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Displacement compressors — Acceptance tests

Compresseurs volumétriques — Essais de réception

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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 1217 was prepared by Technical Committee ISO/TC 118, *Compressors and pneumatic tools, machines and equipment*, Subcommittee SC 6, *Air compressors and compressed air systems*.

This fourth edition cancels and replaces the third edition (ISO 1217:1996), which has been technically revised.

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Displacement compressors — Acceptance tests

1 Scope

This International Standard specifies methods for acceptance tests regarding volume rate of flow and power requirements of displacement compressors. It also specifies methods for testing liquid-ring type compressors (see Annex A).

This International Standard specifies the operating and testing conditions which apply when a full performance test is specified.

For compressors manufactured in batches or in continuous production quantities and supplied against specified data, the tests described in Annexes B, C and D are considered equivalent alternatives.

Annex E, which is normative, applies to any electrically driven compressor manufactured in batches or in continuous production quantities and supplied against specified data having variable speed drive (e.g. variable frequency drive, direct current drive and switched reluctance), which incorporates a displacement compressor of any type driven by an electric motor.

Detailed instructions are given for a full performance test, including the measurement of volume flow rate and power requirement, the correction of measured values to specified conditions and means of comparing the corrected values with the guarantee conditions. This International Standard specifies methods for determining the value of the tolerances to be applied to the measurement of flow, power and specific power.

NOTE   The tolerances to be applied to the measurement of flow, power, specific power, etc. for all acceptance tests carried out in accordance with this International Standard are agreed on by the manufacturer and the purchaser at the contractual stage or prior to the execution of the tests.

Annex F specifies standard inlet conditions for reference purposes. Annex G, which is normative, indicates the uncertainty of measurement.

This International Standard is not applicable to noise statements, which are identified in ISO 2151.

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 3046-1, *Reciprocating internal combustion engines — Performance — Part 1: Declarations of power, fuel and lubricating oil consumptions, and test methods — Additional requirements for engines for general use*

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*

ISO 9300, *Measurement of gas flow by means of critical flow Venturi nozzles*

IEC 60584-1, *Thermocouples — Part 1: Reference tables*

IEC 60584-2, *Thermocouples — Part 2: Tolerances*

IEC 60584-3, *Thermocouples — Part 3: Extension and compensating cables — Tolerances and identification system*

IEC 60953-2, *Rules for steam turbine thermal acceptance tests — Part 2: Method B — Wide range of accuracy for various types and sizes of turbines*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 General

3.1.1
acceptance test
performance test carried out in accordance with this International Standard, i.e. ISO 1217:2009

3.1.2
aftercooling
removal of heat from a gas after the compression is completed

3.1.3
batch
two or more compressors manufactured at the same time in one operation

3.1.4
clearance volume
volume inside the compression space, which contains gas trapped at the end of the compression cycle

3.1.5
displacement compressor
machine that creates a static pressure rise 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

3.1.6
displacement of a displacement compressor
volume swept by the compressing element(s) of the compressor's first stage per unit of time

3.1.7
external coolant
medium externally supplied to the compressor to which the generated heat is finally rejected

NOTE   This is usually ambient air or cooling water.

3.1.8
fuel consumption
total mass of fuel consumed by the engine per unit time while the compressor is running on test at the specified conditions of inlet and discharge pressure and speed, with all engine ancillary equipment such as alternator and water pump connected and operating normally

See Annex D.

3.1.9
ideal multi-stage compression
process by which a perfect gas is isentropically compressed and the gas inlet temperature as well as the amount of work spent are the same for each stage

3.1.10
intercooling
removal of heat from a gas between stages

3.1.11
liquid-injected rotary compressors
rotary compressor in which a liquid is injected into the gas stream before or in the compressor

3.1.12
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

See Annex A.

NOTE 1   A working liquid creating a liquid ring rotating together with the bladed impeller creates either one or two crescent-shaped working spaces.

NOTE 2   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.

3.1.13
packaged compressor
compressor with prime mover, transmission, fully piped and wired internally, including ancillary and auxiliary items of equipment and being stationary or mobile (portable unit) where these are within the scope of supply

3.1.14
polytropic process
compression or expansion process of an ideal gas, in which the relationship between pressure and volume is:

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

NOTE 1   The exponent n can have various values. For example:

$$pV = \text{constant}$$

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

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

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

NOTE 2   Sometimes this process is called adiabatic, but to avoid confusion between adiabatic (no heat exchange with the surroundings) and reversible adiabatic (isentropic) process, the expression isentropic is preferred.

