# INTERNATIONAL STANDARD

# ISO 5389

Second edition
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## Turbocompressors — Performance test code

*Turbocompresseurs — Code d'essais 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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

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 5389 was prepared by Technical Committee ISO/TC 118, *Compressors and pneumatic tools, machines and equipment*, Subcommittee SC 1, *Process compressors*.



This second edition cancels and replaces the first edition (ISO 5389:1992), which has been technically revised. In particular, an improved flow Sheet for determination of setting conditions using similarity conditions has been integrated, taking into account the Reynolds number correction method.

Three classes of conversion of test results have been defined, including tests beyond flow similarity conditions.



The subclause on measuring uncertainties has been revised. The tried and proven procedure for determination of measuring uncertainties using the difference method has been added in order to be able to meet all test requirements, including in particular those occurring in the case of multicasing compressors and machine sets consisting of different driving machines and compressors.

The subclause on guarantee comparison has been enlarged, taking into account all possible cases of performance curves and guarantee points.

ISO 5389 was prepared, based on ASME PTC 10 [1] and VDI 2045-1 [2] and VDI 2045-2 [3].

 

# Turbocompressors — Performance test code

## 1 Scope

This International Standard applies to performance tests on turbocompressors of all types. It does not apply to fans and high-vacuum pumps, or to jet-type compressors with moving drive components

Turbocompressors comprise machines in which inlet, compression and discharge are continuous flow processes. The gas is conveyed and compressed in impellers and decelerated with further increase in pressure in fixed vaned or vaneless stators.

This International Standard is intended to provide standard provisions for the preparation, procedure, evaluation and assessment of performance tests on compressors as specified above. The acceptance test of the performance is based on this performance test code. Acceptance tests are intended to demonstrate fulfilment of the order conditions and guarantees specified in the contract.

## 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 5167-1, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

## 3 Symbols and definitions

### 3.1 Symbols and units

#### 3.1.1 Latin letters

| Symbol | Meaning | Unit |
|---|---|---|
| $A$ | area | m$^2$ |
| $a$ | sonic velocity | m/s |
| $B$ | manufacturing tolerance | % |
| $b$ | outlet width of 1st impeller | m |
| $c$ | velocity | m/s |
| $c_p$, $c_v$ | specific heat capacity | kJ/(kg·K) |
| $c_\mathrm{i}$ | evaluation coefficients | — |
| $D$ | outer impeller diameter of the first impeller | m |
| $f$ | correction factor | — |
| $f_\mathrm{x}$ | mean relative deviation | |

| Symbol | Meaning | Unit |
|---|---|---|
| $G$ | quality grade | % |
| $g$ | local acceleration due to gravity | $m/s^2$ |
| $h$ | specific enthalpy | kJ/kg |
| $k$ | isentropic exponent | — |
| $k_T$ | isentropic exponent, temperature | — |
| $k_V$ | isentropic exponent, volume | |
| $l$ | length of column | mm |
| $Ma$ | Mach number | — |
| $M_{\mathrm{t}}$ | torque | Nm |
| $M$ | molar mass | kg/mol |
| $m$ | temperature exponent | — |
| $\dot{m}$ | mass flow | kg/s |
| $N$ | speed of rotation | 1/s |
| $n$ | polytropic exponent | — |
| $P$ | power | kW |
| $p$ | pressure | MPa (bar) |
| $\dot{Q}$ | heat flow | kW |
| $R$ | specific gas constant | J/(kg·K) |
| $Ra$ | average roughness | µm |
| $R_{\mathrm{mol}}$ | universal gas constant | J/(kmol·K) |
| $Re$ | Reynolds number | — |
| $S$ | digital measuring step | — |
| $s$ | specific entropy | kJ/(kg·K) |
| $T$ | thermodynamic temperature | K |
| $t$ | temperature | °C |
| $u$ | tip speed, referred to $D$ | m/s |
| $u$ | specific internal energy | kJ/kg |
| $V$ | confidence interval or measuring uncertainty | — |
| $v$ | specific volume | $m^3/kg$ |
| $\dot{V}$ | volume flow | $m^3/s$ |
| $W$ | result function | — |
| $w$ | mass fraction | — |
| $X$ | compressibility function | — |
| $X_N$ | ratio of reduced speeds of rotation | — |
| $x$ | vapour content referred to moist mass of vapour of the same gas | kg/kg |
| $x_{\mathrm{(Subscript)}}$ | vapour content of vapour/gas mixtures referred to dry gas | kg/kg |
| $Y$ | compressibility function | — |
| $y$ | function value | — |

| Symbol | Meaning | Unit |
|---|---|---|
| $y$ | specific compression work | kJ/kg |
| $Z$ | compressibility factor | — |
| $z$ | number of stage groups | — |

