
British Standard

Testing of positive displacement compressors and exhausters

Part 1. Methods for acceptance testing

[ISO title: Displacement compressors — Acceptance tests]

Essais des compresseurs et extracteurs volumétriques

Partie 1. Méthodes d'essai de réception

Prüfung von Verdrängerkompressoren und Sauglüftern

Teil 1. Abnahmeprüfung

Contents

	Page		Page
National foreword		Inside front cover	
Committees responsible		Back cover	
Specification			
1 Scope and field of application	2	4 Tolerance for load fluctuation	17
2 References	2	5 Acceptable deviation in percent from type test nominal values	20
3 Definitions	3	6 Dimensions of nozzles and tolerances	26
4 Symbols, units and subscripts	5	7 Nozzle dimensions	30
5 Measuring equipment and methods	6	8 Specified conditions for the guarantee	39
6 Test method	9	9 Guaranteed performance	40
7 Acceptance test for liquid-ring compressors	13	10 Average of test readings	41
8 Accuracy of measurement	15	11 Calculated figures	42
9 Test report and comparison with specified values	18	12 Specified conditions for the guarantee	45
		13 Guaranteed performance	46
		14 Average of test readings	47
		15 Specified conditions for the guarantee	52
		16 Guaranteed performance	52
		17 Average of test readings	53
		18 Calculated figures	54
Annexes		19 Specified conditions for the guarantee	55
A Simplified test of a compressor	20	20 Guaranteed performance	55
B Specification of operating and testing conditions	21	21 Test readings	56
C Performance statements for packaged air compressors of displacement type	23	22 Specified conditions for the guarantee	58
D Flow measurement with a flow straightener	24	23 Guaranteed performance	58
E Simplified method for air volume flow rate measurement by means of circular arc venturi nozzles at critical flow conditions	29	24 Test readings	59
F Alternative methods for determining volume flow rates	32		
G Other measurements of interest	35	Figures	
H Method for measuring specific energy requirement	36	1 Perforated plate for flow straightener	25
I Derivation of the humidity correction formula	37	2 5,56, 9,53 and 15,88 diameter nozzles	27
J Typical test reports	39	3 Nozzles 25,4 mm diameter and larger	28
		4 Measuring pipe	29
		5 Circular arc venturi nozzle	30
		6 Test layout	33
		7 Test layout	40
		8 Test layout	46
		9 Test layout	53
		10 Test layout	56
		11 Test layout	59
Tables			
1 Maximum deviations from specified values and fluctuations from average readings	10		
2 Maximum deviations from the specified values during an acceptance test	13		
3 Inaccuracy of measurement, $\tilde{V}_\theta$, for calibrated liquid-in-glass thermometers	15		

National foreword

This revision of Part 1 of BS 1571, which has been prepared under the direction of the Machinery and Components Standards Committee, supersedes BS 1571 : Part 1 : 1975 which is withdrawn. It is identical with ISO 1217-1986, 'Displacement compressors — Acceptance tests' which was prepared by Technical Committee ISO/TC 118, Compressors, pneumatic tools and pneumatic machines, of the International Organization for Standardization (ISO) and in the development of which the United Kingdom played an active part.

For simplified acceptance tests for air compressors and exhausters, reference should be made to BS 1571 : Part 2.

Terminology and conventions. The text of the international standard has been approved as suitable for publication as a British Standard without deviation. Some terminology and certain conventions are not identical with those used in British Standards; attention is drawn especially to the following.

The comma has been used as a decimal marker. In British Standards it is current practice to use a full point on the baseline as the decimal marker.

Wherever the words 'International Standard' appear, referring to this standard, they should be read as 'British Standard'.

Cross-references

International standard	Corresponding British Standard
ISO 1000-1981	BS 5555 : 1981 Specification for SI units and recommendations for the use of their multiples and of certain other units (Identical)
ISO 1219-1976	BS 2917 : 1977 Specification for graphical symbols used on diagrams for fluid power systems and components (Identical)
ISO 2602-1980	BS 2846 Guide to statistical interpretation of data Part 2 : 1981 Estimation of the mean: confidence interval (Identical)
ISO 2854-1976	Part 4 : 1976 Techniques of estimation and tests relating to means and variances (Identical)
ISO 2954-1975	BS 4675 Mechanical vibration in rotating machinery Part 2 : 1978 Requirements for instruments for measuring vibration severity (Identical)
ISO 3046	BS 5514 Reciprocating internal combustion engines : performance (Identical)
ISO 3744-1981	BS 4196 Sound power levels of noise sources Part 4 : 1981 Engineering methods for determination of sound power levels for sources in free-field conditions over a reflecting plane (Identical)
ISO 3857/1-1977	BS 5791 Glossary of terms for compressors, pneumatic tools and machines Part 1 : 1979 General (Identical)
ISO 3857/2-1977	Part 2 : 1979 Compressors (Identical)
ISO 5167-1980	BS 1042 Measurement of fluid flow in closed conduits Section 1.1 : 1981 Specification for square-edged orifice plates, nozzles and venturi tubes inserted in circular cross section conduits running full (Technically equivalent)
BS 5168-1978	BS 5844 : 1980 Methods of measurement of fluid flow: estimation of uncertainty of a flow-rate measurement (Identical)
ISO 5388-1981	BS 6244 : 1982 Code of practice for stationary air compressors (Identical)
IEC 51 : 1973	BS 89 : 1977 Specification for direct acting indicating electrical measuring instruments and their accessories (Identical)

The Technical Committee has reviewed the provisions of ISO 2151, ISO 3945, ISO 5390, ISO 5941 and IEC 46, to which reference is made in the text, and has decided they are acceptable for use in conjunction with this standard.

A related British Standard for IEC 46 is BS 752 'Test code for acceptance of steam turbines'.

Additional information. With reference to A.1 attention is drawn to BS 1571 : Part 2 'Methods for simplified acceptance testing for air compressors and exhausters'.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

British Standard

Testing of positive displacement compressors and exhausters

Part 1. Methods for acceptance testing

1 Scope and field of application

This International Standard specifies methods for acceptance tests, and technical conditions for the supply of displacement compressors including packaged versions (see annex C).

It gives detailed instructions on the measurement of volume flow rate and power requirement and means of adjusting the measured values to guarantee conditions.

NOTE — This International Standard may be used for full load acceptance testing of lobed rotary (Roots') blowers.

Three types of test are covered, as follows :

a) Acceptance test

This is a full performance test carried out in accordance with this International Standard.

b) Type test

This is also a full performance test carried out in accordance with this International Standard, to establish typical performance of a specific model of compressor produced in significant quantities. The manufacturer shall select at random one typical compressor from a batch of identical compressors for this type test. The test shall be witnessed by an independent expert from, or approved by, a reputable institution.

Provided the production compressors are identical with the compressor type tested, it is strongly recommended that the performance results of the type test should be used in catalogues and descriptive literature.

c) Simplified test

In annex A reference is made to a simplified compressor test. This is a test where volume flow rate and power input are measured using the manufacturer's normal test-stand instrument and equipment.

This test is normally carried out when a type test of an identical compressor has already been made. Provided the performance results obtained are within the tolerances listed in table 5, then the performance of this series-produced compressor is deemed to be the same as the type performance results. (See annex A for full particulars.)

This International Standard also specifies the operating and testing conditions which shall be agreed between the manufacturer and the purchaser (see annex B).

2 References

ISO 1000, *SI units and recommendations for the use of their multiples and of certain other units.*

ISO 1219, *Fluid power systems and components — Graphic symbols.*

ISO 2151, *Measurement of airborne noise emitted by compressor/primemover-units intended for outdoor use.*

ISO 2602, *Statistical interpretation of test results — Estimation of the mean — Confidence interval.*

ISO 2854, *Statistical interpretation of data — Techniques of estimation and tests relating to means and variances.*

ISO 2954, *Mechanical vibration of rotating and reciprocating machinery — Requirements for instruments for measuring vibration severity.*

ISO 3046, *Reciprocating internal combustion engines — Performance.*

ISO 3744, *Acoustics — Determination of sound power levels of noise sources — Engineering methods for free-field conditions over a reflecting plane.*

ISO 3857/1, *Compressors, pneumatic tools and machines — Vocabulary — Part 1 : General.*

ISO 3857/2, *Compressors, pneumatic tools and machines — Vocabulary — Part 2 : Compressors.*

ISO 3945, *Mechanical vibration of large rotating machines with speed range from 10 to 200 rev/s — Measurement and evaluation of vibration severity in situ.*

ISO 5167, *Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full.*

ISO 5168, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

ISO 5388, *Stationary air compressors — Safety rules and code of practice.*

ISO 5390, *Compressors — Classification.*

ISO 5941, *Compressors, pneumatic tools and machines — Preferred pressures.*

IEC Publication 46, *Recommendations for steam turbines — Part 2 : Rules for acceptance tests.*

IEC Publication 51, *Recommendations for direct acting indicating electrical measuring instruments and their accessories.*

3 Definitions

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

3.1 General definitions

3.1.1 displacement compressor : Machine where a static pressure rise is obtained by allowing successive volumes of gas to be aspirated into and exhausted out of a closed space by means of the displacement of a moving member.

