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Vacuum technology — Vacuum gauges — Specifications, calibration and measurement uncertainties for spinning rotor gauges

Technique du vide — Manomètres à vide — Spécifications, étalonnage et incertitudes de mesure pour manomètres à rotor

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Foreword

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document complements ISO 3567 and ISO 27893 when characterizing, calibrating or using spinning rotor gauges (SRGs) as reference gauges.

SRGs are used to measure pressure in the high and medium vacuum. For the dissemination of the pressure scale and measurement of high and medium vacuum pressures by this gauge, the relevant parameters, calibration guidelines and uncertainties should be given, which are described in this document.

Vacuum technology — Vacuum gauges — Specifications, calibration and measurement uncertainties for spinning rotor gauges

1 Scope

This document defines terms related to spinning rotor gauges (SRGs), specifies the necessary parameters for SRGs, details their calibration procedure and describes which measurement uncertainties to consider when operating these gauges. This document is applicable to pressure up to 2 Pa.

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 3529-1, *Vacuum technology — Vocabulary — Part 1: General terms*

ISO 3529-3, *Vacuum technology — Vocabulary — Part 3: Total and partial pressure vacuum gauges*

ISO 3567, *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 Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

IEC 60050-300, *International Electrotechnical Vocabulary - Electrical and electronic measurements and measuring instruments - Part 311: General terms relating to measurements - Part 312: General terms relating to electrical measurements - Part 313: Types of electrical measuring instruments - Part 314: Specific terms according to the type of instrument*

3 Terms and definitions

For the purposes of this document the terms and definitions given in ISO 3529-1, ISO 3529-3, ISO 3567, ISO 27893, ISO/IEC Guide 98-3, ISO/IEC Guide 99, IEC 60050-300 and the following apply.

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

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

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

3.1 Terms related to components

3.1.1
rotor
rotating element, which is magnetically suspended in vacuum

Note 1 to entry: As rotor any magnetic element can be used. For practical reasons, however, only spheres as rotating element are considered in this document. A spherical rotor may exhibit a dipole magnetic field, but also higher orders.

3.1.2
thimble
finger
tube in which the *rotor* (3.1.1) is magnetically suspended

Note 1 to entry: Material of the thimble is preferably non-magnetic stainless steel.

Note 2 to entry: Materials with high electrical conductivity are not suitable.

3.1.3
suspension head
measuring head
sensing head
device to be mounted on the *thimble* (3.1.2) that suspends, stabilizes, and accelerates the *rotor* (3.1.1) under vacuum and detects the signal synchronous with the magnetic signal from the rotor

3.1.4
controller
<of spinning rotor gauge> device which controls the *suspension head* (3.1.3), indicates the deceleration rate of the *rotor* (3.1.1) and the corresponding pressure with the help of setup parameters such as rotor diameter, rotor density, gas species, temperature and effective accommodation factor

3.1.5
flange assembly
projecting flat rim with *thimble* (3.1.2), mounting rails, clamp and retaining screw for *suspension head* (3.1.3), to be mounted to the vacuum vessel

3.2 Terms related to physical parameters

3.2.1
accommodation factor
σ
parameter which under molecular conditions is proportional to the tangential-momentum accommodation coefficient of gas molecules hitting the rotor surface

Note 1 to entry: If the rotor is an ideal sphere, the surface is perfectly smooth and the values of diameter and density of the rotor are exactly known, the accommodation factor is equal to the tangential-momentum accommodation coefficient. This is provided that the mean-free path of the gas molecules is much greater than the diameter of the thimble. In this case, the accommodation factor is lower or equal to 1. In the case of rough rotors, however, σ might be higher than 1. σ is determined by calibration for an individual rotor, taking into account surface roughness.

Note 2 to entry: In some literature, accommodation coefficient is used to represent the same meaning as the accommodation factor defined herein.

Note 3 to entry: At pressures below 30 mPa, the accommodation factor is independent of pressure.

