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Turbocompressors — Performance test code

Turbocompresseurs — Code d'essai des performances

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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.

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.

International Standard ISO 5389 was prepared by Technical Committee ISO/TC 118, *Compressors, pneumatic tools and pneumatic machines*, Sub-Committee SC 1, *Turbo compressors.*

Annexes A, B, C, D and E form an integral part of this International Standard. Annexes F and G are for information only.

Introduction

The terms "guarantee" or "guaranteed" and "performance" used in this International Standard are to be understood in the engineering rather than the contractual sense. A guarantee relates to a specific aspect of the plant or its operation which is defined in the contract.

With the aid of the test described in this International Standard, the actual performance data can be compared with the guaranteed values.

The contractual consequences of any deviations are not covered by this International Standard. A satisfactory test result does not signify acceptance in the contractual sense, as such acceptance may depend on other conditions stipulated in the contract.

This International Standard provides standard directions for conducting and reporting tests on compressors to establish their performance concerning one or more of the following aspects under specified conditions and for comparing the results with the guaranteed performance:

a) the quantity of gas or vapour delivered;

b) the pressure rise or pressure ratio produced;

c) the power required for compression or the efficiency of the compressor (according to specified definitions);

d) the stable working range — surge and maximum flow limits.

To meet this purpose, this International Standard establishes rules concerning

a) the test procedure (including the measurements to be taken, and the preparation and execution of the test);

b) the instrumentation to be used to provide adequate accuracy;

c) the methods of converting the test results in order to provide values that may be compared with the guaranteed figures;

d) the confidence limits of the converted test results according to the accuracy of the particular measurements.

Turbocompressors — Performance test code

1 Scope

This International Standard covers blowers or compressors and exhausters of the centrifugal, mixed flow, or axial flow types (inclusively covered by the term turbocompressors), with and without intercooling, handling any vapour or gas the physical properties of which are reliably known.

It may be applied to any compression process, with or without bleed-off or sidestreams, which takes place in one or more casings.

This International Standard gives no rules for the measurement of any other aspect of the compressor which may be the subject of a guarantee, such as

a) mechanical performance;

b) vibrations;

c) pulsations;

d) noise level;

e) service and reliability;

f) commercial questions.

The theory used in this International Standard is based on the laws of similarity of fluid flow (similar velocity triangles). The observation of these laws determines specific requirements for the execution of acceptance tests. In all cases, where a close approximation to these requirements is not possible, this International Standard can only be applied by mutual agreement. Compressors supplied to handle gases the physical properties of which are not reliably known can only be tested within certain limits.

For identical compressors, produced in series, the testing of an arbitrarily chosen sample may be agreed upon.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 31 (parts 0 to 13)[1], *Quantities, units and symbols.*

ISO 1000 : —[2], *SI units and recommendations for the use of their multiples and of certain other units.*

ISO 5167-1 : 1991, *Measurement of fluid flow by means of pressure differential devices — Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full.*

3 Definitions, formulae and reference processes

For the purposes of this International Standard, the following definitions apply.

3.1 Definitions relating to compressor performance

3.1.1 standard inlet point: The inlet point considered to be representative of the compressor. It is generally at the compressor inlet flange.

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[1] Currently under revision.

[2] To be published. (Revision of ISO 1000 : 1981.)

3.1.2 standard discharge point: The discharge point considered to be representative of the compressor. It is generally at the compressor discharge flange.

3.1.3 Quantity of gas or vapour delivered

3.1.3.1 usable mass rate of flow for a compressor: The mass rate of flow delivered at the standard discharge point.

3.1.3.2 usable mass rate of flow for an exhauster: The mass rate of flow aspirated at the standard inlet point.

3.1.3.3 actual inlet volume flow for a compressor: The actual volume rate of flow compressed and delivered at the standard discharge point, referred to the conditions of temperature, pressure and composition (for example humidity) prevailing at the standard inlet point.

3.1.3.4 actual inlet volume flow for an exhauster: The actual volume rate of flow aspirated at the standard inlet point.

NOTES

1 Unless otherwise specified, the actual inlet volume flow will be referred to total temperature and total pressure.

2 For gas-vapour mixtures, see A.4.2.7.

3.2 Basic formulae for gases

Gas basic formulae are given in table 1.

3.3 Reference process

The determination of the internal power (3.6.5) is based on the assumption of a reversible reference process, hence the necessity of a definition of the corresponding efficiency, taking account of energy losses due to the irreversibility of the actual compression process.