3.1.15
relative clearance volume
ratio of clearance volume of the stage under consideration to the swept volume of the compressing element of this stage

3.1.16
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

3.1.17
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

3.1.18
shaft rotational speed
number of revolutions of the compressor drive shaft per unit of time

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3.1.19
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 both

$$\text{Shaft-speed irregularity} = 2\,\frac{N_{\max.} - N_{\min.}}{N_{\max.} + N_{\min.}} \tag{1}$$

3.1.20
specific fuel consumption
mass per unit time divided by the compressor volume flow rate, both measurements being corrected to standard conditions by the methods given in Annex D

3.1.21
standard discharge condition
condition of the compressed gas at the standard discharge point of the compressor

3.1.22
standard discharge point
discharge point considered representative of each compressor

NOTE   This point varies with compressor design and type of installation:

a)   for a bare compressor, it is generally at the compressor discharge flange:

　　1)   reciprocating type compressors: discharge flange of the last (or only) stage cylinder or any chamber fitted as standard to that cylinder to reduce pulsations in the delivered compressed gas and so indicated by the manufacturer in the sales data for the particular type of compressor;

　　2)   rotary type compressors: discharge flange of the last (or only) rotor casing;

b)   for a packaged compressor, it is the terminal outlet of the package.

3.1.23
standard inlet condition
condition of the aspirated gas at the standard inlet point of the compressor

3.1.24
standard inlet point
inlet point considered representative of each compressor and which varies with compressor design and type of installation

NOTE 1   For a bare compressor, it is generally the inlet flange to the first (or only) stage cylinder or rotor casing, i.e. after any inlet filter or silencing equipment which can normally be used for test purposes, unless otherwise identified.

NOTE 2   The standard inlet point of a packaged air compressor, unless otherwise indicated by the manufacturer, is the point at which ambient air enters the package or, in the case of a non-enclosed package, where air first enters the confines of the machine, probably the air inlet filter.

3.1.25
swept volume of a displacement compressor
volume swept in one revolution by the compressing element(s) of the compressor's first stage

3.1.26
turn-down ratio
ratio expressed in percentage of the difference between maximum and minimum speed divided by the maximum speed of the main driver

3.2   Pressure

3.2.1
absolute pressure
pressure measured from absolute zero, i.e. from an absolute vacuum, equal to the algebraic sum of atmospheric pressure and effective pressure

3.2.2
ambient pressure
absolute pressure of the atmospheric air measured in the vicinity of the compressor

3.2.3
atmospheric pressure
absolute pressure of the atmospheric air measured at the test place

3.2.4
discharge pressure
total mean absolute pressure at the standard discharge point

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

3.2.5
dynamic pressure
velocity pressure
total pressure minus the static pressure

3.2.6
effective pressure
gauge pressure
pressure measured above the atmospheric pressure

3.2.7
inlet pressure
total mean absolute pressure at the standard inlet point

3.2.8
static pressure
pressure measured in a gas in such a manner that no effect on measurement is produced by the gas velocity and which, in stationary gas, is numerically equal to the total pressure

3.2.9
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

3.3   Temperature

3.3.1
ambient temperature
total temperature of the atmospheric air in the vicinity of the compressor, but unaffected by it

3.3.2
discharge temperature
total temperature at the standard discharge point of the compressor

3.3.3
inlet temperature
total temperature at the standard inlet point of the compressor

3.3.4
total temperature
temperature that 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

3.4 Flow rate

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 prevailing at the standard inlet point

NOTE   Composition can refer to humidity, for instance.

3.4.2
free air
air at the ambient conditions of the compressor, but unaffected by it

3.4.3
standard volume flow rate
actual volume flow rate of compressed gas as delivered at the standard discharge point but referred to standard inlet conditions (for temperature, pressure and inlet gas composition)

3.5 Power

3.5.1
isentropic power
power that 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

NOTE   The theoretical isentropic power required is the sum of the isentropic power required at all the stages.

3.5.2
isothermal power
power that 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

3.5.3
packaged compressor power input
⟨electrically driven machines⟩ sum of the electrical power inputs to the prime mover and any ancillaries and auxiliaries driven from the compressor shaft or by a separate prime mover at rated supply conditions, including the effect of all equipment included in the package

NOTE 1   Auxiliaries include oil pump, cooling fan and integral compressed air dryer.

NOTE 2   Rated supply conditions refer to phase, voltage, frequency and ampere capability.