NOTE — For the definition of a liquid-ring compressor, see 7.1.1.

3.1.2 swept volume of a displacement compressor : Volume swept in one revolution by the compressing element(s) of the compressor first stage.

3.1.3 displacement of a displacement compressor : Volume swept by the compressing element(s) of the compressor first stage per unit of time.

3.1.4 shaft-driven reciprocating compressor : Displacement compressor in which gas intake and compression are achieved by the straightforward alternating movement of a moving element in a space constituting a compression chamber due to a shaft rotation.

3.1.5 rotary compressor : Displacement compressor in which the element is one or more rotors operating in a casing, the displacement being effected by vanes, meshing elements, or by displacement of the rotor itself.

3.1.6 packaged compressor : Compressor unit supplied by the manufacturer, fully piped and wired internally (see annex C). These may be stationary or mobile (portable) units.

3.1.7 clearance volume : Volume inside the compression space, which contains gas trapped at the end of the compression cycle.

3.1.8 relative clearance volume : Ratio of clearance volume of the stage under consideration to the swept volume of the compressing element of this stage.

3.1.9 standard inlet point : Inlet point considered representative for each compressor. This point varies with compressor design and type of installation.

NOTES

1 The standard inlet point of a stationary compressor is generally at the inlet flange.

2 The standard inlet point of a packaged air compressor is a point close to the compressor, chosen so that the thermometer is unaffected by the compressor operation.

3.1.10 standard inlet condition : Condition of the aspirated gas at the standard inlet point of the compressor.

3.1.11 standard discharge point : Discharge point considered representative for each compressor. This point varies with compressor design and type of installation.

NOTES

1 The standard discharge point of a stationary compressor is generally at the compressor discharge flange.

2 The standard discharge point of a packaged air compressor is the terminal outlet.

3.1.12 standard discharge condition : Condition of the compressed gas at the standard discharge point of the compressor.

3.1.13 intercooling : Removal of heat from a gas between stages.

3.1.14 aftercooling : Removal of heat from the gas after the compression is completed.

3.1.15 polytropic process : Compression or expansion process of an ideal gas in which the relation between pressure and volume follows the equation

$$pV^n = \text{constant}$$

The exponent n can have various values. For example :

$$pV = \text{constant}$$

describes an isothermal process, i.e. the gas temperature remains constant.

$$pV^\gamma = \text{constant}$$

describes an isentropic process, i.e. the gas entropy remains constant.

NOTE — Sometimes this process is called adiabatic, but to avoid confusion between adiabatic (no heat exchange with the surroundings) and reversible adiabatic (isentropic) processes, the expression isentropic is preferred.

3.1.16 ideal multi-stage compression : Process when a perfect gas is isentropically compressed and the gas inlet temperature as well as the amount of work spent is the same for each stage.

3.1.17 shaft rotational speed : Number of revolutions of the compressor drive shaft per unit of time.

3.1.18 shaft-speed irregularity : Dimensionless number obtained when the difference between maximum and minimum instantaneous shaft-speeds during one period is divided by the arithmetic mean of these two.

$$\text{Shaft-speed irregularity} = 2 \frac{n_{\max} - n_{\min}}{n_{\max} + n_{\min}}$$

3.2 Pressures

3.2.1 total pressure : Pressure measured at the stagnation point when a gas stream is brought to rest and its kinetic energy is converted by an isentropic compression from the flow condition to the stagnation condition.

3.2.2 static pressure : Pressure measured in a gas in such a manner that no effect on measurement is produced by the gas velocity.

In stationary gas the static and the total pressures are numerically equal.

3.2.3 dynamic (velocity) pressure : Total pressure minus the static pressure.

3.2.4 atmospheric pressure : Absolute pressure of the atmosphere measured at the test place.

3.2.5 effective (gauge) pressure : Pressure measured above the atmospheric pressure.

3.2.6 absolute pressure : Pressure measured from absolute zero, i.e. from an absolute vacuum. It equals the algebraic sum of atmospheric pressure and effective pressure.

3.2.7 inlet pressure : Total mean absolute pressure at the standard inlet point.

NOTE — The total absolute pressure may be replaced by the static absolute pressure provided that the dynamic pressure is less than 0,5 % of the static pressure.

3.2.8 discharge pressure : Total mean absolute pressure at the standard discharge point.

NOTE — The total absolute pressure may be replaced by the static absolute pressure provided that the dynamic pressure is less than 0,5 % of the static pressure.

3.3 Temperatures

3.3.1 total temperature : Temperature which would be measured at the stagnation point if a gas stream were brought to rest and its kinetic energy converted by an isentropic compression from the flow condition to the stagnation condition.

3.3.2 inlet temperature : Total temperature at the standard inlet point of the compressor.

3.3.3 discharge temperature : Total temperature at the standard discharge point of the compressor.

3.4 Flow rates

3.4.1 actual volume flow rate of a compressor : Actual volume flow rate of gas compressed and delivered at the standard discharge point, referred to conditions of total temperature, total pressure and composition (e.g. humidity) prevailing at the standard inlet point.

NOTE — The expression "actual capacity" should be avoided as it may be confusing.

3.4.2 standard volume flow rate : Actual volume flow rate of compressed gas as delivered at the standard discharge point, but referred to standard conditions (for temperature, pressure, and inlet gas composition).

NOTE — The expression "standard capacity" should be avoided as it may be confusing.

3.4.3 free air : Air at the atmospheric conditions of the site and unaffected by the compressor.

3.5 Powers

3.5.1 isothermal power required : Power which is theoretically required to compress an ideal gas under constant temperature, in a compressor free from losses, from a given inlet pressure to a given discharge pressure.

3.5.2 isentropic power required : Power which is theoretically required to compress an ideal gas under constant entropy, from a given inlet pressure to a given discharge pressure. In multi-stage compression, the theoretical isentropic power required is the sum of the isentropic power required at all the stages.

3.5.3 shaft power : Power required at the compressor drive-shaft. It is the sum of the mechanical losses and the internal power. Losses in external transmissions such as gear drives or belt drives are not included unless part of the scope of supply.

3.5.4 packaged compressor power input : Sum of the power input to the prime mover and any accessories (e.g. oil-pump, cooling fan, etc.) driven from the compressor shaft or

by a separate prime mover at rated supply conditions (e.g. phase, voltage, frequency and ampere capability). The power input shall include the effect of any equipment such as flow rate controls, intake filters, silencers, liquid separation equipment including their return systems, dryer, outlet shut-off valves, etc., included in the package (see annex C).

NOTE — The power input of a packaged compressor is always higher than the shaft power due to the motor losses and the power taken up by the accessories. These two concepts cannot therefore be compared.

3.6 Efficiencies

3.6.1 isentropic overall efficiency : Ratio of the required isentropic power to the power input for the scope of supply.

3.6.2 isothermal efficiency : Ratio of the isothermal power required to shaft power.

3.6.3 isentropic efficiency : Ratio of the isentropic power required to shaft power.

3.6.4 volumetric efficiency : Ratio of the actual volume flow rate to the displacement of the compressor.

3.7 Specific energy requirements

3.7.1 theoretical specific energy requirement : Work necessary to compress a unit mass of gas (mass specific

energy) or unit volume of gas (volume specific energy) according to the specified process (isothermal, isentropic, polytropic).

3.7.2 actual specific energy requirement of a bare compressor : Shaft input power per unit of actual compressor volume flow rate.

3.7.3 actual specific energy requirement of a packaged compressor : Packaged compressor input power per unit of actual compressor volume flow rate.