The reference process is characterized by the law

$$p = f(v)$$

which is used to determine the specific compression work:

$$W_m = \int_1^2 v \, \mathrm{d}p$$

The total specific compression work is thus determined using the equation

$$W_{m,\mathrm{t}} = W_m + \frac{c_2^2 - c_1^2}{2}$$

By approximation with the low flow speeds ($Ma < 0{,}2$) normally prevailing in the inlet and discharge nozzles, the total pressures and total temperatures can be used in the calculation directly:

$$W_{m,\mathrm{t}} = \int_1^2 (v \, \mathrm{d}p)_\mathrm{t}$$

Table 1 — Gas basic formulae

No.	Term	Formula	
		For a real gas	For a perfect gas
3.2.1	Equation of state	$pV = ZRT$	$pV = RT$
3.2.2	Compressibility factor	Z	$Z = 1$
3.2.3	Isothermal deviation factor	$Y = \frac{p}{V}\left(\frac{\partial V}{\partial p}\right)_T = 1 - \frac{p}{Z}\left(\frac{\partial Z}{\partial p}\right)_T$	$Y = 1$
3.2.4	Isobaric deviation factor	$X = \frac{T}{V}\left(\frac{\partial V}{\partial T}\right)_p - 1 = \frac{T}{Z}\left(\frac{\partial Z}{\partial T}\right)_p$	$X = 0$
3.2.5	Isentropic exponent	$\kappa = -\frac{V}{p}\left(\frac{\partial p}{\partial V}\right)_S = \frac{\gamma}{Y}$	$\kappa = \gamma = \frac{c_p}{c_V}$

NOTES

1 The data serving as a reference for the determination of gas properties shall be agreed between purchaser and vendor.

2 Clause A.1 deals with general recommendations relating to the thermodynamic data for gases and gas mixtures.

3 Clause A.2 deals with specific recommendations for some of the more common gases.

3.4 Reference processes for use with perfect or near-perfect gases

The following methods of computation of specific compression work are recommended to be applied

- when agreed between purchaser and vendor, or
- when the deviation of gas properties from perfect gas laws at any state point of the compression process of an uncooled compressor, or at any state point of a compression section included between two successive intercoolers of a cooled compressor, do not exceed the limits given in table 2 for the appropriate pressure ratio.

Within the limits given, the errors in specific isentropic compression work and discharge specific volume will be less than 1 % and 2 % respectively if calculations are made according to perfect gas laws instead of real gas equations.

It is recommended that in most cases polytropic compression be used as the reference process.

Polytropic compression should always be adopted for any case in which the gas used for the acceptance test has a ratio of specific heats which differs from that of the guarantee gas by more than 1 %.

3.4.1 Polytropic compression

3.4.1.1 A polytropic compression process follows the law

$$p v^n = p_1 v_1^n = \text{constant}$$

where for perfect gases

$$n = \frac{\lg\left(\frac{p_2}{p_1}\right)}{\lg\left(\frac{p_2}{p_1} \cdot \frac{T_1}{T_2}\right)}$$

3.4.1.2 The specific compression work based on static conditions is calculated using

$$W_{m,\text{pol}} = \int_1^2 (v\,\mathrm{d}p)_{\text{pol}} = \left(\frac{n}{n-1}\right) p_1 v_1 \left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right]$$

3.4.1.3 In its general form the polytropic compression offers, owing to the free choice of the exponent n, great liberty in adapting it to any change of state. With $n = \gamma$ the compression becomes isentropic. When n approaches unity, the compression approaches an isothermal process. If, with multistage compressors, a single-stage reference compression does not represent the actual process with sufficient accuracy, a multistage polytropic compression may be chosen. From the above it follows that the polytropic compression is suited for cooled and uncooled, and for single-stage and multistage, compressors.

3.4.1.4 In the case of compressors with interstage cooling the polytropic compression approaches isothermal compression at one extreme, and isentropic compression at the other, depending on whether the process takes place at a constant temperature or the aerodynamic flow losses only are removed by the cooler. An approximation has to be made by suitable choice of the exponent n and the number of stage groups according to the arrangement and effectiveness of the cooling.

3.4.1.5 For compressors without cooling (adiabatic compression) the isentropic process is often used as a reference, but here too the polytropic process offers a better basis on which to assess the aerodynamic losses of a compressor.

It takes into account the increased compression work caused by the reheat losses. This increase is particularly noticeable at either high pressure ratios or low efficiencies.