3.5.4
shaft power
power required at the compressor drive-shaft, equal to the sum of mechanical losses and the internal power, not including losses in external transmissions such as gear drives or belt drives unless part of the scope of supply

3.6 Efficiency

3.6.1
isentropic efficiency
ratio of the required isentropic power to shaft power

3.6.2
isothermal efficiency
ratio of the required isothermal power to shaft power

3.6.3
volumetric efficiency
ratio of the actual volume flow rate to the displacement of the compressor

3.7   Specific energy requirements

3.7.1
specific energy requirements of a bare compressor
shaft input power per unit of compressor actual volume flow rate

3.7.2
specific energy requirements of a packaged compressor
packaged compressor power input per unit of compressor actual volume flow rate

3.7.3
specific fuel consumption
specific steam consumption
fuel or steam mass flow per unit of compressor actual volume flow rate

3.8   Gas properties

3.8.1
compressibility factor
expression of the deviation of the real gas from an ideal gas

3.8.2
mixing ratio
ratio of mass of moisture contained in the gas to the mass of the dry gas

3.8.3
relative vapour pressure
ratio of the partial pressure of a vapour to its saturation pressure at the same temperature

4   Symbols

4.1   Symbols and units

Symbol	Term	SI unit	Other practical unit
A	Area	m^2	mm^2
b	Specific fuel consumption	kg/m^3	—
c	Velocity	m/s	—
e_m	Mass-specific energy requirement	J/kg	kJ/kg
e_V	Volume-specific energy requirement	J/m^3	J/l, kWh/m^3
E	Relative clearance volume	—	—
f	Parameter for uncertainty calculations	unit of symbol	—
F	Fuel consumption	kg/s	kg/h, g/s
G	Quality class	%	—
h	Level for liquid column	m	mm
H_1	Absolute inlet humidity	—	—

Symbol	Description	Unit	Alt Unit
K	Correction factor	—	—
K_1	Correction factor for shaft speed		
K_2	Correction factor for tests where polytropic exponents for specified conditions and test conditions are different		
K_3	Correction factor for external coolant temperature		
K_4	Correction factor for shaft speed ($= K_1$)		
K_5	Correction factor for inlet pressure, polytropic exponent and pressure ratio		
K_6	Correction factor for isentropic exponent		
K_7	Correction factor for humidity in multi-stage compressors		
K_8	Correction factor for external coolant inlet temperature		
K_9	Correction factor for pressure ratio		
K_{10}	Correction factor for working liquid temperature		
K_{11}	Correction factor for gas inlet temperature		
K_{12}	Correction factor for shaft speed		
K_{13}	Correction factor for condensate formation		
m	Manufacturing tolerance		
M	Torque	N·m	—
n	Exponent for polytropic process in pV diagram	1	—
N	Rotational frequency (shaft speed)	s^{-1}	min^{-1}
p	Pressure	Pa	MPa (bar[a], mbar)
P	Power	W	MW, kW
q	Rate of flow	kg/s or m^3/s	kg/h or m^3/h, m^3/min, L/s
q_m	Mass rate of flow	kg/s	kg/h
q_V	Volume rate of flow	m^3/s	m^3/h, m^3/min, L/s
r	Pressure ratio	1	—
R	Gas constant	J/(kg·K)	—
t	Celsius temperature	°C	—
T	Thermodynamic temperature	K	—
V	Volume	m^3	L
$\bar{V}$	Absolute uncertainty	unit of symbol	—
W	Work	J	MJ, kJ, kWh
x	Mixing ratio	kg/kg	g/kg
z	Number of stages	1	—
Z	Compressibility factor	1	—
Δ	Difference of quantity		—
η	Efficiency	1	—
κ	Isentropic exponent	1	—
μ	Dynamic viscosity	Pa·s	kg/(m·s)
ρ	Mass density	kg/m^3	kg/L
τ	Relative uncertainty	1	—
φ	Relative vapour pressure	1	—
ω	Angular velocity	rad/s	—

[a] 1 bar = 0,1 MPa = 0,1 N/mm^2 = 10^5 N/m^2.

4.2 Subscripts

Subscript	Term	Remark
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	
air	dry air	
b	atmospheric	Characterizes the atmospheric pressure and temperature
C	contractual	Indicates the quantities specified in the contract
cd	condensate	
co	coupling	
comb	combination	
corr	corrected	
corr, C	corrected to contractual requirements	
cr	critical	Characterizes the critical pressure and temperature
d	dynamic	Characterizes the dynamic pressure and properties
e	effective	
E	full-scale value	
el	electric	
f	flow measuring device	Without condensate
g	dry gas	
i	individual measurement in a series of n measurements	
in	internal	
int	intercooler temperature	Absolute temperature of air or gas leaving the intercooler under observation
L	working liquid	
m	mass	Characterizes the mass-specific rates of flow, energies and volumes
me	mechanical	
M	motor	
n	number of measurements in the series	
N	normal	
P	package	
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
res	resulting	
s	saturated	
S	isentropic	Characterizes an isentropic process
t	total	
T	isothermal	Characterizes an isothermal process
th	theoretical	
v	vapour	
V	volume	Characterizes the volume-specific rates of flow and energy
w	coolant	

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5 Measuring equipment, methods and accuracy

5.1 General

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

All inspection, measuring, test equipment and devices that can affect the test shall be calibrated and adjusted at prescribed intervals, or prior to use, against certified equipment having a known valid relationship to nationally recognized standards.