3.7.4 specific fuel (or steam) consumption : Fuel (or steam) mass flow per unit of compressor actual volume flow rate.

3.8 Gas properties

3.8.1 compressibility factor, Z : Factor expressing the deviation of the real gas from an ideal gas.

3.8.2 relative vapour pressure : Ratio of the partial pressure of a vapour to its saturation pressure at the same temperature.

NOTE — In the case of water, the expression "relative humidity" was used previously.

4 Symbols, units and subscripts

4.1 Symbols and units

Quantity	Symbol	Dimensions	SI unit	Other practical units
Area	A	L^2	m^2	mm^2
Volume	V	L^3	m^3	l
Time	t	T	s	h, min
Velocity	c	LT^{-1}	m/s	—
Angular velocity	ω	T^{-1}	rad/s	—
Correction factor	K	—	pure number	—
Rotational frequency (shaft-speed)	N	T^{-1}	s^{-1}	min^{-1}
Mass density	ρ	ML^{-3}	kg/m^3	kg/l
Celsius temperature	θ	Θ	$^{\circ}C$	—
Thermodynamic temperature	T	Θ	K	—
Pressure	p	$ML^{-1}T^{-2}$	Pa	$MPa, bar, kPa, mbar$
Pressure ratio	r	—	pure number	—
Work	W	ML^2T^{-2}	J	MJ, kJ, kWh
Power	P	ML^2T^{-3}	W	MW, kW
Mass specific energy	W_m	L^2T^{-2}	J/kg	kJ/kg
Volume specific energy	W_V	$ML^{-1}T^{-2}$	J/m^3	$J/l, kWh/m^3$
Mass rate of flow	q_m	MT^{-1}	kg/s	kg/h
Volume rate of flow	q_V	L^3T^{-1}	m^3/s	$m^3/h, m^3/min, l/s$
Relative clearance volume	e	—	pure number	—
Exponent for polytropic process in pV diagram	n	—	pure number	—
Molar gas constant	R	$ML^2T^{-2}\Theta^{-1}N^{-1}$	$J/(K \cdot mol)$	$kJ/(K \cdot mol)$
Absolute humidity	x	—	pure number	—
Compressibility factor	Z	—	pure number	—
Dynamic viscosity	η	$ML^{-1}T^{-1}$	$Pa \cdot s$	—
Efficiency	η	—	pure number	—
Isentropic exponent	κ	—	pure number	—
Relative vapour-pressure	ϕ	—	pure number	—

M = mass L = length T = time Θ = temperature N = quantity of matter

4.2 Letters and figures used as subscripts

Subscript	Meaning	Remarks
0	ambient condition	
1	inlet	Indicates the quantities measured at the standard inlet point of the compressor.
2	discharge	Indicates the quantities measured at the standard discharge point of the compressor.
a	absolute	
ab	absorbed	
ap	approximate	
av	average	
b	atmospheric	Characterizes the atmospheric pressures and temperatures.
c	contractual	Indicates the quantities specified in the contract.
cd	condensate	
corr	corrected	
cr	critical	Characterizes the critical pressures and temperatures.
d	dynamic	Characterizes the dynamic pressures and temperatures.
e	effective	
g	gas	
in	internal	
m	mass	Characterizes the mass specific rates of flow, energies and volumes.
me	mechanical	
N	normal	
pol	polytropic	Characterizes a polytropic process.
r	reduced	Characterizes the reduced pressures and temperatures.
R	reading	Indicates the quantities read during the test or predetermined as test conditions.
s	saturated	
t	total	
T	isothermal	Characterizes an isothermal process.
th	theoretical	
v	vapour	
V	volume	
w	coolant	

5 Measuring equipment and methods

5.1 General

The equipment and methods given in this International Standard are not intended to restrict the use of other equipment with the same or better accuracy. Where an International Standard exists, relating to a particular measurement or type of instrument, any measurements made or instruments used shall be in accordance with such Standard.

5.2 Measurement of pressure

5.2.1 General

5.2.1.1 Pressure taps in the pipe or receiver shall be normal to, and flush with, the inside wall.

NOTE — For low pressures or high flow velocities, it should be noted that minor irregularities such as burrs can give serious errors.

5.2.1.2 Connecting piping to gauges shall be as short as possible.

Tightness shall be tested (for example with soap solution) and all leaks eliminated.

5.2.1.3 Connecting piping to gauges shall be not less than 6 mm bore.

Connecting piping shall be arranged so that there are no traps where liquid can collect.

5.2.1.4 Instruments shall be mounted so that they are not susceptible to harmful vibrations.

5.2.1.5 The measuring instrument (analogue or digital) shall have an accuracy of $\pm 1\%$.

5.2.1.6 The total pressure is the sum of the static and the dynamic pressures. It shall be measured with a Pitot tube having the axis parallel to the flow. When the dynamic pressure is less than 5 % of the total pressure, it shall be calculated on the basis of a calculated average velocity.

5.2.1.7 If the amplitudes of low frequency (< 1 Hz) pressure waves in the inlet pipe or the discharge pipe are found to exceed 10 % of the prevailing average absolute pressure, the piping installation shall be corrected before proceeding with the test.

Where the amplitudes of such pressure waves exceed 10 % of the specified average inlet or discharge pressures, a test shall not be undertaken under the requirements of this International Standard unless agreed to in writing by the parties to the test.

5.2.1.8 Gauges of the Bourdon type shall be calibrated under pressure and temperature conditions similar to those prevailing during the test, using dead-weight test gauges.

5.2.1.9 Dead-weight gauges shall be examined to ensure that the piston moves freely. The diameter of the piston shall be measured and the weights shall be compared with authentic standards.

5.2.1.10 Column readings and dead-weight gauges shall be corrected for the gravitational acceleration at the location of the instrument.

5.2.1.11 Column readings shall be corrected for ambient temperature.

5.2.1.12 In case of low frequency (< 1 Hz) flow pulsations, a receiver with inlet throttling shall be provided between the pressure tap and the manometer.

5.2.1.13 Oscillations of gauges shall not be reduced by throttling with a valve. However, a restricting orifice may be used.

5.2.2 Pressure less than or equal to 2 bar¹⁾

5.2.2.1 The atmospheric pressure shall be measured with a mercury barometer, reading to the nearest millimetre.

The temperature for correcting the barometer reading shall be read with an accuracy of ± 1 K.

A boiling manometer or a precision aneroid barometer may also be used, but the accuracy shall be checked.

If a reliable barometer is not available, an approximation shall be obtained by using records of the nearest meteorological station, and correcting for the difference in altitude between the station and the compressor.

5.2.2.2 For sloping-limb and other amplifying instruments, the relation between the scale readings and the true water column length shall be determined previously by calibration against an absolute manometer of suitable sensitivity.

The inclination to the horizontal and the density of the manometer liquid shall be the same as for the calibration.

Manometers or columns for low pressure measurement shall comprise glass tubing of not less than 10 mm bore for the single-limb type and not less than 6 mm for the double-limb U-type, with a scale clearly graduated to allow the column to be read to within 1 mm.

The manometers shall be filled with a stable liquid of known mass density.

5.2.3 Pressure greater than 2 bar

For absolute pressure above 2 bar, calibrated gauges of Bourdon type or dead-weight gauges, mercury manometers or their equivalent shall be employed.

5.2.4 Inlet pressure

The inlet pressure of an air compressor operating without intake pipe or filter shall be measured by a barometer.

If an intake pipe is provided for the test, it shall be as close in size and shape as possible to the actual installation.

In cases of pulsating flow, a receiver volume with inlet throttling shall be provided between the manometer and the intake pipe (see 5.2.1.12 and 5.2.1.13).

5.2.5 Intercooler pressure

The intercooler pressure shall be measured after the inter-cooler.

5.2.6 Discharge pressure

The pressure tap shall be placed close to the standard discharge point of the compressor, if necessary on a pulsation damper with a throttling device before the manometer.

5.3 Measurement of temperature

5.3.1 Temperature shall be measured by certified or calibrated instruments such as thermometers, thermo-electrical instruments, resistance thermometers or thermistors inserted into the pipe or into pockets.

5.3.2 The measurement of the inlet temperature of the gas and the coolant shall be made with an accuracy of ± 1 K.

Commercial or industrial metal-encased thermometers shall not be used for temperatures that will influence the fulfilment of the guarantee.