3.4.2 Isentropic compression

3.4.2.1 In this reference process, compression takes place over the whole part of the pressure range (depending on whether it is a single-stage or multistage machine) at constant entropy, i.e. $n = \kappa$.

Table 2[1] — Limits for the pressure ratio

Pressure ratio[2] $\frac{p_2}{p_1}$	Maximum ratio between maximum and minimum values of κ ($= \gamma$)	$X_{\max}$	$X_{\min}$	$Y_{\max}$	$Y_{\min}$
1,4	1,12	0,279	− 0,344	1,071	0,925
2	1,10	0,167	− 0,175	1,034	0,964
4	1,09	0,071	− 0,073	1,017	0,982
8	1,08	0,050	− 0,041	1,011	0,988
16	1,07	0,033	− 0,031	1,008	0,991
32	1,06	0,028	− 0,025	1,006	0,993

1) Table taken from [1].

2) For pressure ratios between those shown, the limiting values shall be obtained by interpolation.

3.4.2.2 Isentropic compression follows the law

$$p v^{\kappa} = p_1 v_1^{\kappa} = \text{constant}$$

3.4.2.3 The specific compression work based on static conditions is expressed by the equation

$$W_{m,\mathrm{s}} = \int_1^2 (v\,\mathrm{d}p)_\mathrm{s} = \frac{\kappa}{\kappa - 1} p_1 v_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{\kappa - 1}{\kappa}} - 1 \right]$$

3.4.3 Isothermal compression

In this reference process, compression takes part over the whole (single stage) or part (multistage) of the pressure range at a constant temperature. As a rule the inlet temperature T_1 of the compressor or stage group under consideration is used. The exponent $n = 1$, and the specific compression work based on static conditions is defined by the equation

$$W_{m,\mathrm{T}} = \int_1^2 (v\,\mathrm{d}p)_\mathrm{T} = p_1 v_1 \ln \left(\frac{p_2}{p_1} \right)$$

3.5 Reference processes for use with real gases

3.5.1 General

When tables, equations of state or charts giving the appropriate thermodynamic data are available, it is recommended that they be used to determine the specific compression work (see 3.5.2).

When such tables, equations of state or charts are not available and the limits of table 2 are exceeded, it is recommended that polytropic compression be adopted as the reference process and the specific compression work should be computed by the Schultz method of polytropic analysis (see 3.5.3 and [2]).

3.5.2 Method using tables or charts

If possible, the gas properties, especially for gas mixtures, are best determined from tables and equations of state since the diagrams are in general less accurate (see clauses A.1 to A.3).

The properties represented in diagrams and tables are today frequently compiled in the form of computer programs which can readily be included as subprograms in the calculation programs for the design of the compressor and test evaluation.

Specific information about the determination of these gas properties and changes of state cannot be listed here owing to the multiplicity of the processes and values used. The user of this International Standard is referred to the relevant literature.

3.5.3 Methods of polytropic analysis (Schultz method)

3.5.3.1 The formulae of the following method are derived from the method developed by Schultz (see [2]).

3.5.3.2 The determination of exponent n for the general case of real gases is carried out assuming that the efficiency remains constant throughout the process:

$$\eta_\mathrm{pol} = v \frac{\mathrm{d}p}{\mathrm{d}h} = \frac{\int_1^2 (v\,\mathrm{d}p)_\mathrm{pol}}{h_2 - h_1}$$

3.5.3.3 This makes it possible to determine an average polytropic exponent with sufficient exactitude:

$$n = - \frac{1}{Y_\mathrm{M} - m\,(1 + X_\mathrm{M})}$$

where

$$m = \frac{Z_\mathrm{M} R}{c_{p\mathrm{M}}} \left(\frac{1}{\eta_\mathrm{pol}} + X_\mathrm{M} \right) = \frac{\lg \left(\frac{T_2}{T_1} \right)}{\lg \left(\frac{p_2}{p_1} \right)}$$

$$\eta_\mathrm{pol} = \frac{R\,Z_\mathrm{M}}{m c_{p\mathrm{M}} - R\,Z_\mathrm{M} X_\mathrm{M}}$$

with average values for the gas stream:

$$Z_\mathrm{M} = \frac{Z_1 + Z_2}{2}$$

$$X_\mathrm{M} = \frac{X_1 + X_2}{2}$$

$$c_{p\mathrm{M}} = \frac{c_{p1} + c_{p2}}{2}$$

The above averages are a simplification valid for pressure ratios $\frac{p_2}{p_1} \leqslant 4$.