### 3.1.2 Greek letters

| Symbol | Meaning | Unit |
|---|---|---|
| $\alpha$ | coefficient of heat transfer | W/(m$^2$·K) |
| $\beta$ | coefficient of cubic expansion | 1/K |
| $\gamma$ | weighting factor | — |
| $\Delta$ | difference | — |
| $\varepsilon$ | calculation coefficient | — |
| $\eta$ | efficiency | — |
| $\eta$ | dynamic viscosity | Ns/m$^2$ |
| $\vartheta$ | ratio of $(RZ_1 T_1)$ values | — |
| $\kappa$ | ratio of specific heat capacities | — |
| $\nu$ | polytropic ratio | — |
| $\nu$ | kinematic viscosity | m$^2$/s |
| $\Pi$ | pressure ratio | — |
| $\rho$ | density | kg/m$^3$ |
| $\tau$ | relative uncertainty of measurement | — |
| $\phi$ | ratio of volume flow ratios | — |
| $\varphi$ | flow coefficient | — |
| $\varphi$(Subscript) | relative humidity | — |
| $\psi$ | reference process work coefficient | — |
| $\omega$ | angular speed | 1/s |



### 3.1.3 Subscripts

| Index | Meaning |
|---|---|
| 1 | inlet (suction side) |
| 2 | outlet (discharge side) |
| I, II, III, ..., $z$ | stages, numbered in direction of flow |
| $\infty$ | at an infinitely large Reynolds number |
| A | uncooled section of an intercooled compressor |
| air | dry air |
| amb | ambient (air, temperature) |
| an | assumption, driving machine |
| av | average |
| B | cooled section of a multi-stage intercooled compressor |
| cal | calibration |

| Index | Meaning |
|---|---|
| co | converted to guarantee conditions |
| cog | converted to the pressure ratio and inlet volume flow of the guarantee point |
| comb | combined sections |
| cond | condensate |
| cou | coupling |
| crit | critical |
| d | dynamic |
| dev | deviation |
| dr | driving machine |
| dry | dry |
| eff | effective |
| Ex | extreme value of $\phi$ |
| g | guarantee or reference conditions |
| gas | gas |
| $i$ | $i$th term of a sum ($i$ = 1, 2, 3, ...) |
| i | internal |
| in | input |
| $j$ | number of stage group ($j$ = I, II, III, ..., $z$) |
| k | isentropic exponent |
| L | leakage |
| lub | lubricant |
| M | measurement, motor |
| $\dot{m}$ | mass flow |
| mech | mechanical |
| n | standard state |
| $N$ | frequency of rotation |
| out | output |
| p | polytropic |
| $P$ | power |
| Pr | reference or standard process |
| pr | precalculated or predicted test results |
| rad | radiation and convection |
| ran | relevant measuring range of instrument |
| Re | referred to Reynolds number |
| red | reduced speed |
| ref | reference value |
| res | result |
| s | isentropic |
| sat | saturated steam/vapour |

| Index | Meaning |
|---|---|
| seal | sealing liquid |
| side | sidestream or extractions |
| st | static |
| sup | supply |
| sur | surface |
| sys | system |
| T | isothermal |
| t | temperature |
| te | test result |
| term | terminals |
| tol | permissible deviation |
| tot | total |
| u | tip or peripheral |
| us | usable |
| $V$ | volume |
| vap | vapour, steam |
| wet | moist |
| wf | working fluid |
| W | cooling water or coolant |
| x | between inlet and outlet |
| y | function value |



Where no specific remark is made to the contrary, the thermodynamic variables of state used without indices in this International Standard describe total state.

## 3.2 Definitions

For the purposes of this document, the following terms and definitions apply. Additional terms and definitions are given in Annex E.