5.3.3 The inlet gas temperature shall be measured near the inlet flange or connection, but sufficiently distant to avoid radiation and conduction errors.

5.3.4 Thermometer pockets shall be as thin, and their diameters as small, as is practical, with their outside surface substantially free from corrosion or oxide. The pocket shall be partially filled with a suitable fluid.

5.3.5 The thermometers or the pockets shall extend into the pipe to a distance of 100 mm, or one-third the diameter of the pipe, whichever is less.

5.3.6 When taking readings, the thermometer shall not be lifted out of the medium being measured nor out of the pocket when such is used.

¹⁾ 1 bar = 10^5 Pa

5.3.7 The thermometer reading shall be corrected for the emergent stem according to the following formula :

$$\theta = \theta_R + l\gamma (\theta_R - \theta_{av})$$

where

θ is the true temperature in degrees Celsius;

θ_R is the actual temperature reading in degrees Celsius;

θ_{av} is the average temperature of the emergent fluid column in degrees Celsius;

l is the length of the emerging fluid column expressed in kelvins;

γ is the apparent expansion coefficient of the thermometer fluid (for mercury-in-glass, $\gamma = 1/6\ 300$).

5.3.8 Precautions shall be taken to ensure

a) that the immediate vicinity of the insertion point and the projecting parts of the connection are well insulated so that the pocket is virtually at the same temperature as the medium being observed;

b) that the sensor of any temperature measuring device or thermometer pocket is well swept by the medium (the sensor or thermometer pocket shall point against the gas stream; in extreme cases a position perpendicular to the gas stream may be used);

c) that the thermometer pocket does not disturb the normal flow.

5.3.9 Thermocouples shall have a welded hot junction and shall be calibrated together with their wires for the anticipated operating range. They shall be made of materials suitable for the temperature and the gas being measured. If thermocouples are used with thermometer pockets, the hot junction of the couple shall, where possible, be welded to the bottom of the pocket.

5.4 Measurement of humidity

If the compressed air or gas contains moisture, the relative vapour pressure shall be checked during the test.

For tests with an open system, the dry and wet bulb temperatures shall be measured with a psychrometer of the Assmann type or another instrument with similar accuracy. The moisture content is then found from psychrometric tables or from an enthalpy/humidity chart.

For tests with a closed system, the humidity shall be measured with a dew point instrument, a psychrometer or another instrument with similar accuracy.

The humidity shall, if possible, be measured at the standard inlet point. If this is not possible the humidity shall be estimated.

5.5 Measurement of rotational frequency

If possible, the total number of compressor revolutions during the test run shall be measured with a revolution counter free from slip and the time of the test run shall simultaneously be accurately measured.

If a synchronous motor is used, a synchronous clock may replace the revolution counter.

If an asynchronous motor is used, the net frequency and the slip may be measured.

5.6 Measurement of flow rate

5.6.1 If possible, the actual volume flow rate of the compressor shall be calculated from a measurement of the delivered flow rate.

The test should be performed as indicated in ISO 5167.

It is necessary to ensure that all the requirements of ISO 5167 are completely fulfilled during the measurement period.

For testing the volume flow rate of a compressor, measurement of the aspirated volume shall be used if measurement of the delivered volume is not practical and if the leakage losses can be measured separately and with sufficient accuracy.

NOTES

1 When the demands on length of straight pipe upstream of the measuring device as given in ISO 5167 cannot be met, an alternative measuring pipe design is given in annex D.

2 Alternative methods for determining the actual volume flow rate are given in annex F.

5.6.2 The coolant flow rate may be determined with the aid of a vessel of known volume and a stop-watch or with a calibrated flow meter. The measurement may also be made with an orifice or nozzle according to ISO 5167.

5.7 Measurement of power and energy

5.7.1 The measurement of the output of the prime mover shall be made according to a recognized test code.

5.7.2 The power input to the compressor may be measured directly by reaction mounted drivers, or a torque meter, or indirectly determined from measurements of electrical input to the driving motor and the motor efficiency.

5.7.3 Precision torque meters shall not be used below one-third of their rated torque. They shall be calibrated after the test with the torsion member at the same temperature as during the test. Readings shall be made with a series of increasing loads with the precaution that, during the taking of readings with increasing loads, the load shall at no time be decreased.

Similarly, when readings are made with decreasing loads, the load shall at no time be increased. The calculation of output shall be based on the average of the increasing and decreasing loads as determined by the calibration. If the torque difference between increasing and decreasing loads exceeds 1 %, the torque meter is unsatisfactory.

5.7.4 The shaft power of an electrically-driven compressor shall be determined by measuring the electrical power supplied and multiplying by the motor efficiency. Only precision instruments shall be used. Power, voltage and current shall be measured. The voltage coils of the instruments shall be connected immediately before the terminals of the motor, so that voltage drop in cables will not affect the measurement. If remote instruments are used, the voltage drop shall be determined separately and taken into consideration (see IEC Publication 51).

5.7.5 For three-phase motors, the two-wattmeter method or some other method with similar accuracy shall be used.

5.7.6 Current and voltage transformers shall be chosen to operate as near their rated load as possible so that their ratio error will be minimized.

For checking purposes it may be convenient to have a recently adjusted kWh-meter connected to the circuit during the test.

5.7.7 As a basis for the efficiency of the transmission, the following figures shall be used, at nominal load, unless other reliable information is available :

- for properly lubricated precision gears : 98 % for each stage,
- for belt drive : 95 % for each stage.

5.8 Miscellaneous measurements

5.8.1 Fuel consumption

If the compressor is driven by a combustion type engine or a gas turbine, the mean fuel consumption shall be determined by weighing or by measuring the volume of the fuel consumed during the test. (See ISO 3046.)

5.8.2 Steam consumption

If the compressor is driven by a steam engine or turbine, the non-bleeding steam rate shall be determined. (See IEC Publication 46.)

5.8.3 Gas composition

When tests are performed with gases other than air, the chemical composition and the physical properties of the gas entering the compressor during the tests shall be determined and if necessary checked at regular intervals.

5.8.4 Condensation rate

Before and after every test, the condensate shall be drained from the intercoolers and their separators in such a way that the steady state of the compressor is not disturbed. The separated quantities shall be weighed for every cooler and divided by the time between the draining operations.

NOTE — Any oil carried over with the condensate should be separated from the condensate before the mass of the latter is measured. If water separators are provided, the efficiency of separation can be determined.

The condensate collected in aftercoolers, receivers and other places after the discharge flange, but before the flow measuring device, shall be measured.

5.9 Calibration of instruments

Initial calibration records of the instruments shall be available prior to the test.

Recalibration after the test shall be made for those instruments of primary importance which are liable to variation in their calibration as a result of use during the test.

Any change in the instrument calibrations which will create a variation exceeding the class of the instrument may be a cause for rejecting the test.

6 Test method

6.1 General

6.1.1 Before acceptance tests begin, the compressor shall be examined to ascertain whether it is in suitable condition to conduct an acceptance test. All external leakage shall be eliminated : in particular the pipe system shall be checked for leakage.

6.1.2 All parts likely to accumulate deposits, and particularly the coolers, shall be clean both on the gas and coolant sides.

6.2 Test arrangements

6.2.1 Preliminary tests shall be run for the purpose of

- checking instruments;
- training personnel.

A preliminary test may, by agreement, be considered the acceptance test, provided that all requirements for an acceptance test have been met.

6.2.2 During the test, all such measurements as have any bearing on the performance shall be made. In the following clauses the determination of the flow rate and the power absorbed by the compressor are covered in detail.

6.2.3 The measurements shall be carried out by competent persons with measuring equipment according to clause 5.

6.2.4 The test conditions shall be as close as reasonably possible to the guarantee conditions; deviations from these shall not exceed the limits specified in table 1.

6.2.5 Where it is not feasible to test a machine with the gas specified by the purchaser or within the limitations specified in table 1, special conditions of test or special corrections shall be agreed upon between purchaser and manufacturer.

6.2.6 The governing mechanism shall be maintained in its normal operating condition.

6.2.7 During the test, the lubricant and the rate of feed shall comply with the operating instructions.

6.2.8 During the test, no adjustments other than those required to maintain the test conditions and those required for normal operation as given in the instruction manual shall be made.

6.2.9 Before readings are taken, the compressor shall be run long enough to ensure that steady state conditions are reached

so that no systematic changes occur in the instrument readings during the test.