For higher pressure ratios, it is recommended that Schultz's method be followed, i.e. averages are formed with double weight given to the mid-point. The mid-point can be chosen at the square root of the pressure ratio and half the temperature rise.

For pressure ratios up to 4, the difference between the results of both methods is less than 0,2 % for specific polytropic compression work and 0,5 °C for discharge temperature.

3.5.3.4 Theoretically, the exact assessment of the specific polytropic compression work assumes the previous computation of factor ξ by use of the formula

$$\xi = \frac{h'_2 - h_1}{\dfrac{\kappa}{\kappa - 1} R \left(Z_2 T_2 - Z_1 T_1\right)}$$

where

h_1 is the enthalpy at the inlet;

h'_2 is the resulting enthalpy at the outlet if the process had been isentropic.

NOTE — Where specific values of the factors X, Y and Z are not available values may be obtained from the generalized curves given in annex D.

3.5.3.5 The specific compression work based on static conditions may thus be determined:

$$W_{m,\text{pol}} = \int_1^2 (v\, \mathrm{d}p)_{\text{pol}} = \frac{Z_{\text{M}} R T_1}{m} \xi \left[\left(\frac{p_2}{p_1} \right)^m - 1 \right]$$

NOTE — This equation is not strictly correct (see [2]) and should only be used in cases where the compressibility factor Z is substantially constant throughout the compression process.

The equation for $W_{\text{m,pol}}$ given in figure D.9 can also be used.

3.5.3.6 For compression ratios $\dfrac{p_2}{p_1} \leqslant 4$ the correction factor ξ may be considered as equal to 1 and can therefore be neglected in the computation.

3.5.3.7 For similarity testing of compressors without intermediate cooling, a single-stage process should be adopted, determining an average polytropic exponent such as defined above.

3.5.3.8 For tests of compressors with intermediate cooling a multistage reference process should be adopted with polytropic exponents suited to each section included between two successive intercoolers.

3.5.3.9 Similarity calculations according to Schultz's method are shown schematically in figure D.7.

3.6 Definition of reference efficiency, power and losses

3.6.1 reference efficiency, η_{pol}, η_{s} or η_{T}: Ratio of the specific compression work to the total enthalpy rise in the machine (or section of the machine) within which there is no deliberate cooling and when based on static conditions as defined by the formula:

$$\eta = \frac{\int_1^2 v\, \mathrm{d}p}{h_2 - h_1} = \frac{W_m}{h_2 - h_1}$$

Unless otherwise agreed, the reference efficiency is based on total conditions and the formula becomes

$$\eta_{\text{t}} = \frac{W_m + \dfrac{(c_2^2 - c_1^2)}{2}}{h_{\text{t},2} - h_{\text{t},1}}$$

Where there is deliberate cooling within the machine (or section of the machine) under consideration, this formula becomes

$$\eta_{\text{t}} = \frac{W_m + \dfrac{(c_2^2 - c_1^2)}{2}}{h_{\text{t},2} - h_{\text{t},1} - Q_{1-2}}$$

where Q_{1-2} is the heat removed by the cooling within the machine (or section of the machine).

The above definition is complete only when the type of the reference process adopted is indicated by the corresponding subscript. Consequently reference efficiencies are given by the following formulae.

3.6.1.1 The polytropic efficiency

$$\eta_{\text{pol}} = \frac{W_{m,\text{pol}}}{h_2 - h_1 - Q_{1-2}}$$

$$\eta_{\text{pol,t}} = \frac{W_{m,\text{pol}} + \dfrac{(c_2^2 - c_1^2)}{2}}{h_{\text{t},2} - h_{\text{t},1} - Q_{1-2}}$$

See also 3.5.3.3.

3.6.1.2 The isentropic efficiency

$$\eta_{\text{s}} = \frac{W_{m,\text{s}}}{h_2 - h_1 - Q_{1-2}}$$

$$\eta_{\text{s,t}} = \frac{W_{m,\text{s}} + \dfrac{(c_2^2 - c_1^2)}{2}}{h_{\text{t},2} - h_{\text{t},1} - Q_{1-2}}$$

3.6.1.3 The isothermal efficiency

$$\eta_{\text{T}} = \frac{W_{m,\text{T}}}{h_2 - h_1 - Q_{1-2}}$$

$$\eta_{\text{T,t}} = \frac{W_{m,\text{T}} + \dfrac{(c_2^2 - c_1^2)}{2}}{h_{\text{t},2} - h_{\text{t},1} - Q_{1-2}}$$

3.6.2 reference power P_{pol}, P_{s} or P_{T}: Power absorbed by the gas during the reversible reference process excluding any losses. The reference power shall be defined with the subscript corresponding to the adopted reference process.