**3.2.1**
**ratio of volume flow ratios**

$$\phi = \frac{\left(\dot{V}_1 / \dot{V}_2\right)_{\text{te}}}{\left(\dot{V}_1 / \dot{V}_2\right)_{\text{g}}} \tag{1}$$

**3.2.2**
**ratio of reduced speeds of rotation**

$$X_N = \frac{\left(\dfrac{N}{\sqrt{R \cdot Z_1 \cdot T_1}}\right)_{\text{te}}}{\left(\dfrac{N}{\sqrt{R \cdot Z_1 \cdot T_1}}\right)_{\text{g}}} \tag{2}$$

**3.2.3**
**tip Mach number**

$$Ma_u = \frac{u}{a_1} \tag{3}$$

**3.2.4**
**tip Reynolds number**

$$Re_u = \frac{ub}{\upsilon_1} \tag{4}$$

**3.2.5**
**volume flow coefficient**

$$\varphi = \frac{\dot{V}_1}{\frac{\pi}{4} \cdot D^2 \cdot u} \tag{5}$$

**3.2.6**
**reference process work coefficient**

$$\psi_{Pr} = \frac{y_{Pr}}{u^2/2} \tag{6}$$

**3.2.7**
**enthalpy coefficient**

$$\psi_i = \frac{\Delta h}{u^2/2} \tag{7}$$



**3.2.8**
$RZ_1T_1$ **ratio**

$$\vartheta_j = \frac{(R \cdot Z_1 \cdot T_1)_j}{(R \cdot Z_1 \cdot T_1)_I} \qquad \vartheta_{j,B} = \frac{(R \cdot Z_1 \cdot T_1)_j}{(R \cdot Z_1 \cdot T_1)_{I,B}} \tag{8}$$

where I,B is the first stage of cooled section B

**3.2.9**
**section**
one to several successive stages of a turbocompressor without intercooling through which the same mass flow flows

## 4 Guarantees

### 4.1 General

The customer and the manufacturer shall make a contractual agreement specifying which properties and characteristics of the compressor are to be guaranteed and demonstrated by the acceptance test. Verification of these properties is effected by means of the values measured in the acceptance test and converted to the guarantee conditions.

Fulfilment of the guarantee may be demanded only if all components of the compressor system are in correct condition at the acceptance test (see 6.1.3).

 

### 4.2 Preconditions for the guarantee

The conditions that apply as a precondition for the guarantee, modification of which will affect the functioning of the compressor, shall be specified in the contract of supply. These conditions can include the following:

a) inlet pressure (or discharge pressure in the case of suction-type compressors) and inlet temperature;

b) in the case of inward sidestreams, their thermodynamic states and the ratio of the side mass flows to the inlet mass flow, in the case of intermediate extraction the ratio of the extracted mass flows to the inlet mass flow and the extraction pressure;

c) in the case of intercooled compressors, the recooling temperatures and pressure drops between the relevant compressor sections;

d) physical properties of the gas or vapour and its composition in volume or mass fractions;

e) coolant, its mass flow and inlet temperature;

f) operating conditions of the driving machine (e.g. enthalpy differences, inlet and outlet state, heat value of the fuel, type, voltage and frequency of electrical current, speed);

g) inlet and outlet state referred to the inlet and outlet flow area of the compressor;

h) speed (necessary deviations to meet the guarantee points shall be agreed upon between customer and manufacturer).



### 4.3 Object of the guarantee

The following values can be guaranteed under the preconditions specified in 4.2:



a) actual inlet volume flow as defined in E.4.2;

b) discharge pressure (or inlet pressure in the case of suction-type compressors) and intermediate pressures in the case of inward sidestreams and intermediate extraction;

c) the power for specified inlet volume flows and discharge pressures (or inlet pressures in the case of vacuum-type compressors) in the form of

- compressor power at the compressor coupling, or
- power of the compressor with gearbox at the coupling of the driving machine, or
- electrical power at the terminals of the drive motor, or
- driving machine fuel consumption.

Where the compressor and driving machine have common components (e.g., bearings, oil pumps, etc.), an agreement shall be made specifying the manner in which the losses occurring inside the components are to be apportioned (see 5.9).

The related power or the efficiency related to a suitable reference process (see E.5) may also be guaranteed instead of power.

d) the power of auxiliary machinery (e.g. oil pumps or cooling-water pumps) where such is not included in the guaranteed power;

 

e) operating range limits, as follows:

- maximum actual inlet volume flow at a specified discharge pressure or maximum pressure at a specified actual inlet volume flow,
- minimum actual inlet volume flow at a specified discharge pressure,
- surge limit.

See E.9.