However, should the test conditions be such that systematic changes cannot be avoided, or if individual readings are subject to great variations, then the number of readings shall be increased and due regard paid to this in the calculation of the tolerances.

6.2.10 For each load, a sufficient number of readings shall be taken to indicate that steady-state conditions have been reached. The number of readings and the intervals shall be chosen to obtain the required accuracy.

6.2.11 After the test, the compressor plant and the measuring equipment shall be inspected. Should any faults be found that may have affected the test results, then a further test shall be run after these faults have been corrected.

6.3 Evaluation of readings

6.3.1 Before final calculations are undertaken, the recorded data shall be scrutinized for consistency of operating conditions. The fluctuations of readings during one test shall not exceed the limits given in table 1.

Table 1 — Maximum deviations from specified values and fluctuations from average readings
(for liquid-ring compressors, see also table 2)

Measured variable	Maximum allowable deviations	Maximum allowable fluctuation from average during any set of readings
Inlet pressure, p_1	$\pm 10 \%$	$\pm 0,5 \%$
Pressure ratio, r	$\pm 5 \%$	$\pm 5 \%$
Inlet temperature, θ_1	not specified	$\pm 2 \text{ K}$
Absolute inlet humidity, x_1	not specified	$\pm 5 \%$
Isentropic exponent, κ	$\pm 3 \%$	not specified
Gas constant, R	$\pm 5 \%$	not specified
Shaft-speed, N	$\pm 4 \%$	$\pm 1 \%$
Temperature difference between coolant and gas	$\pm 10 \text{ K}$	$\pm 2 \text{ K}$
Coolant flow rate	$\pm 10 \%$	$\pm 10 \%$
Temperature at the nozzle or orifice plate	not specified	$\pm 2 \text{ K}$
Differential pressure over nozzle or orifice plate	not specified	$\pm 3 \%$
Voltage	$\pm 5 \%$	$\pm 2 \%$
Net frequency	$\pm 1 \%$	$\pm 0,5 \%$

NOTES

- 1 The test can be performed if the deviations from the specified conditions are equal to or less than the deviation tolerances.
- 2 If the deviation from test conditions results in a deviation in absorbed power higher than $\pm 10 \%$, then the test is not within the limits.
- 3 See 5.2.1.7.
- 4 For outdoor tests with portable compressors, the allowable inlet temperature fluctuation is increased to $\pm 3 \text{ K}$.
- 5 A test at a shaft-speed different from the specified value is not accepted if unpermitted resonant pressure pulsations occur.
- 6 For the test of a gas compressor with a gas different from the actual one, a bigger variation in gas properties often occurs. This should be agreed upon by both parties.

6.3.2 All accepted readings from any test run shall be consecutive.

6.3.3 Sets of readings showing excessive fluctuation may be discarded but only at the beginning or the end of a test run. All readings in any set shall be taken as nearly as possible simultaneously.

6.3.4 The moisture content shall be determined from psychrometer readings at the standard inlet point, according to 5.4.

The moisture content for the different compression stages and at the flow measuring device shall then be determined from condensate measurements.

6.4 Computation of test results

6.4.1 Test results, except those for flow measurements, shall be calculated from the arithmetic average values of the accepted readings.

6.4.2 The mass flow rate shall be determined according to 5.6.

6.4.3 When the gas being compressed is not dry, the influence of the moisture shall be taken into account by correcting the absorbed power.

6.4.4 The actual volume flow rate at the inlet is obtained by converting the gas flow measured through the measuring device from the condition there to the condition at the standard inlet point, due consideration being paid to any separated moisture.

Any vapour condensed between the standard inlet point and the measuring device shall be added to the measured mass flow to obtain the mass flow at the standard inlet point. Then from the mass flow at the standard inlet point the volume flow rate at this point is calculated. This is the actual inlet volume flow rate.

6.4.5 Some unloading systems exhaust warm gas from the unloaded side of the piston to the inlet at part load. The inlet temperature thus becomes higher at part load than at full load, whereby the volume flow rate apparently seems to attain a higher value. In such cases, therefore, the part load flow rate is calculated with the inlet temperature valid for full load.

6.4.6 Test conditions never agree exactly with specified conditions. Therefore, before test results and specified values are compared, corrections shall be applied to volume flow rate and absorbed power.

6.4.7 When the specified operating conditions cannot be met, the influence of the operating conditions on the performance of the actual compressor shall be determined by a method of variation, so that the size of each correction to the specified operating conditions can be determined by interpolation or, in extreme cases, by extrapolation.

If this is difficult to arrange, the correction methods given in this clause shall be used.

6.4.8 Within the limits specified in table 1, this International Standard provides for adjustment of the volume flow rate and the absorbed power when the test conditions deviate from those specified. The volume flow rate shall be adjusted for deviation in shaft-speed, pressure ratio, isentropic exponent and coolant temperature. The absorbed power shall be adjusted for deviation in inlet pressure, isentropic exponent, pressure ratio, coolant temperature, humidity and shaft-speed.

NOTE — Other corrections, such as correction for the compressibility factor, may have to be made.

6.4.9 For process compressors where certain amounts of compressed medium are injected or extracted between the stages, the specific energy concept is meaningless and shall be replaced by the power input to the compressor shaft.

6.4.10 If the test is carried out with a gas different from the one specified, a correction shall be made. A change in the gas constant will affect the leakage and hence the flow rate. Such corrections shall be agreed upon by the parties concerned.

6.4.11 If the deviation or fluctuation exceeds the value given in table 1, the methods described in 6.4.8 shall be used if agreed to by the parties concerned.

6.5 Volume flow rate corrections

6.5.1 Correction factor for shaft-speed, K_1

The correction factor is

$$K_1 = \frac{N_c}{N_R}$$

where

N_c is the specified shaft-speed;

N_R is the measured shaft-speed during the test.

6.5.2 Correction factor for polytropic exponent and pressure ratio, K_2

This correction factor can generally be neglected except for when testing single stage reciprocating compressors.

A change in the ratio of specific heat-capacities and in the pressure ratio will influence the volume flow rate as the expansion of the gas trapped in the clearance volume is affected. The degree of this influence is not fully known, so that the test supervisor should strive to operate as near the specified pressure ratio as possible. For differences within the limits given in table 1, the formula below shall be used :

$$K_2 = [1 - e^{(r_c^{1/n_c} - 1)}] / [1 - e^{(r_R^{1/n_R} - 1)}]$$

where

r_R is the measured pressure ratio;

r_c is the specified pressure ratio;

e is the relative clearance volume;

n is the polytropic exponent (should be taken as $0,9 \chi$, in which χ is the isentropic exponent).

For pressure ratios below 3 the correction is simplified to :

$$K_2 = 1 + e (r_R^{1/n_R} - r_c^{1/n_c})$$

6.5.3 Correction factor for coolant temperature, K_3

The temperature difference between the coolant and the gas at their intake points will affect the gas temperature in the compressor cylinders as well as in the intercoolers. As this influence varies with compressor type, size and shaft-speed, no general correction formula can be given. If the specified conditions cannot be met, the compressor shall be operated at two different coolant inlet temperatures and at constant gas inlet temperature and then the required value shall be obtained by interpolating or extrapolating to the specified conditions with a straight line through the two test points.

For liquid injected displacement-type rotary compressors, the volume flow rate is affected by the temperature of the liquid injected into the compressor. This effect is due to heat transfer between the air and the liquid in the intake passages before compression begins and changes in sealing due to changes in viscosity. The system will be affected by the action of any thermostatic valve which may be fitted to enable the liquid to bypass the cooler until a given liquid temperature is reached. For a given air inlet temperature, the injection of colder liquid normally gives higher volume flow rate due to less preheating of incoming air and more efficient cooling during compression. The magnitude of this influence depends upon compressor design, internal clearances, rotor tip speed and also on liquid flow rate, liquid viscosity, etc.

The correction factor, K_3 , should be based on tests with the specific type of unit.

6.5.4 Correction for deviation in gas constant and compressibility factor

A change in gas constant or compressibility factor will affect the leakage and hence the volume flow rate. A general expression for this influence cannot be given. For deviations smaller than those given in table 1 this correction may be omitted.

6.6 Corrected volume flow rate

The corrected volume flow rate is

$$q_V = K_1 K_2 K_3 q_{VR}$$

where q_{VR} is the measured volume flow rate calculated from observed results of the test.