The formulae for the reference power are also different depending on the calculation system of the specific compression work.

Unless otherwise agreed the reference power is based on total conditions and is given by the following formulae.

3.6.2.1 The polytropic reference power

$$P_{\mathrm{pol,t}} = q_m \left(W_{m,\mathrm{pol}} + \frac{c_2^2 - c_1^2}{2} \right)$$

3.6.2.2 The isentropic reference power

$$P_{\mathrm{s,t}} = q_m \left(W_{m,\mathrm{s}} + \frac{c_2^2 - c_1^2}{2} \right)$$

3.6.2.3 The isothermal reference power

$$P_{\mathrm{T,t}} = q_m \left(W_{m,\mathrm{T}} + \frac{c_2^2 - c_1^2}{2} \right)$$

Where the local Mach number at the standard inlet and discharge points is less than 0,2 it is sufficiently accurate to calculate the reference power directly from total conditions using the following approximate formulae:

$$P_{\mathrm{pol,t}} \approx q_m W_{m,\mathrm{pol,t}} = q_m \int_1^2 (v\,\mathrm{d}p)_{\mathrm{t,pol}}$$

$$P_{\mathrm{s,t}} \approx q_m W_{m,\mathrm{s,t}} = q_m \int_1^2 (v\,\mathrm{d}p)_{\mathrm{t,s}}$$

$$P_{\mathrm{T,t}} \approx q_m W_{m,\mathrm{T,t}} = q_m \int_1^2 (v\,\mathrm{d}p)_{\mathrm{t,T}}$$

3.6.3 heat transmission losses, Q_α: Losses due to heat transmission from the area A_{Cs} of the compressor casing to the ambient atmosphere, expressed by the formula

$$Q_\alpha = \alpha A_{\mathrm{Cs}} (t_{\mathrm{MCs}} - t_{\mathrm{a}})$$

For values of Q_α less than 0,02 P_{e}, an approximate value can be adopted for α, i.e.

$$\alpha = 14\ \mathrm{W/(m^2 \cdot K)}$$

3.6.4 power loss due to leakage, P_{L}: Losses due to leakage through external labyrinths; these can generally be calculated using the formula

$$P_{\mathrm{L}} = \Sigma\, q_{m,\mathrm{L}} \cdot \Delta h_{\mathrm{t_L}}$$

3.6.5 internal power, P_{in}: Power effectively absorbed by gas during the actual compression process. It is given by the formula

$$P_{\mathrm{in}} = \frac{P_{\mathrm{pol,t}}}{\eta_{\mathrm{pol,t}}} + Q_\alpha + P_{\mathrm{L}}$$

or

$$P_{\mathrm{in}} = \frac{P_{\mathrm{s,t}}}{\eta_{\mathrm{s,t}}} + Q_\alpha + P_{\mathrm{L}}$$

or

$$P_{\mathrm{in}} = \frac{P_{\mathrm{T,t}}}{\eta_{\mathrm{T,t}}} + Q_\alpha + P_{\mathrm{L}}$$

For compressors with intermediate cooling the sum of internal powers in each section between two successive intercoolers should be computed:

$$P_{\mathrm{in}} = P_{\mathrm{in_I}} + P_{\mathrm{in_{II}}} + \ldots + P_{\mathrm{in}_i}$$

3.6.6 mechanical power losses, P_{f}: Losses due to friction in the bearings and sealing rings and in any transmission gear contractually included within the compressor.

3.6.7 effective compressor power, P_{e}: Power input at the coupling of the compressor or at the coupling of the transmission gear depending on the contract agreement. It is given by the formula

$$P_{\mathrm{e}} = P_{\mathrm{in}} + P_{\mathrm{f}}$$

3.6.8 power loss in driving machine, P_{Pr}: Power loss in the turbine or in any other driver of the compressor and the intermediate driving system.

3.6.9 total power of the unit, P_{un}: Power given by the formula

$$P_{\mathrm{un}} = P_{\mathrm{e}} + P_{\mathrm{Pr}}$$

3.6.10 internal efficiency, η_{in}: Ratio of the reference power defined in 3.6.2 to the internal power.

