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

*Technique du vide — Manomètres à vide — Évaluation de l'incertitude  
des résultats des étalonnages par comparaison directe avec un  
manomètre de référence*

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

- an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;
- an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

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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order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn.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again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.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 27893 was prepared by Technical Committee ISO/TC 112, *Vacuum technology*.

# Vacuum technology — Vacuum gauges — Evaluation of the uncertainties of results of calibrations by direct comparison with a reference gauge

## 1 Scope

This Technical Specification gives guidelines for the determination and reporting of measurement uncertainties arising during vacuum gauge calibration by direct comparison with a reference gauge in accordance with ISO/TS 3567. It describes methods for uniform reporting of uncertainties in vacuum gauge certificates. Uncertainties reported in accordance with this Technical Specification are transferable in the sense that the uncertainty evaluated for one result can be used as a component in the uncertainty evaluation of another measurement or calibration in which the first result is used.

This specification defines two measurement models that are sufficient to cover most practical cases. However, it is possible that the models given cannot be applied to newly developed vacuum gauges.

The final uncertainty to be reported in a certificate is evaluated from the uncertainties of the input quantities and influence quantities. The principal quantities that may affect the result of a vacuum calibration are described; however, a complete list of the possible quantities that may have an influence on the final result lies outside the scope of this Technical Specification.

NOTE It is intended to give such details in Technical Specifications for the calibration of specific types of vacuum gauges.

## 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/TS 3567, *Vacuum gauges — Calibration by direct comparison with a reference gauge*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99:2007, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

### 3 Terms and definitions

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

**3.1 corrected reading**  
value resulting after the reading of the gauge has been corrected for systematic errors (e.g. for the results given in the calibration certificate of the reference standard)

**3.2 long-term instability**  
possible change of calibrated value after long periods of time

EXAMPLE Change that has resulted from transportation of the device.

NOTE Long-term instability is different from reproducibility as defined in ISO/IEC Guide 99:2007, 3.7.

**3.3 model**  
(uncertainty of measurement) mathematical model set out in ISO/IEC Guide 98-3

**3.4 offset zero error (of a measuring instrument)**  
datum measurement error where the specified measured quantity value is zero

NOTE Adapted from ISO/IEC Guide 99:2007, 4.28.

EXAMPLE The reading when there is no pressure (absolute or differential) or a pressure far below the resolution limit applied to a vacuum gauge.

**3.5 deviation of offset**  
The possible difference of an **offset** (3.4) value at the time of the measurement of the **offset** (3.4) and the time when a pressure reading is taken

**3.6 reference gauge 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

NOTE Adapted from ISO/IEC Guide 99:2007, 6.6.

EXAMPLE The gauge or standard that gives traceability to the SI unit in the calibration apparatus in accordance with ISO/TS 3567.

**3.7 calibration pressure**  
(vacuum gauges) pressure evaluated from the corrected reading of the reference standard and all necessary corrections (e.g. for known differences between gauge ports) at the gauge port of the unit under calibration

## 4 Symbols and abbreviated terms

Symbol or abbreviated term	Designation	Unit
UUC	unit under calibration (vacuum gauge)	
$e$	error of reading	in relative units
$p_{\text{ind}}$	pressure indication of a UUC	Pa <sup>1)</sup>
$p_{\text{std}}$	pressure indication of reference gauge (reference standard) corrected for known deviations	Pa
$r$	the quantity determined by a calibration in the quotient model	
$S$	a sensitivity of the output of a vacuum gauge	
$x_{\text{ind}}$	indication of a UUC	any unit
$X_i$	(often unknown) input quantities and corrections	
$\Delta p$	error of reading in absolute units	
$\delta p_i$	(often unknown) deviations in the pressure unit	Pa
$\sigma_{\text{eff}}$	the effective accommodation coefficient of a spinning rotor gauge	

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## 5 Basic concept and model

In a vacuum gauge calibration in accordance with ISO/TS 3567, the corrected reading of a reference gauge gives the value of the quantity that is traceable to the SI. All vacuum gauges shall be calibrated in terms of pressure. This means that the user of the vacuum gauge calibrated in accordance with ISO/TS 3567 and this Technical Specification obtains a clear assignment of the output quantity of the gauge to the SI unit of pressure, the pascal.