6.7 Power corrections

6.7.1 Correction factor for shaft-speed, K_4

The absorbed power is affected by the shaft-speed. It may be assumed that the compressor efficiency remains unchanged for deviations in test shaft-speed from the specified shaft-speed of $\pm 4\%$.

The correction factor is then

$$K_4 = \frac{N_c}{N_R}$$

where

N_c is the specified shaft-speed;

N_R is the measured shaft-speed during the test.

6.7.2 Correction factor for inlet pressure, polytropic exponent and pressure ratio, K_5

The corrections for variation in inlet pressure and pressure ratio are fairly easy to obtain, with great accuracy, from practical tests.

The specified pressure ratio can normally be maintained within $\pm 1\%$ by adjusting the discharge pressure. If correction curves have not been established from earlier tests with the specific compressor type, the correction shall be based on a comparison of the work of compression using an appropriate polytropic exponent.

NOTE — The actual polytropic exponent varies during the compression process. If no test results are available, the isentropic exponent should be used. (For air $\chi = 1,40$.)

If the inlet pressure, polytropic exponent and the pressure ratio deviate from the figures specified in the contract, then the correction methods below shall be used.

6.7.2.1 For single-stage machines, cooled and uncooled :

$$K_5 = \frac{[\chi/(\chi - 1)]_c}{[\chi/(\chi - 1)]_R} \times \frac{p_{1c}}{p_{1R}} \times \frac{r_c^{[(\chi - 1)/\chi]_c} - 1}{r_R^{[(\chi - 1)/\chi]_R} - 1} \times K_2$$

6.7.2.2 For multi-stage compressors with intercoolers :

$$K_5 = \frac{p_{1c}}{p_{1R}} \times \frac{\lg r_c}{\lg r_R}$$

6.7.2.3 If the pressure ratio during the test is held within $\pm 0,2\%$, the power input correction for all displacement compressors can be simplified to

$$K_5 = \frac{p_{1c}}{p_{1R}}$$

6.7.3 Correction factor for humidity, multi-stage compressors, K_6

If in a multi-stage compressor vapour has condensed in the intercoolers, decreasing quantities of vapour are compressed in the various stages. The correction factor (see annex I) is

$$K_6 = 1 + \left[\frac{R_v}{R_g} \times \frac{n-1}{n} \right] \times \left[\frac{T_{1wR}}{T_{1R}} \left(x_{1R} - \frac{1}{n-1} \sum_{i=2}^n x_{iR} \right) - \frac{T_{1wc}}{T_{1c}} \left(x_{1c} - \frac{1}{n-1} \sum_{i=2}^n x_{ic} \right) \right]$$

where

R_v is the gas constant of the vapour in joules per mole kelvin;

R_g is the gas constant of the gas in joules per mole kelvin;

n is the number of stages;

x is the absolute humidity of the gas at the inlet of any stage (the absolute humidity may be calculated from the partial pressure of the vapour);

T_1 is the absolute gas inlet temperature in kelvins;

T_{1w} is the absolute coolant inlet temperature in kelvins.

When the specified gas is dry and at the same temperature as the coolant, the formula is simplified to

$$K_6 = 1 + \frac{R_v}{R_g} \times \frac{n-1}{n} \times \frac{T_{1wR}}{T_{1R}} \left(x_{1R} - \frac{1}{n-1} \sum_{i=2}^n x_{iR} \right)$$

6.7.4 Correction factor for coolant inlet temperature, K_7

The relation between the coolant inlet temperature and the power absorbed is very complicated and has many parameters.

For this correction it is advisable to follow the recommendation of 6.5.3.

For liquid-injected displacement type rotary compressors the inlet air temperature, the temperature of the injected liquid, and the differential between them all affect the absorbed power, because the heating of the inlet air and changes in injected liquid viscosity will affect the internal leakage and the hydraulic losses. Correction factors shall be based on tests by the manufacturer.

6.8 Corrected absorbed power

The corrected absorbed power is

$$P = K_4 K_5 K_6 K_7 P_R$$

6.9 Corrected specific energy requirement

The corrected specific energy requirement is obtained by dividing the corrected absorbed power by the corrected volume flow rate (see 6.6 and 6.8).

7 Acceptance test for liquid-ring compressors

Liquid-ring compressors are of the displacement type but due to their specific design characteristics they are covered separately in this clause.

This clause gives rules for the measurement of the volume flow rate referred to inlet conditions, of the power absorbed and rules for conversion of the performance figures to specified conditions. (See also ISO 2602 and ISO 2854.)

7.1 Definition

liquid-ring compressor : Machine with a rotating impeller with protruding blades eccentrically mounted in a stationary round housing or centrally mounted in a stationary elliptical housing. A liquid ring rotating together with the bladed impeller creates one or two crescent-shaped working spaces.

The volumes trapped between each pair of blades, the hub and the liquid ring will vary periodically, thereby creating a change in pressure that will generate a flow from the suction to the discharge side of the compressor.

7.2 Measuring equipment and methods

See clause 5.

7.3 Test

See 6.1.1 to 6.3.3; however, table 1 is replaced by table 2.

7.4 Conversion of test results to specified conditions

Table 2 — Maximum deviations from the specified values during an acceptance test

Measured variable	Maximum allowable deviation
Inlet pressure, p_1	$\pm 5 \%$
Discharge pressure, p_2	$\pm 5 \%$
Rotational frequency, N	$\pm 3 \%$
Working liquid flow rate	$\pm 10 \%$
Working liquid temperature in degrees Celsius	$\pm 5 \%$

NOTES

1 Whenever the pressure ratio is used as basis for conversion, it must agree within $\pm 2 \%$ with the specified value.

2 Whenever the relative vapour pressure is used as basis for conversion, it must agree as closely as possible with the specified value.

Whenever the test conditions deviate from the specified conditions, a conversion of the intake volume flow rate and the power absorbed or specific energy requirement must be made. The intake volume flow rate is influenced by deviations in shaft-speed, suction- and discharge pressures, moisture content and temperature of the liquid.

The power input is influenced by deviations in shaft-speed, inlet and discharge pressures.

If the acceptance test is not carried out with the gas specified, the parties shall agree beforehand upon the conversion method to be used.

If the deviation or fluctuation of the measured variables exceeds the limits of table 2, the parties shall agree beforehand upon the conversion method to be used.

7.5 Inlet volume flow rate corrections

7.5.1 Correction factor for shaft-speed, K_1

The correction factor is

$$K_1 = \frac{N_c}{N_R}$$

where

N_c is the specified shaft-speed;

N_R is the measured shaft-speed during the test.

7.5.2 Correction factor for working liquid temperature, K_2

The correction factor is

$$K_2 = \frac{p_{1c} - p_{Lc}}{p_{1R} - p_{LR}} \times \frac{T_{LR}}{T_{Lc}}$$

where

p_{1c} is the specified absolute inlet pressure in bar;

p_{Lc} is the partial pressure of the working liquid, in bar, at its specified temperature;

p_{1R} is the measured absolute inlet pressure in bar;

p_{LR} is the partial pressure of the working liquid, in bar, at its actual temperature;

T_{LR} is the measured absolute temperature of the working liquid in kelvins;

T_{Lc} is the specified absolute temperature of the working liquid in kelvins.

NOTE — This correction factor is valid on condition that the heat transfer between the liquid and the gas allows the gas to attain the

same temperature as the liquid before the compression process commences.

7.5.3 Correction factor for gas inlet temperature, K_3

The correction factor is

$$K_3 = \frac{T_{1c}}{T_{1R}}$$

where

T_{1c} is the specified absolute inlet gas temperature, in kelvins;

T_{1R} is the measured absolute inlet gas temperature, in kelvins.

NOTE — This correction factor is valid on condition that the heat transfer between the liquid and the gas allows the gas to attain the same temperature as the liquid before the compression process commences.

7.6 Corrected inlet volume flow rate

The corrected volume flow rate is

$$q_{V1} = K_1 K_2 K_3 q_{R1}$$

where q_{R1} is the measured volume flow rate calculated from observed results of the test.

7.7 Power correction

7.7.1 Correction factor for shaft-speed, K_4

The correction factor is

$$K_4 = \left(\frac{N_c}{N_R} \right)^2$$

where

N_c is the specified shaft-speed;

N_R is the measured shaft-speed during the test.