### 4.4 Supplementary guarantees

Additional guarantees (for part-load efficiencies, sealants, temperature of the gas compressed, cooling efficiency of coolers and condensers) can be required in cases were they are of significance for operation, or for any other reasons.

### 4.5 Guarantee comparison

In case of an acceptance test, the test results measured and converted to the guarantee conditions shall be assessed against the values guaranteed (see Clause 8), making allowance for the limits of measuring uncertainties (see 6.4).

Any manufacturing tolerances for the guarantee shall be deemed to constitute a component of the contract of supply and not of this International Standard.



### 4.6 Guarantees for series production

Where a series of compressors of the same design are manufactured within a short period of time, it is not customary to perform an acceptance test on each individual compressor. Such a test performed on a few compressors selected at random from the series and completed successfully, constituting a type-test, shall be deemed to suffice. The details of this procedure shall be governed by the contract of supply.



## 5 Measuring methods and measuring equipment

### 5.1 General

#### 5.1.1 Measuring methods and measuring uncertainties

Following measuring methods and measuring instruments inclusive of the rules necessary for their use shall be used if applicable.

Other measuring methods may be used upon agreement regarding testing and fitting.

#### 5.1.2 Facilities for measurement

The measuring points and equipment for measurement of pressure, temperature, flow, power and speed shall be incorporated into the compressor during design and during its installation into the subsequent system. Above all, it shall be ensured at all points for measurement of flow as specified in ISO 5167-1 that adequate lengths of straight pipe are available and suitable flanged joints for installation of the orifices and nozzles. Figures E.3 and E.4 illustrate a suitable arrangement for two measuring points each for pressure and temperature on the compressor. Guarantees should be referred to the measuring points provided and prepared. Sockets for reference instruments should be provided at the main measuring points.

 

#### 5.1.3 Measuring instruments

The following measuring instruments shall be used for acceptance tests:

a) measuring instruments which have been calibrated by comparison with measuring instruments as specified in 5.1.3 c),

b) measuring instruments for which a calibration or test certificate issued by an accredited authority is submitted,

c) other tried and proven measuring instruments of a known accuracy, the use of which has been agreed between the parties to the contract.

All measuring instruments (and orifices and nozzles in particular) shall be checked immediately before installation and/or before and after the test for condition and dimensional accuracy. It shall, in addition, be ensured that the installation point, installation itself, and the measuring instrument itself comply with the relevant specifications. The result of this check shall be recorded.

#### 5.1.4 Use of transducers; data acquisition

When electronic measuring instruments are used with transducers of any type and digital evaluation is possible, the transducers shall be calibrated and a record kept of calibration. It shall be possible to check the measuring systems by suitable means. This provision applies analogously to the use of data acquisition systems and electronic data processing.

### 5.2 Pressures



#### 5.2.1 Static pressure

The static pressure present at a wall should be measured by means of holes drilled in the wall. Such holes shall have neither a burr on the wall surface, nor a flared opening. The diameter of the holes shall be kept as small as possible; the lower limit is that adequate to avoid the danger of blockage.

In long straight pipes, flow parallel to the pipe axis is established. The static pressure may then be assumed to be constant in every flat flow cross-section perpendicular to the axis of the pipe; sampling of pressure by means of a hole drilled in the pipe wall then suffices for the purpose of measurement (see Figures E.3 and E.4 for the pressure-sampling apparatus).

#### 5.2.2 Dynamic pressure and total pressure

Where an average velocity, $c$, is known from flow measurement and flow area, an average dynamic pressure, $p_{\mathrm{d}}$, can be calculated from this and with the static pressure, $p$, an average total pressure, $p_{\mathrm{tot}}$, can be calculated as follows:

For the average velocity:

$$c = -\frac{c_p \cdot p \cdot A}{\dot{m} \cdot R \cdot Z} + \sqrt{\left(\frac{c_p \cdot p \cdot A}{\dot{m} \cdot R \cdot Z}\right)^2 + 2 \cdot c_p \cdot T_{\mathrm{tot}}} \qquad (9)$$

For the ratio of total to static pressure:

$$\frac{p_{\mathrm{tot}}}{p} = \frac{p + p_{\mathrm{d}}}{p} = \left(\frac{T_{\mathrm{tot}}}{T}\right)^{\frac{k}{k-1}} \qquad (10)$$

This approximation for the calculation of the dynamic and total pressure with the average velocity, $c$, is regarded as sufficiently accurate in the scope of the present rules.

