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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.

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

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