The value of pressure obtained from the corrected reading of the reference standard output can be used to determine the pressure at the entrance port of the unit under calibration (UUC). This is referred to as calibration pressure value. Often the corrected reading of the reference standard is identical to the calibration pressure value and valid for all gauge ports.

The calibration pressure value can be used to determine an error of the reading,  $\Delta p$ , of the unit under calibration. In this case, a sum model gives an adequate description of the measurement.

The calibration pressure value can also be used to determine a correction factor, a sensitivity coefficient, an effective accommodation coefficient or a gauge constant, in which case a quotient model gives an adequate description of the measurement.

In both models it can be assumed that all the input quantities are uncorrelated.

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1) 1 Pa = 0,01 mbar.

**5.1 Sum model**

In the sum model, the difference between the reading of the UUC,  $p_{ind}$ , and the “true” calibration pressure traceable to the SI units is taken as the measurand,  $\Delta p$ . The calibration pressure is given by the reference standard pressure value,  $p_{std}$ , and possibly by a correction term,  $\delta p_m$ , due to the calibration method considering known effects like height correction, thermal transpiration, and pressure non-uniformity. The general sum model thus becomes

$$\Delta p = p_{ind} - (p_{std} + \delta p_m) \tag{1}$$

The first term refers to the UUC, the second to the reference standard, and the third to the calibration method. The sum of the last two terms gives the calibration pressure value. All quantities shall be expressed in the SI unit of pressure, the pascal.

Each of these terms is again expressed by another model equation, which makes all necessary corrections due to offsets, temperature corrections, deviation of indication from the SI value in accordance with the calibration certificate, etc.

**5.2 Quotient model**

In the quotient model, the ratio of the reading of the UUC,  $x_{ind}$ , and the standard pressure value,  $p_{std}$ , is taken as the measurand,  $r$ . The general quotient model thus becomes

$$r = \frac{x_{ind}}{p_{std}} \prod_i X_i \tag{2}$$

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The numerator refers to the UUC, the denominator to the reference standard, and the product to the calibration method and conditions. The latter may be also defined by the vacuum gauges under study, e.g. the emission current in a hot cathode ionization gauge. It is possible to express  $x_{ind}$  in any reasonable unit, e.g. that of pressure, voltage or current. The  $X_i$  may be expressed in any meaningful physical unit or be without dimension.

Each of these factors is expressed by another model equation, which makes all necessary corrections due to offsets, temperature corrections, deviation of indication in accordance with calibration certificate, etc.

Examples of  $r$  are

- a)  $f_c^{-1}$  the reciprocal of a dimensionless correction factor, where  $x_{ind} = p_{ind}$  and  $X_i = 1$ ;
- b)  $S$  a sensitivity of the analogue output,  $V_{ind}$ , of a capacitance diaphragm gauge, where  $x_{ind} = V_{ind}$ ;
- c)  $S$  a sensitivity of the analogue output,  $V_{ind}$ , of a thermal conductivity gauge, where  $x_{ind} = V_{ind}$ ;
- d)  $\sigma_{eff}$  the effective accommodation coefficient of a spinning rotor gauge, where  $x_{ind} = p_{ind}$ , when  $\sigma_{eff} = 1$  was entered into the controller;
- e)  $S$  a sensitivity of a Bayard-Alpert gauge with a hot cathode, where  $x_{ind} = I_{ind}$  is the positive ion current of the collector and  $X_1 = 1/I_e$ , where  $I_e$  is the emission current.