Its value depends on the type of adopted reference process. Internal efficiency is given by the formulae

$$\eta_{\mathrm{in,pol}} = \frac{P_{\mathrm{pol,t}}}{P_{\mathrm{in}}}$$

$$\eta_{\text{in,s}} = \frac{P_{\text{s,t}}}{P_{\text{in}}}$$

$$\eta_{\text{in,T}} = \frac{P_{\text{T,t}}}{P_{\text{in}}}$$

3.6.11 mechanical efficiency, η_{f}**:** Ratio of the internal power to the effective power at the coupling of the compressor, or at the coupling of the transmission gear, depending on the contract agreement. It is given by the formula

$$\eta_{\text{f}} = \frac{P_{\text{in}}}{P_{\text{e}}} = \frac{P_{\text{in}}}{P_{\text{in}} + P_{\text{f}}}$$

3.6.12 effective efficiency, η_{e}**:** Ratio of the reference power defined in 3.6.2 to the effective power at the coupling of the compressor, or at the coupling of the transmission gear, depending on the contract agreement. It is given by the formula

$$\eta_{\text{e}} = \frac{q_m \int_1^2 (v\,\mathrm{d}p)_{\text{t}}}{P_{\text{e}}} = \eta_{\text{in}}\,\eta_{\text{f}}$$

Its value depends on the type of adopted reference process.

3.6.13 primary efficiency, η_{Pr}**:** Ratio of the effective power of the compressor to the power or energy input to the driver. It is given by the formula

$$\eta_{\text{Pr}} = \frac{P_{\text{e}}}{P_{\text{un}}} = \frac{P_{\text{e}}}{P_{\text{e}} + P_{\text{Pr}}}$$

3.6.14 overall efficiency of the unit, η_{un}**:** Efficiency of the unit which takes account of all energy losses of the unit, including compressor, transmission gear and driver. It is given by the formula

$$\eta_{\text{un}} = \eta_{\text{e}}\,\eta_{\text{Pr}}$$

3.7 Definition of tolerance, inaccuracy and uncertainty

As used in this International Standard, the terms "tolerance", "inaccuracy" and "uncertainty" have specific and clearly different meanings.

3.7.1 tolerance: Amount by which the value of a particular parameter or a quantity is permitted to deviate from a set value by the terms of the contract or other agreement.

3.7.2 inaccuracy: Extent by which the measured or computed value of a parameter or quantity deviates from the true value, resulting from the inevitable errors in measurement and computation.

3.7.3 uncertainty: Maximum likely magnitude of the inaccuracy of a particular parameter or quantity such that it can be said with at least 95 % confidence that the measured or computed value does not deviate from the true value by an amount greater than the stated uncertainty.

4 Symbols and subscripts

The symbols, subscripts and definitions used in this International Standard are in accordance with ISO 31 and ISO 1000, and are given in tables 3 and 4.

Equations used are dimensionally homogeneous.

To simplify use of this International Standard, conversion factors are given in annex C.

Table 3 — Symbols

Symbols	Quantities	Definitions and observations	Dimensions[1)]
A	Area		$\mathrm{L^2}$
a	Sonic velocity	$a = \sqrt{\kappa ZRT}$	$\mathrm{LT^{-1}}$
b	Outlet tip width		L
C_p	Molar specific heat at constant pressure	$C_p = Mc_p$	$\mathrm{ML^2T^{-2}\Theta^{-1}mol^{-1}}$
C_V	Molar specific heat at constant volume	$C_V = Mc_V$	$\mathrm{ML^2T^{-2}\Theta^{-1}mol^{-1}}$
c	Absolute velocity		$\mathrm{LT^{-1}}$
c_p	Specific heat at constant pressure		$\mathrm{L^2T^{-2}\Theta^{-1}}$
c_V	Specific heat at constant volume		$\mathrm{L^2T^{-2}\Theta^{-1}}$
D	Reference diameter of the rotor		L
F	Torque		$\mathrm{ML^2T^{-2}}$
G	Precision class		dimensionless
h	Specific enthalpy		$\mathrm{L^2T^{-2}}$
h_t	Total specific enthalpy	$h_\mathrm{t} = h + \left(\frac{c^2}{2}\right)$	$\mathrm{L^2T^{-2}}$
M	Molar mass	Mass which corresponds to one mole	M
Ma	Mach number of the flow	$Ma = \frac{c}{a}$	dimensionless
Ma_t	Approximate Mach number of gas flow through area A	$Ma_\mathrm{t} = \frac{q_m}{A\,p_\mathrm{t}}\sqrt{\frac{ZRT_\mathrm{t}}{\kappa}}$	dimensionless
Ma_u	Peripheral Mach number (arbitrary definition)	Refers in this International Standard to inlet conditions	dimensionless
m	Polytropic exponent in the $p-T$ diagram	$\frac{p^m}{T}$ = constant See also 3.5.3.3	dimensionless
m_i	Mass proportion of a gas component		dimensionless
N	Speed of rotation		$\mathrm{T^{-1}}$
N_r	Ratio of reduced speeds	$N_\mathrm{r} = \left(\frac{N}{\sqrt{RZ_1T_{\mathrm{t},1}}}\right)_\mathrm{Te} \Bigg/ \left(\frac{N}{\sqrt{RZ_1T_{\mathrm{t},1}}}\right)_\mathrm{Gu}$	dimensionless
n	Polytropic exponent in the $p-V$ diagram	pV^n = constant See also 3.4.1	dimensionless
P	Power		$\mathrm{ML^2T^{-3}}$
p	Absolute static pressure	Force to be exerted on the unit area moving with the gas	$\mathrm{ML^{-1}T^{-2}}$
p_a	Atmospheric pressure		$\mathrm{ML^{-1}T^{-2}}$
p_d	Dynamic pressure	See 8.1.3	$\mathrm{ML^{-1}T^{-2}}$
p_e	Effective (or gauge) pressure	$p_\mathrm{e} = p - p_\mathrm{a}$	$\mathrm{ML^{-1}T^{-2}}$
p_sat	Saturation pressure	Saturation pressure at temperature of the vapour-gas mixture	$\mathrm{ML^{-1}T^{-2}}$
p_t	Total pressure	$p_\mathrm{t} = p + p_\mathrm{d}$	$\mathrm{ML^{-1}T^{-2}}$