### 5.2.3 Installation of measuring lines

Measuring lines installed between the sampling point and the display instrument shall be installed with great care. Any leaks shall be eliminated. Provisions shall be made to prevent blockage by foreign bodies. Where condensate occurs in the measuring lines, such lines shall be completely filled with condensate or shall be reliably kept free of condensate (e.g. by arranging the measuring instrument at a geodetic higher level than the measuring point).

## 5.3 Temperatures

The static temperature, $T$, and total temperature, $T_{tot}$, cannot be directly measured as variables of state of a gas in flow.

Ratio of total to static temperature:

$$\frac{T_{tot}}{T} = \frac{1}{1 - \frac{c^2}{2 \cdot c_p \cdot T_{tot}}} \qquad (11)$$

Temperature sensors of conventional type and size (liquid thermometers, thermocouples, resistance thermometers with or without thermowells for installation) gravitate, even when correctly installed, to their so-called characteristic temperature, which is located between $T$ and $T_{tot}$, as soon as they are exposed to the flowing gas. There are, however, temperature probes ("total temperature measurement instruments") such as plate-type, hook, and diffusor thermometers, the indication of which approximates extremely closely to the total temperature (temperature at rest) of the gas.



Where it can be shown that the velocity recovery effect is insignificant, it may be neglected. In no case should it be neglected if the dynamic head exceeds 0,5 % of the specific compression work. The velocity recovery factor to be used should be agreed on. In the absence of any more specific values, the following may be used:

a) thermometers and thermocouples in wells: 0,65;

b) bare thermocouples: 0,80;

c) bare thermocouples with insulation shields: 0,97.

## 5.4 Gas density

For gases and vapours of known composition, density can be determined from equations of state, state charts, or tables. In the case of gas mixtures of unknown composition, density should be measured directly using an acknowledged method.

## 5.5 Gas composition

### 5.5.1 General

Where mixtures of gases or gas/vapour mixtures are being compressed, the composition of the mixture shall, if necessary, be checked at regular intervals using an acknowledged method. The frequency, nature and accuracy of such checks will vary according to fluctuations in gas composition.

 

#### 5.5.2 Moisture content

##### 5.5.2.1 Air humidity

The relative humidity, expressed in percent, of air at atmospheric pressure ($p_{amb}$) can be calculated as follows using the temperatures read on the wet ($t_{wet}$) and dry ($t_{dry}$) thermometer of a psychrometer (as defined, for instance, by *Assmann*) using Sprung's approximation equation:

$$\varphi_{vap} = \frac{p_{sat} - 0{,}5 \cdot \left(t_{dry} - t_{wet}\right) \cdot \frac{p_{amb}}{755}}{p_{dry}} \cdot 100 \qquad (12)$$

where

$p_{sat}$ is the saturated vapour pressure at $t_{wet}$;

$p_{dry}$ is the saturated vapour pressure at $t_{dry}$;

$p_{amb}$ is the ambient pressure reading.

Relative humidity ($\varphi_{vap}$) can be read from an $h_{air}$ - $x_{air}$ chart for any pressure, $p$, of the air at known values for $t_{wet}$ and $t_{dry}$ and the barometer level $p_{amb}$.

The relative humidity of compressed air can be determined by diverting a side stream from the centre of the pressure line and depressurizing it to atmospheric pressure. The relative humidity, $\varphi_{vap}$, measured at atmospheric pressure, shall then be converted to the state in the line.



Recognized methods other than the psychrometric measuring method are also permissible (e.g. the dewpoint, freezing-out, lithium chloride and absorption methods).



##### 5.5.2.2 Moisture in other gases

The other methods mentioned in 5.5.2.1 are recommended for use with gases other than air [instead of Equation (12)].

### 5.6 Gas velocity

#### 5.6.1 Quantitative measurement

The numerical value for local velocity can be measured using indicating anemometers or probes (e.g. Prandtl or pitot tube), which are non-direction-dependent within certain limits (see 5.7.3).

#### 5.6.2 Determination of direction

The direction of velocity can be determined using fixed calibrated probes, or by means of the pressure differences measured at adjustable probes.

Determination of direction is not necessary in long straight piping sections.

### 5.7 Volume flow and mass flow

#### 5.7.1 Flow measurement using orifices and nozzles

ISO 5167-1 is definitive for measurement of flow using orifices and nozzles. Measurement may be effected using non-standardized orifices and nozzles if special agreements to this effect have been made (see e.g. References [4] and [5]).