3.2.2
effective accommodation factor
σ_{eff}
parameter which is obtained by calibration of a *rotor* (3.1.1) while only nominal values of diameter and density of the rotor are known

3.2.3
residual drag
RD
α_{RD}
part of the deceleration rate of the *rotor* (3.1.1) that does not depend on vacuum pressure

Note 1 to entry: Residual drag is caused by eddy currents in the sphere itself, the thimble and suspension head generated by the rotating magnetic field of the rotor and changes of the temperature of the rotor. The latter contribution stems from the so-called Pirouette effect related with changes in the diameter of the sphere due to thermal expansion. Sometimes, this effect is not included in the residual drag but treated separately. This can be beneficial if the coefficient of thermal expansion of the rotor and the temperature drift $\Delta T/\Delta t$ of the rotor are known. The latter is normally not known and for this reason the residual drag is defined here including the effects due to changes in temperature.

Note 2 to entry: The residual drag often depends on the frequency of the rotor.

Note 3 to entry: Residual drag shall be determined prior to measurement at a pressure below the lower measuring limit of the SRG.

3.2.4
offset
p_{offs}
equivalent pressure of the gas species under concern of the *residual drag* (3.2.3)

3.2.5
deceleration rate
DCR
absolute value of the change of rotor frequency in a time interval divided by the average rotor frequency in this interval

Note 1 to entry: The deceleration rate of the rotor is due to residual drag and impinging gas molecules.

3.2.6
sampling time
sampling interval
time interval at which the value of *deceleration rate* (3.2.5) is determined

Note 1 to entry: Appropriate sampling time setting depends on the required measurement accuracy and the measurand.

Note 2 to entry: Sampling time is also the time interval between consecutive spinning rotor gauge signal outputs.

3.2.7
warm-up period
duration between the instant after which the rotor is suspended and accelerated and the instant when the spinning rotor gauge (SRG) indicates pressures within the specified measurement uncertainties

Note 1 to entry: The warm-up period of the SRG is typically 3 h to 6 h, depending on the specified measurement uncertainties.

3.2.8
internal volume
space enclosed in the *thimble* (3.1.2) up to the sealing plane of the connecting port

3.2.9
measurement range
coverage of pressures in which a specified expected measurement uncertainty is satisfied

3.2.11
long-term instability
relative quantity characterizing the typical change of the *accommodation factor* (3.2.1) over time where the period needs to be specified

4 Symbols and abbreviated terms

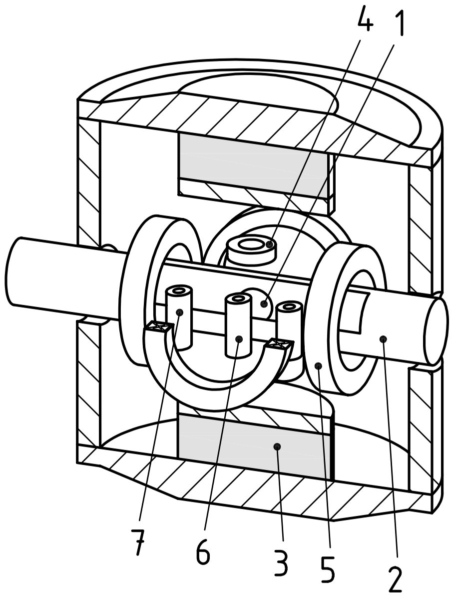
Symbol	Designation	Unit
d	diameter of spherical rotor	m
DCR	deceleration rate	s^{-1}
f	frequency	Hz
p	pressure	Pa
p_{offs}	offset	Pa
α_{RD}	residual drag	s^{-1}
T	temperature	K
t	time	s
ρ	density of rotor	kg/m^3
σ	accommodation factor	1
σ_{eff}	effective accommodation factor	1
$\sigma_{eff,0}$	effective accommodation factor for $p \to 0$	1
ω	angular velocity	rad s^{-1}
$\bar{c}$	mean thermal velocity of gas molecules	m s^{-1}
SRG	spinning rotor gauge	
UUC	unit under calibration	