Table 3 — Symbols (*continued*)

Symbols	Quantities	Definitions and observations	Dimensions[1)]
p_V	Partial vapour pressure		$ML^{-1}T^{-2}$
Q	Heat flow	Quantity of heat supplied or delivered per unit time	ML^2T^{-3}
Q_{co}	Corrected heat losses (equivalent)		ML^2T^{-3}
Q_{in}	Internal heat losses (equivalent)		ML^2T^{-3}
Q_{me}	Mechanical heat losses (equivalent)		ML^2T^{-3}
Q_α	Heat losses by thermal transmission from the surface		ML^2T^{-3}
q_m	Mass rate of flow		MT^{-1}
q_V	Volume rate of flow		L^3T^{-1}
R	Specific gas constant	$R = \frac{R_{mol}}{M}$	$L^2T^{-2}\Theta^{-1}$
Re_u	Peripheral Reynolds number (arbitrary)	$Re_u = \frac{ub}{\nu_{t,1}}$ Refers in this International Standard to total inlet conditions	dimensionless
R_{mol}	Universal gas constant	$R_{mol} = 8\,314$ J·kmol^{-1}·K^{-1}	$ML^2T^{-2}\Theta^{-1}$ mol^{-1}
r_i	Volumetric proportion of a component		dimensionless
s	Specific entropy		$L^2T^{-2}\Theta^{-1}$
T	Absolute static temperature	Temperature on Kelvin scale	Θ
t	Usual static temperature	Temperature on Celsius scale	Θ
t_d, T_d	Dynamic temperature		Θ
t_{sat}, T_{sat}	Saturation temperature		Θ
t_t, T_t	Stagnation temperature (total)	$t_t = t + t_d$ $T_t = T + T_d$ See 8.1.4	Θ
u	Peripheral velocity	$u = \pi DN$ Peripheral velocity at reference diameter	LT^{-1}
V	Volume		L^3
V_r	Ratio of volume rate of flow ratios	$V_r = \frac{(q_{V,t,2}/q_{V,t,1})_{Te}}{(q_{V,t,2}/q_{V,t,1})_{Gu}}$	dimensionless
v	Specific volume	Volume per unit mass	$M^{-1}L^3$
W_m	Specific compression work	$W_m = \int v\,dp$	L^2T^{-2}
X	Isobaric deviation factor	See 3.2.4	dimensionless
x	Variable		as used
Y	Isothermal deviation factor	See 3.2.3	dimensionless
y	Molar proportion		dimensionless
Z	Compressibility factor	See 3.2.2	dimensionless
z	Number of stages considered	Indicates also number of stage groups separated by intercoolers	dimensionless
α	Heat transfer coefficient	Rate of heat flow per unit area of surface per unit temperature difference	$MT^{-3}\Theta^{-1}$
γ	Ratio of specific heats	$\gamma = \frac{c_p}{c_V}$	dimensionless