### 5.3 Combination of the two models

It is possible to evaluate some of the input quantities in each model by either of the two models. First, for example,  $p_{\text{std}}$  as well as its uncertainty can be evaluated by the quotient model, thus

$$p_{\text{std}} = \frac{x_{\text{ind}}}{r} \quad (3)$$

The result can then be used in Equation (1). This is unavoidable, if  $r$  is given in the certificate applying Equation (2) (e.g. the sensitivity of an analogue output).

It is, however, not recommended to combine the sum and quotient model in one equation. This task should be left to experts, since complicated sensitivity coefficients may appear that are not covered in this Technical Specification for reasons of clarity. The relative error of reading,  $e$ , however, is a common case, where an easy to handle combination of the two methods is possible.

The error of reading,  $e$ , can be expressed mathematically as

$$\begin{aligned} e &= \frac{p_{\text{ind}} - (p_{\text{std}} + \delta p_{\text{m}})}{(p_{\text{std}} + \delta p_{\text{m}})} \\ &= \frac{p_{\text{ind}}}{p_{\text{std}} + \delta p_{\text{m}}} - 1 \end{aligned} \quad (4a)$$

or, if  $\delta p_{\text{m}} = 0$

$$\begin{aligned} e &= \frac{p_{\text{ind}} - p_{\text{std}}}{p_{\text{std}}} \\ &= \frac{p_{\text{ind}}}{p_{\text{std}}} - 1 \end{aligned} \quad (4b)$$

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See Clause 4 for the designations of  $p_{\text{ind}}$ ,  $p_{\text{std}}$ , and  $\delta p_{\text{m}}$ . The uncertainty of  $e$  is described in Clause 8.

## 6 Calculation of uncertainty in the sum model

### 6.1 Total uncertainty (sum model)

The total uncertainty in the sum model,  $u(\Delta p)$ , is given by

$$u(\Delta p) = \sqrt{u(p_{\text{ind}})^2 + u(p_{\text{std}})^2 + u(\delta p_{\text{m}})^2} \quad (5)$$

where

$u(p_{\text{ind}})$  is the standard uncertainty of the indication of vacuum gauge UUC;

$u(p_{\text{std}})$  is the standard uncertainty of the value of standard pressure;

$u(\delta p_{\text{m}})$  is the standard uncertainty of the deviations due to the calibration method.

**6.2 Uncertainty contributions due to reference standard**

The measurement of the standard pressure,  $p_{std}$ , is given by

$$p_{std} = p_{ind, std} - p_{offs, std} + \delta p_{drft, std} + \delta p_{cal, std} + \delta p_{t, std} + \delta p_{T, std} + \delta p_{res, std} \quad (6)$$

where

- $p_{ind, std}$  is the indication of the reference standard;
- $p_{offs, std}$  is the offset (zero deviation) of the reference standard;
- $\delta p_{drft, std}$  is the deviation of offset due to drift (in most cases,  $\delta p_{drft, std} = 0$ );
- $\delta p_{cal, std}$  is the correction in accordance with the calibration certificate;
- $\delta p_{t, std}$  is the deviation due to long-term instability (in most cases,  $\delta p_{t, std} = 0$ );
- $\delta p_{T, std}$  is the deviation due to temperature at the calibration laboratory;
- $\delta p_{res, std}$  is the deviation due to other influences (e.g. inclination of device) (in most cases,  $\delta p_{res, std} = 0$ ).

All quantities in Equation (6) refer to the reference standard gauge.

NOTE If the offset is deducted or adjusted to zero in the device itself,  $p_{offs, std} = 0$ .