7.8 Corrected absorbed power

The corrected absorbed power is

$$P = K_4 P_R$$

7.9 Corrected specific energy requirement

The corrected specific energy requirement is obtained by dividing the corrected absorbed power by the corrected volume flow rate (see 7.6 and 7.8).

7.10 Accuracy of measurement

See clause 8.

7.11 Test report and comparison with specified values

See clause 9.

8 Accuracy of measurement

NOTE — A calculation of the probable error, according to this clause, is not always necessary.

8.1 General

Due to the very nature of physical measurements, it is impossible to measure a physical quantity without error or, in fact, to determine the true error of any one particular measurement. However, if the conditions of the measurement are sufficiently well-known, it is possible to estimate or calculate a characteristic deviation of the measured value from the true value, such that it can be asserted with a certain degree of confidence that the true error is less than the said deviation. The value of such a deviation (normally the 95 % confidence limit) constitutes a criterion of the accuracy of the particular measurement.

It is assumed that all systematic errors that may occur in the measurement of the individual quantities measured and of the characteristics of the gas may be compensated for by corrections. A further assumption is that the confidence-limits in errors in reading and integration errors may be negligible if the number of readings is sufficient. The (small) systematic errors that may occur are covered by the inaccuracy of measurements. Quality classifications and limits of error are often invoked for ascertaining the inaccuracy of individual measurements because apart from the exceptions (e.g. electrical transducers), they constitute only a fraction of the quality class or the limit of error.

The information about ascertaining the inaccuracy of the measurement of the individual quantities measured and on the confidence limits of the gas properties are approximations. These approximations can only be improved at a disproportionate expense. (See ISO 2602 and ISO 2854.)

8.2 Inaccuracy of individual measurements

8.2.1 Inaccuracy of pressure measurements

8.2.1.1 Precision Bourdon-type pressure gauges

The relative inaccuracy, $\tau_{\Delta p}$, of measurement of pressure difference as a percentage, using a precision Bourdon pressure gauge is

$$\tau_{\Delta p} = \frac{\tilde{V}_{\Delta p}}{\Delta p}$$

$$\tau_p = \pm G \frac{p_{En}}{p_R}$$

where

G is the quality class as a percentage (if the quality class of the pressure gauge is $< 0,2$, G is still be taken as $0,2$ in the above formula to allow for errors in mounting);

p_{En} is the full scale value of the instrument;

p_R is the measured pressure.

8.2.1.2 Liquid columns

When liquid columns are used, the inaccuracy of the measurement depends primarily on the ease with which the difference in level, Δh , can be read. If no special aid is used, an inaccuracy of measurement, $\tilde{V}_{\Delta h}$, of ± 1 mm can be reached.

In the range from $0,1 \text{ m} < h < 1,0 \text{ m}$ the relative inaccuracy of measurement, $\tau_{\Delta h}$, as a percentage, is

$$\tau_{\Delta h} = \frac{\tilde{V}_{\Delta h}}{\Delta h}$$

$$\tau_{\Delta h} = \frac{1}{\Delta h}$$

At $\Delta h > 1 \text{ m}$ the relative inaccuracy of measurement as a percentage is :

$$\tau_{\Delta h} = \pm 0,1$$

8.2.1.3 Other measuring instruments

All other measuring instruments for pressure with the quality classification referred to the final value of the range of measurement are dealt with according to 8.2.2.3. As with these measuring instruments the measured value most often becomes apparent at the end of a series of measurements, the rules for series of measurements are to be observed.

8.2.2 Inaccuracy of temperature measurements

8.2.2.1 Liquid-in-glass thermometers

The inaccuracy of measurement, $\tilde{V}_\theta$, to be inserted is the extended temperature limit obtained by calibration and supplemented by the addition of the failure margins. In most cases the inaccuracy of measurement may be taken from table 3.

Table 3 — Inaccuracy of measurement, $\tilde{V}_\theta$, for calibrated liquid-in-glass thermometers

Temperature range °C	Scale divisions, K				
	0,1	0,1	0,5	1	2
– 50 to – 5	0,6	0,8	1,7	2,0	4,0
– 5 to 60	0,3	0,4	1,0	1,4	2,0
60 to 110	0,5	0,6	1,0	2,0	3,0
110 to 210	–	1,0	2,0	3,0	4,0
210 to 310	–	–	3,0	4,0	6,0

8.2.2.2 Thermocouples

If a works test certificate of recent date of a calibration of the entire equipment used for the fixed points on the temperature scale is available and measurement has been made with precision compensation instruments (quality class 0,1), an inaccuracy of measurement, $\tilde{V}_\theta$, of $\pm 1,0$ K may be used up to temperatures of 300 °C.

By using special combinations of instruments, considerably smaller inaccuracies of measurement can be reached, especially in the measurement of small temperature differences.

8.2.2.3 Resistance thermometers

If a works test certificate of recent date is available for a calibration of the entire range of measurement at the fixed temperature points, an inaccuracy of measurement, $\tilde{V}_\theta$, of $\pm 1,0$ K can be applied for temperatures up to 300 °C.

8.2.3 Inaccuracy of flow measurements

The tolerance, τ_q , on flow measurements with standardized throttling devices shall be calculated according to ISO 5168. If the suppression of pulsations was unsuccessful, corrections should be applied. In that case, the tolerance should be increased by 20 % of the correction.

8.2.4 Inaccuracy of shaft-speed measurements

With shaft-speed measured by means of calibrated analogue measuring instruments, the relative inaccuracy of measurement, τ_N , as a percentage, is

$$\tau_N = \frac{\tilde{V}_N}{N}$$

$$\tau_N = \pm G \frac{N_{En}}{N_R}$$

where

G is the quality class as a percentage;

N_{En} is the full scale value of the instrument;

N_R is the measured shaft-speed.

With shaft-speed measured by means of digital measuring instruments, the relative inaccuracy of measurement, as a percentage, is

$$\tau_N = \pm \frac{S}{A}$$

where

S is the digital step;

A is the measured value read from the scale.

8.2.5 Inaccuracy of power measurements

8.2.5.1 Torque measurements

With torque measurements by means of calibrated torsion dynamometers, the relative inaccuracy of measurement, τ_{M_d} , as a percentage, is

$$\tau_{M_d} = \frac{\tilde{V}_{M_d}}{M_d}$$

$$\tau_{M_d} = \pm G \frac{M_{dEn}}{M_{dR}}$$

where

G is the quality class, as a percentage;

M_{dEn} is the full scale value of the instrument;

M_{dR} is the measured value.

When torque measurements are made with an electric dynamometer, the inaccuracy of measurement indicated by the manufacturer may be used.

8.2.5.2 Inaccuracy of the two-wattmeter method

The tolerance for a two-wattmeter measurement is a combination of the tolerance for the instrument readings calculated in the normal way, and the tolerance for the instrument errors calculated according to the following.

For a two-wattmeter measurement, the relative inaccuracy of the measurement of the electric power input is

$$\tau_{P_{el}} = \frac{\tilde{V}_{P_{el}}}{P_{el}}$$

$$\tau_{P_{el}} = \pm \left[G_u^2 + G_i^2 + G_W^2 \left(\frac{\alpha_E}{\alpha_1 + \alpha_2} \right)^2 f_t + (f_u^2 + f_i^2) f_f \right]^{1/2}$$

with

$$f_t = \left(1 + \frac{\theta - 20}{10} \times \frac{\alpha_1}{\alpha_E} \right)^2 + \left(1 + \frac{\theta - 20}{10} \times \frac{\alpha_2}{\alpha_E} \right)^2$$

$$f_f = 3,3 \times 10^3 \times [(3K - 1)^2 + (3K - 2)^2]$$

where

G_u is the quality class of the voltage transformers, as a percentage;

G_i is the quality class of the current transformers, as a percentage;

G_W is the quality class of the wattmeters, as a percentage;

θ is the temperature of instruments, in degrees Celsius;

Γ_U are the limits of the angle errors of the voltage transformers, in radians;

Γ_i are the limits of the angle errors of the current transformers, in radians;

α is the actual reading of the wattmeters;

α_E is the full scale reading of one wattmeter;

K is the part load of the first wattmeter $\left(K = \frac{P_{el1}}{P_{el2}}\right)$.

