramp[3]. The time to heat the element up to the threshold is pressure dependent. In terms of measurement uncertainties, this type of thermal conductivity gauge is similar as the Pirani gauge and this standard can be applied to these type of gauges as well.

6 Specifications for Pirani gauge

6.1 General

The following features and specifications are required, in order to enable users of the gauges to estimate the measurement uncertainty and/or to disseminate the pressure scale.

6.2 Measuring principle

It shall be specified how the heat dissipation in the gauge head is measured (continuously, pulsed, convection-enhanced).

6.3 Type of output

The type of output (analogue, digital) and the unit (or units) of indicated signal (e.g. voltage, current, pressure) shall be specified. If the indicated signal output is not given in pressure units, the conversion of the signal unit to pressure given in the manufacturer's manual shall be used.

6.4 Range of output and output display resolution

The range of output and the corresponding resolution for digital output shall be specified.

6.5 Measurement range and full scale

The measurement pressure range and full scale for nitrogen shall be specified. The measurement range generally depends on the measurement uncertainty. The measurement range for a given measurement uncertainty for nitrogen of a newly produced gauge shall be specified by the manufacturer. The measurement range is the range between minimum and maximum pressure where the reading of the gauge is within the defined measurement uncertainty limits. If the pressure range is not given in pascal, the value in pascal shall be given in addition.

6.6 Expected measurement uncertainty

The expected measurement uncertainty in the measurement range as given in 6.5 for the type of device as can be achieved by any individual device of this type shall be specified. It should be given as relative quantity of reading in %. It shall be specified how the gauge has to be adjusted to meet the measurement uncertainties. If an adjustment at a certain pressure has to be made, the gas species has to be specified.

NOTE The expected measurement uncertainty of type of device includes the measurement error. In the case of the Pirani gauge, this is mainly caused by the nonlinearity of the gauge.

The measurement uncertainty of an individual gauge is given by a calibration certificate (see 8.6). The measurement uncertainty of an individual gauge may be significantly smaller than the expected measurement uncertainty for the same type of device, since it does not need to include the measurement error.

6.7 Material exposed to gas

The material of the gauge head exposed to operating gas shall be specified.

6.8 Connecting flange

The type and size of the flange of the gauge head shall be specified.