5 Principle of a spinning rotor gauge

A spinning rotor gauge (SRG) is a device in which gas molecules decelerate the rotational angular velocity, ω, of a magnetically suspended rotor in vacuum (see Figure 1). The gas molecules hit the rotor surface, remain there for some time and leave the surface again with the additional tangential velocity of the rotor surface. This additional momentum of the gas molecule is gained from the momentum of the rotor thereby reducing the rotor frequency. For a spherical rotor, the pressure can be calculated by Formula (1)[8]. For practical use, Formula (2) can be applied.

$$p = \frac{\pi \bar{c} \rho d}{20\sigma} \left(-\frac{\dot{\omega}}{\omega} - \alpha_{RD} \right) \tag{1}$$

$$p = \frac{\pi \bar{c} \rho d}{20\sigma} \left(-\frac{\dot{\omega}}{\omega} \right) - p_{offs} \tag{2}$$



Key

1 rotor
2 thimble
3 permanent magnet with soft iron pole armature
4 two coils for vertical stabilization
5 four drive coils
6 two signal sensing coils
7 four coils for horizontal stabilization

Figure 1 — Functional elements of a spinning rotor gauge

6 Specifications for spinning rotor gauge

6.1 Diameter and density of rotor

The diameter and density of the rotor shall be given. If nominal values are used, this shall be clearly stated.

6.2 Materials of rotor and thimble

The materials of the rotor and thimble shall be specified.

6.3 Connecting flange of thimble

Size and sealing type of the connecting flange of the thimble to the vacuum system shall be specified.

6.4 Leak rate of thimble with flange

The leak rate of thimble with flange assembly may be specified.

6.5 Suspension head positioning

The procedure to adjust the suspension head shall be specified.

6.6 Limits of rotor frequency

The upper and lower frequency limits under which the sphere will rotate shall be specified. If they are changeable, the range shall be specified.

6.7 Warm-up period

The warm-up period shall be specified.

6.8 Baking temperature

The maximum baking temperature with and without suspension head shall be specified.

6.9 Measurement range

The measurement range for nitrogen of an SRG in which a specified expected measurement uncertainty is satisfied shall be specified. The pressure range shall be given in Pa. Other units can also be used.

6.10 Sampling time

The sampling time shall be specified. If it is changeable, the range shall be specified.

6.11 Internal volume

The internal volume of the thimble shall be specified.

6.12 Interface and pin connections of controller

The protocol of communication with a computer shall be specified. The connector type and the function of the pin connections (pin-out) shall be specified.

6.13 Dimensions and weights of suspension head and controller

Dimensions of the suspension head and/or controller with an outline drawing and their weights in SI unit shall be specified. It may be expressed as width, depth and height (W*D*H). Other units (e.g. inch) can also be used.

6.14 Display and signal output

On the controller, the display shall show the SI unit of pascals (Pa). Other units (e.g. mbar) can also be used. The raw signal of deceleration rate in s^{-1} shall be shown.

6.15 Nominal operating (environment) conditions

Temperature and relative humidity ranges in which the suspension head and controller can be operated shall be specified.

6.16 Storage and transportation conditions

Conditions of storage and transportation shall be specified with respect to avoiding damage and harm to the gauge. This includes, for example, the method to maintain the stability of the rotor, temperature and relative humidity. Vibration and shock conditions are optional.

6.17 Input power and electrical requirements

The voltage (AC or DC), current, frequency and their requirements shall be specified. The power consumption shall be specified.

7 Additional (optional) specifications for spinning rotor gauge

7.1 Long-term instability

The long-term instability should be expressed as a percentage of the accommodation factor for a specified period, for example, one year (see ISO 20146:2019, 3.2.1). For such measurements, stable or repeatable pressure should be used and the gauge operated under its normal conditions. Typical values may be given.

7.2 Expected measurement uncertainty

An expected measurement uncertainty of SRG should be specified. This shall be given in Pa or the percentage of the accommodation factor. The necessary measurement conditions (e.g. temperature, gas composition) to obtain the expected measurement uncertainty should be specified.

The calibration uncertainty of an individual gauge may be given by a calibration certificate (see 8.4).

The calibration uncertainty of an individual gauge can be significantly lower than the expected measurement uncertainty for the same type of device, because the measurement error is corrected and excluded in the certificate.

7.3 Compatibility between a suspension head and a rotor

The type or model number of the suspension head for the rotor should be specified.