It is assumed that G and Γ are equal in both measuring circuits. If for the wattmeter preresistors with the error limits G_R are used, the term $G_R^2 [1 + 2K(K - 1)]$ shall be added inside the brackets of $\tau_{P_{el}}$.

8.2.5.3 Inaccuracy of direct current measurements

With direct current, a similar procedure can be followed broadly if voltmeters and amperemeters are used and the readings are multiplied.

The measuring errors for tension, τ_U , and current, τ_i , are combined to give

$$\tau_{1c} = \pm \sqrt{\tau_U^2 + \tau_i^2}$$

8.2.5.4 Inaccuracy of the results of measurement at the coupling of the prime mover

When measurements of the power at the coupling are made through the medium of the power drawn by an electric motor, the relative inaccuracy of measurement, $\tau_{P_{Co}}$, as a percentage, is

$$\tau_{P_{Co}} = \frac{\tilde{V}_{P_{Co}}}{P_{Co}}$$

$$\tau_{P_{Co}} = \pm \left[\left(\frac{\tilde{V}_{P_{el}}}{P_{el}} \right)^2 + \left(\frac{\tilde{V}_{\eta_M}}{\eta_M} \right)^2 \right]$$

$$\tau_{P_{Co}} = \pm \sqrt{\tau_{P_{el}}^2 + \tau_{\eta_M}^2}$$

where

$\tilde{V}_{P_{el}}$ is the inaccuracy of measurement of the electric power;

$\tilde{V}_{\eta_M}$ is the uncertainty in the determination of the efficiency of the motor. The supplier of the electric motor shall provide curves showing the variation of the efficiency of the motor with the load, and shall indicate its uncertainty.

8.2.5.5 The uncertainty in the efficiency figures given in 5.7.7 can be estimated to $\pm 0,5 \%$ for precision gears and $\pm 1 \%$ for belt drives.

If there is no test record for the establishment of these efficiencies, the conditions for application of the rule of error distribution according to Gauss are not met. The tolerances for the efficiencies shall then be algebraically added to the tolerance for the power requirement of the compressor.

8.2.5.6 The measured input will be affected by load fluctuations occurring during each measurement. To cover this influence an additional tolerance is required. This additional tolerance is determined from the actual, absolute fluctuation of the load above and below the average value.

Table 4 – Tolerance for load fluctuation

Values in percentage

Average fluctuation in power input	Additional tolerance
± 2	$\pm 0,0$
± 3	$\pm 0,5$
± 4	$\pm 1,0$
± 5	$\pm 1,5$

This tolerance shall be algebraically added to the resulting tolerance from 8.3.3.

8.2.6 Confidence limits of gas properties

When the composition of the gas fluctuates, special care shall be taken to secure a suitable sample. If the fluctuations exceed the measure that can thus be compensated for, the confidence limits shall be increased.

The following information presumes, further, that suitable chemical or physical analyses will be undertaken to determine the composition of the gas.

8.2.6.1 Gas constant

If the gas constant is taken from standard tables, its confidence limits may be neglected.

If the conditions of 8.2.6 are adhered to, the confidence limits, V_R , of the gas constant may be neglected. If the gas constant is determined from a density measurement made with accurate instruments, a relative confidence limit, V_R/R , of $\pm 0,5 \%$ shall be used.

8.2.6.2 Compressibility factor

The confidence limits of the compressibility factors of the pure gases most often compressed may be taken from the relevant literature.

For gas mixtures the greatest accuracy is attainable by measuring the compressibility.

The calculation of the compressibility factor yields only approximate values. In the estimation of the confidence limits of the compressibility factor of the mixture, the confidence limits of the compressibility factor of the components occupying the greatest proportion by volume and the confidence limits of the components whose compressibility factors diverge most from unity are the data chiefly used.

8.2.6.3 Isentropic exponent

If the isentropic exponent for approximately ideal gases is taken from standard tables, the confidence limits of the isentropic exponent may be neglected.

No exact information is available about the confidence limits of the isentropic exponents of gases that differ to a large extent from the ideal state. The confidence limits shall be estimated.

8.2.7 Inaccuracies caused by the correction methods

To the tolerances given above, further tolerances shall be added expressing the uncertainty of the correction methods used to convert the measured values to contract conditions.

For these tests within the limits of table 1, this tolerance may amount to $\pm 20\%$ of the correction.

8.3 Inaccuracy of results of measurement

8.3.1 Relative inaccuracy of the result of measurement of the volume flow rate

The effects of the isentropic exponent, the pressure ratio, the difference between the inlet temperatures of the gas and the cooling medium, and the clearance space on the inaccuracy of measurement may usually be neglected.

The relative inaccuracy, τ_{ErgR} , of the result of measurement, as a percentage, is then :

$$\tau_{\text{ErgR}} = \pm \sqrt{\tau_{qR}^2 + \tau_{NR}^2 + \tau_{p1R}^2 + \tau_{T1R}^2 + \tau_{Z1R}^2}$$

8.3.2 Relative inaccuracy of the result of measurement of the pressure ratio

The relative inaccuracy, τ_{ErgR} , of the result of measurement of the pressure ratio, as a percentage, is

$$\tau_{\text{ErgR}} = \pm \sqrt{\tau_{p1R}^2 + \tau_{p2R}^2}$$

8.3.3 Relative inaccuracy of the result of measurement of the power absorbed, the specific energy requirement, and the efficiency

The effect of the viscosity of the lubricant on the inaccuracy of measurement may usually be neglected.

If the power at the coupling with the prime mover is measured, the relative inaccuracy, $\tau_{\text{Erg}P_{Co}}$, of the result of measurement, as a percentage, is

$$\tau_{\text{Erg}P_{Co}} = \tau_{\text{Erg}(P_{Co}/V)}$$

$$\tau_{\text{Erg}P_{Co}} = \tau_{\text{Erg}} \eta_{Co}$$

$$\tau_{\text{Erg}P_{Co}} = \pm \left[\tau_{P_{CoR}}^2 + \tau_{qR}^2 + \tau_{T1R}^2 + \left(\frac{Z-1}{Z} \tau_{Tw1} \right)^2 + \varepsilon_2^2 \times \tau_K^2 \right]^{1/2}$$

$$\text{with } \varepsilon_2 = \frac{1}{1 - K_R} + \frac{1}{K_R} \times \ln r_R / \left[1 - r_R^{(1 - K_R)/K_R} \right]$$

If the power at the coupling, P_{Co} , is determined by measuring the torque, M_d , and the shaft-speed, N , then $(\tau_{M_dR}^2 + \tau_{NR}^2)$ replaces $\tau_{P_{CoR}}^2$ in the equation above.

8.3.4 Relative inaccuracy of the result of measurement on a single stage of a multi-stage compressor

In the process of building up the total characteristic curve from the curves of stages measured singly, or of groups of curves, the relative inaccuracy, τ_{combR} , in the measurement below is as indicated, in percentages.

8.3.4.1 Volume flow rate

$$\tau_{\text{comb}q} = \pm [1 + 0,2 (Z - 1)^{1/2}] \times \frac{\sum \tau_{qj}}{Z}$$

8.3.4.2 Pressure ratio

$$\tau_{\text{comb}r} = \pm [1 + 0,2 (Z - 1)^{1/2}] \times \sum \tau_{rj} \times \frac{Y_j}{\sum Y_j}$$

8.3.4.3 Power consumption

$$\tau_{\text{comb}P} = \pm [1 + 0,2 (Z - 1)^{1/2}] \times \sum \tau_{Pj} \times \frac{P_j}{\sum P_j}$$

The factors 0,2 and $(Z - 1)$ allow for the inevitable inaccuracies in the measurement of the separate groups of stages and in the compounding of the results.

9 Test report and comparison with specified values

9.1 A test report shall be made by the supervisor of the test and shall contain everything needed for evaluating the test.

9.2 The test report shall state the object, the place and time of the test.

9.3 The test report shall contain :

- a brief description with the principal data of the compressor and the prime mover;
- the manufacturer's name and the manufacturing number;
- a statement of the methods and the equipment used for the test with a diagrammatic layout of the test arrangement with all measurement points marked;
- a statement of the values specified by the vendor with regard to the volume flow rate, the input power and the function of the compressor in operation and the operating conditions under which the specifications apply;
- for important instruments the manufacturer's name, the manufacturing number and the construction and quality class, the steps taken for control and adjustments, etc. The calibration records and correction diagrams for the various instruments should preferably be included as appendices.