5.2 Measurement of pressure

5.2.1 General

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, minor irregularities such as burrs can lead to serious error.

Connecting piping shall be leak-free, as short as possible, of sufficient diameter and arranged so as to avoid blockage by dirt or condensed liquid. For measurement of liquid pressure or pressure of liquid-gas mixtures, the instrument shall be mounted at the same height as the measuring point and the connecting piping shall be arranged so that the height of liquid columns in the piping exerts no influence. Otherwise, account shall be taken of the difference in height. Tightness shall be tested and all leaks eliminated.

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

The measuring instrument (analogue or digital) shall have an accuracy of $\pm$ 1 % at the measured value.

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 should be calculated on the basis of a calculated average velocity.

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 in accordance with the requirements of this International Standard shall not be carried out.

Transmitters and gauges shall be calibrated under pressure and temperature conditions similar to those prevailing during the test, using dead-weight or electrical testing equipment of an equivalent accuracy.

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

Column readings shall be corrected for ambient temperature.

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

Oscillations of gauges shall not be reduced by throttling with a valve placed before the instrument. However, a restricting orifice may be used.

5.2.2 Atmospheric pressure

The atmospheric pressure shall be measured with a barometer having an accuracy better than ± 0,15 %.

5.2.3 Intercooler pressure

Intercooler pressure shall be measured immediately after any intercooler.

5.3 Measurement of temperature

Temperature shall be measured by certified or calibrated instruments such as thermometers, thermo-electrical instruments, resistance thermometers or thermistors having an accuracy of ± 1 K inserted into the pipe or into pockets.

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 liquid.

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.

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

Precautions shall be taken to ensure that the:

a) 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) 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) thermometer pocket does not disturb the normal flow.

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 material 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. The selection and use of thermocouples shall be in accordance with IEC 60584-1, IEC 60584-2 and IEC 60584-3.

5.4 Measurement of humidity

If the gas contains moisture, the humidity shall be checked during the test. The humidity shall be measured at the standard inlet point with an instrument having an accuracy of ± 3 % or better.

5.5 Measurement of rotational frequency

Shaft speed shall be determined by using methods that have an accuracy of ± 0,5 % or better.

5.6 Measurement of flow rate

The actual delivered flow rate of the compressor shall be measured by performing a test as indicated in ISO 5167-1 or ISO 9300.

Measurement of the aspirated volume flow rate may be used:

— when measurement of delivered volume flow rate is not practical;

— if leakage flows can be measured separately and are then deducted from the aspirated volume flow rate; where it can be confirmed that there is no external leakage of compressed gas from the compressor, as is the case with liquid-injected rotary compressors;

— where effects of condensation of components of intake gas give rise to possible inaccuracy of measurement of delivered volume flow rate (see 6.5.5 and 6.6);

— where aspirated air is measured, in which case the measurement device should not restrict the measurement.

The external coolant flow shall be determined by using a measuring method with an accuracy of ± 5 % of the measured value or better.

5.7   Measurement of power and energy

The power input to the compressor shall be measured directly by reaction-mounted drivers, or a torque meter, or indirectly determined from measurements of electrical input to a calibrated driving motor or from the certified performance characteristics of a driving prime mover.

The measurement of the shaft power of the prime mover shall be carried out according to a recognized test code.

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.

The shaft power of an electrically driven compressor shall be determined by measuring the electrical power supplied and multiplying by the motor efficiency value obtained from the certified calibration of the motor. 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 60051-1). Factors influencing the measurement, such as voltage drop in supply cables or measurement systems, shall be taken into account.

Electric power of the machine shall be referred to the electrical input terminals. Factors influencing the measurement, such as voltage drop in supply cables or measurement systems, shall be taken into account.

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

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

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

5.8 Miscellaneous measurements

5.8.1 Fuel consumption

If the compressor is driven by an internal combustion engine or a gas turbine, the mean fuel consumption shall be determined by weighing or measuring the volume of the fuel consumed per unit of time, while running at the constant conditions of a particular test point (see ISO 3046-1).