7.4 Inspection record and calibration certificate

An inspection record of a spinning rotor gauge increases the user's confidence in the readings. If a calibration certificate is available, it shall contain information on the national standard to which it is traceable. It should be specified whether an inspection record and/or calibration certificate will be issued or not.

7.5 Allowed vibration level

The allowed vibration level for stable operation of the spinning rotor gauge should be specified.

7.6 Cable length

The cable length which is usually supplied should be specified. The maximum cable length provided on demand should also be specified.

NOTE A longer cable can be sensitive to electromagnetic interference.

7.7 Photograph

For clear outlook and details, computer graphics, a photograph or a drawing of the suspension head shall be given. Front and back panels (connector side) of the controller are recommended.

8 Calibration

8.1 Parameters to be calibrated

There are two possible parameters to be calibrated:

a) The pressure independent accommodation factor, $\sigma_{\mathrm{eff},0}$; or

b) the error of reading.

If the error of reading is determined, the accommodation factor shall be determined in advance and the input parameters of the SRG shall be set in the controller accordingly. For higher accuracy, up to pressures of 10 mPa, it is recommended to determine RD between each calibration point.

It is recommended to calibrate the accommodation factor $\sigma_{eff,0}$.

8.2 Calibration procedures

8.2.1 General

The known pressure for calibration can be generated by a fundamental measuring standard or by a system according to ISO 3567 with a reference gauge. If a reference gauge is used, it should be either another calibrated SRG or, for pressures greater than 100 mPa, a calibrated capacitance diaphragm gauge with full scale of 133 Pa or lower. An independent gauge, which is normally an ionization gauge, shall be installed on the system to measure the base pressure in the system. This pressure plus the expanded measurement uncertainty (k = 2) of this gauge shall not exceed 10^{-5} Pa.

Before the calibration, RD shall be determined. This value shall be subtracted from the signal during calibration in the same unit, either a pressure or DCR unit.

The indication of the SRG is sensitive to vibration due to its principle (see ISO 3567:2011, B.8).

During calibration, the SRG can be connected to an uninterruptible power supply (UPS). While the determination of the error of reading needs no further explanation in addition to 8.1 b), there are two calibration methods, A and B, that can be used to calibrate the pressure independent accommodation factor $\sigma_{eff,0.}$ Method A is easier and quicker to perform but does not deliver the pressure dependence of σ_{eff} beyond 30 mPa. Method B needs some higher effort, but provides the customer, in addition to $\sigma_{eff,0}$, with a known pressure dependence of σ_{eff} up to 2 Pa.

8.2.2 Calibration method A for $\sigma_{eff,0}$

The accommodation factor is set to 1 in the controller. The rotor shall be exposed to a fixed pressure p_{cal} between 10 mPa and 30 mPa and the indicated pressure, p_{ind}, of the SRG shall be taken with at least five repeat measurements with 30 s sampling time each. Three measurement cycles, which include pumping to residual pressure conditions and readmitting calibration gas between each cycle, are recommended to determine $\sigma_{eff,0}$. The pressure, p_{cal}, shall be stable within 0,2 % in this time interval. To estimate the change of RD, it shall be determined after the measurement again. If the change is significant, the mean of the value before and after shall be used.

It is

$$\sigma_{eff,0} = \frac{p_{ind}}{p_{cal}} \tag{3}$$

Alternatively, p_{ind} can also be calculated from the DCR values using Formulae (1) or (2).

8.2.3 Calibration method B for $\sigma_{eff,0}$

The accommodation factor is set to 1 in the controller and the viscosity to 0 in the controller. The rotor shall be exposed to at least 3 pressures p_{cal} between 80 mPa and 2 Pa, where the ratio of the highest pressure to the lowest pressure is greater than or equal to 10. For each p_{cal} the indicated pressure p_{ind} of the SRG shall be taken with five repeat measurements with 10 s sampling time each.

The reduced sampling time of 10 s is necessary, since at higher pressures reacceleration will heat both the rotor and thimble and cause a significant drift at longer periods. For the same reason, only five repeat measurements shall be taken at higher pressures.