The standard uncertainty of the standard pressure,  $u(p_{std})$ , is then given by

$$u(p_{std}) = \sqrt{u(p_{ind, std})^2 + u(p_{offs, std})^2 + u(\delta p_{drft, std})^2 + u(\delta p_{cal, std})^2 + u(\delta p_{t, std})^2 + u(\delta p_{T, std})^2 + u(\delta p_{res, std})^2} \quad (7)$$

where

- $u(p_{ind, std})$  is the uncertainty originating from the dispersion of measurement values, including dispersion due to digitizing, resolution scatter, etc.;
- $u(p_{offs, std})$  is the uncertainty of the offset values at measurement of the offset [without reproducibility of the offset covered by  $u(\delta p_{drft, std})$ ];
- $u(\delta p_{drft, std})$  is the uncertainty of the offset values at time of calibration due to offset drift or other systematic dependencies (e.g. due to the frequency dependence of spinning rotor gauges);
- $u(\delta p_{cal, std})$  is the uncertainty of the standard in accordance with the calibration certificate;
- $u(\delta p_{t, std})$  is the uncertainty component allowing for the long-term instability;
- $u(\delta p_{T, std})$  is the uncertainty component due to the temperature influence under the conditions of the calibration laboratory;
- $u(\delta p_{res, std})$  is the uncertainty due to the specific conditions at the calibration laboratory (e.g. different mounting position of built-in devices).

For a  $p_{ind, std}$  that has not been obtained from repeated observations, estimate  $u(p_{ind, std})$  from scientific judgement based on all of the available information on the possible variability (including uncertainty component due to digitizing, repeatability, etc.).

For a temperature at calibration different from that shown in the calibration certificate,  $u(\delta p_{T, std})$  should be included, if significant.

### 6.3 Uncertainty contributions due to unit under calibration

The measurement of the pressure of the UUC,  $p_{\text{ind}}$ , is given by

$$p_{\text{ind}} = p_{\text{ind,UUC}} - p_{\text{offs,UUC}} + \delta p_{\text{drft,UUC}} + \delta p_{\text{res,UUC}} \quad (8)$$

where

- $p_{\text{ind,UUC}}$  is the indication of the UUC;
- $p_{\text{offs,UUC}}$  is the offset (zero point deviation) of the UUC;
- $\delta p_{\text{drft,UUC}}$  is the deviation of offset drift (in most cases,  $\delta p_{\text{drft,UUC}} = 0$ );
- $\delta p_{\text{res,UUC}}$  represents the deviations due to other influence (e.g. inclination) (in most cases,  $\delta p_{\text{res,UUC}} = 0$ ).

The standard uncertainty of the measurement of the pressure with UUC,  $u(p_{\text{UUC}})$ , is then given by

$$u(p_{\text{UUC}}) = \sqrt{u(p_{\text{ind,UUC}})^2 + u(p_{\text{offs,UUC}})^2 + u(\delta p_{\text{drft,UUC}})^2 + u(\delta p_{\text{res,UUC}})^2} \quad (9)$$

where

- $u(p_{\text{ind,UUC}})$  is the uncertainty originating from the dispersion of measurement values of UUC, including dispersion due to digitizing, resolution scatter, etc.;
- $u(p_{\text{offs,UUC}})$  is the uncertainty of the offset values of the UUC at measurement of the offset (without reproducibility of the offset covered by the following quantity);
- $u(\delta p_{\text{drft,UUC}})$  is the uncertainty of the offset values of the UUC due to offset drift or other systematic dependencies (e.g. due to speed dependence in the case of spinning rotor gauges);
- $u(\delta p_{\text{res,UUC}})$  represents the other uncertainty components, which can also stem from the calibration item, e.g. temperature influences.

For a  $p_{\text{ind,UUC}}$  that has not been obtained from repeated observations, estimate  $u(p_{\text{ind,UUC}})$  from scientific judgement based on all of the available information on the possible variability (including uncertainty component due to digitizing, repeatability, etc.).

If the above-mentioned dependencies or values are not known, or cannot be estimated by the calibration laboratory, or manufacturer's specifications are not available, carry out at least two repeat measurements on different days. The uncertainty component of the values of the calibration item,  $u(p_{\text{ind}})$ , is then determined from

$$u(p_{\text{ind}}) = u(p_{\text{rep,ind}}) \quad (10)$$

where  $u(p_{\text{rep,ind}})$  is the repeatability (standard deviation) of the (at least) three measurement values determined for one pressure point or over a larger range.