Table 3 — Symbols (*concluded*)

Symbols	Quantities	Definitions and observations	Dimensions[1]
Γ	Work input coefficient	$\Gamma = \frac{\Delta h_t}{u^2}$	dimensionless
Δx	Absolute difference or variation of x		same as for x
$\frac{\Delta x}{x}$	Relative difference or variation		dimensionless
δ	Blade position	Position of adjustable guide vanes or blades	
ε_x	Absolute possible deviation of x		same as for x
$\frac{\varepsilon_x}{x}$	Relative deviation		dimensionless
ζ_i	Coefficient	$i = 3, 4$ or p (see clause 9)	dimensionless
η	Efficiency		dimensionless
κ	Isentropic exponent	$\kappa = -\frac{V}{p}\left(\frac{\partial p}{\partial V}\right)_S$	dimensionless
λ_{ik}	Coefficient	$i = 1, 2, 3 \ldots$ (see annex B) $k = 1, 2, 3 \ldots$	dimensionless
μ	Dynamic viscosity		$\mathrm{ML^{-1}T^{-1}}$
ν	Kinematic viscosity	$\nu = \frac{\mu}{\varrho}$	$\mathrm{L^2T^{-1}}$
ξ	Correction factor	See 3.5.3.4, 3.5.3.5 and 3.5.3.6	dimensionless
ϱ	Density	Mass per unit volume	$\mathrm{ML^{-3}}$
σ	Standard deviation	See 5.9.4	same as for x
τ_x	Relative measuring uncertainty or tolerance on x	See 3.7	dimensionless
Φ	Flow coefficient	$\Phi = \frac{q_{V,t}}{D^2 u}$	dimensionless
φ	Relative humidity	See A.4.2.1	dimensionless
χ	Humidity content	See A.4.2.1	dimensionless
Ψ	Reference process work coefficient	$\Psi_i = \frac{W_{m,i}}{u^2}$ where i = pol, s or T	dimensionless
ω	Acentric factor	See A.3.1	dimensionless

[1] L = length; M = mass; T = time; Θ = temperature; mol = amount of substance.

Table 4 — Subscripts

Subscripts	Meaning	Observations
I, II, ..., j	Section I, Section II, ..., Section j	The Roman type figures relate to numbers of order of the compressor sections
$\mathrm{II_c}$	Cooled section	Cooled section when compressor is divided into uncooled section I and cooled section $\mathrm{II_c}$
1	Inlet	Relates to quantities measured at the standard inlet point. In combination with other subscripts denotes "inlet"
2	Discharge	Relates to quantities measured at the standard discharge point. In combination with other subscripts denotes "outlet"
a	Atmospheric	Characterizes atmospheric pressures and temperatures
adj	Additional	Additional uncertainty when inner tolerance limit is exceeded (see clause D.2)
Cd	Condensate	
Co	Converted	Relates to the quantities converted to specified conditions by similarity computation
Cr	Critical	Characterizes critical pressures and temperatures
Cs	Casing	Characterizes the quantities measured on the compressor casing
comb	Combined	When x_{comb} is combined by superposition of results of several stages
D	Rotor	
d	Dynamic	Characterizes dynamic pressures and temperatures
En	End	
Ex	Extreme	
e	Effective	Characterizes the power input at the coupling of the compressor
el	Electrical	
f	Friction	Characterizes the friction losses (mechanical losses)
fluc	Fluctuation	Additional uncertainty due to fluctuations of power input
G	Dry gas	Characterizes the quantities of dry gas
Gu	Guaranteed	Relates to the quantities specified in the contract
$\mathrm{IC_I}$, $\mathrm{IC_{II}}$, ..., IC_j	Intercooler I, II, ..., j	Relates to first, second, ..., jth intercooler
i	Component	Relates to component i of a gas mixture
in	Internal	
L	Leakage	
M	Arithmetic mean	Characterizes the arithmetical means of inlet and outlet quantities
m	Mixture	
max	Maximum	
min	Minimum	
mol	Molar	
oil	Oil	Characterizes lubricating (and sealing) oil (mechanical losses)
Pr	Primary	Characterizes the driver of the compressor
p	Isobaric	Characterizes an isobaric (constant pressure) process
pol	Polytropic	Characterizes a polytropic process
r	Reduced	Characterizes reduced pressures and temperatures
res	Resulting	When x results from combination of several variables with individual errors
s	Isentropic	Characterizes an isentropic process