5.8.2 Steam consumption

If the compressor is driven by a steam engine or turbine, the steam rate shall be determined in accordance with IEC 60953-2.

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

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

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 since the preceding draining operation.

Any oil carried over with the condensate should be separated from the condensate before the mass of the latter is measured.

5.9 Calibration of instruments

Calibration records of the instruments shall be available prior to the test.

Recalibration after the test shall be carried out 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 accuracy of the instrument, may be cause for rejecting the test.

6 Test procedures

6.1 General

Before acceptance tests begin, the compressor shall be examined to ascertain whether or not it is in a suitable condition to undergo an acceptance test. External leakage shall be eliminated as far as possible. In particular, the pipe systems shall be checked for leakage.

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

6.2   Test arrangements

Test arrangements are the following.

a)   Preliminary tests may be run for the purposes of, for example

— checking instruments, and

— training personnel.

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

c)   During the test, all measurements having any bearing on the performance shall be carried out. The determination of the flow rate and the power absorbed by the compressor are covered in detail in 6.3 to 6.9.

d)   The test conditions shall be as close as reasonably possible to the conditions of guarantee; deviations from these shall not exceed the limits specified in Table 1. If no inlet conditions have been agreed, then the provisions of Annex F shall apply.

e)   Where it is not feasible to test a machine with the gas intended to be used with the compressor under test or within the limitations specified in Table 1, alternative test conditions or alternative corrections shall be identified.

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

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

h)   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.

i)   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.

j)   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.

k)   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.

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

Table 1 — Maximum deviations from specified values and fluctuations from average readings

Measured variable	Maximum permissible deviations	Maximum permissible fluctuation from average during any set of readings
Inlet pressure, p_1	± 10 %	± 1 %
Discharge pressure, p_2	Not specified	± 1 %
Pressure ratio, r	See 8.3.1	—
Inlet temperature, T_1	Not specified	± 2 K
Absolute inlet humidity, H_1	Not specified	± 5 %
Isentropic exponent, κ	± 3 %	Not specified

Table 1 (*continued*)

Measured variable	Maximum permissible deviations	Maximum permissible fluctuation from average during any set of readings
Gas constant × compressibility factor, $R \times Z$	± 5 %	Not specified
Shaft speed, N	± 4 %	± 1 %
Liquid injection temperature [a]	± 5 K	Not specified
Difference between inlet temperature of external coolant and the gas inlet temperature	± 10 K For coolant air ± 5 K For coolant liquid	± 2 K ± 2 K
External coolant flow	± 10 %	± 10 %
Temperature at the nozzle or orifice plate	Not specified	± 2 K
Differential pressure over nozzle or orifice plate	Not specified	± 2 %

[a] For internally cooled, liquid-injected rotary compressors.

NOTE 1   The test can be performed if the deviations from the specified conditions are equal to or less than the deviation tolerances.

NOTE 2   If the deviation from test conditions results in a deviation in absorbed power higher than ± 10 %, then the test is not within the limits.

NOTE 3   See 5.2.1.

NOTE 4   A test at a shaft speed different from the specified value is not accepted if resonant pressure pulsations exceed permitted levels.

NOTE 5   For the test of a gas compressor with a gas different from that specified, a bigger variation in gas properties often occurs. This is agreed upon by both parties.

NOTE 6   For liquid-ring compressors, see also Table A.1.

6.3   Evaluation of readings

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.

All accepted readings from any test run shall be consecutive.

Sets of readings showing excessive fluctuation may be discarded, but only at the beginning or end of a test run. All readings in any set shall be taken as near as possible to one another.

The moisture content shall be determined 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

Computation of the test results shall be in accordance with the following.

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

b)   The mass flow rate shall be determined according to 5.6.

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

d)   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 according to 6.5.4 and 6.6.

e) Some unloading systems exhaust warm gas back to inlet at part load conditions. 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, the part load flow rate is calculated with the inlet temperature valid for full load.

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

g) 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, isentropic or polytropic exponent, external coolant temperature and discharged condensate. The absorbed power shall be adjusted for deviation in speed, inlet pressure, isentropic or polytropic exponent, humidity effects and external coolant temperature.

NOTE 1   Other corrections, such as correction for gas constant and the compressibility factor, can be made.

h) Outside the limits specified in Table 1, the influence of the actual 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.

NOTE 2   Such corrections are agreed upon by the parties concerned.

i) 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.

j) 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 volume flow rate.

NOTE 3   Such corrections are agreed upon by the parties concerned.

6.5 Volume flow rate corrections

6.5.1 Correction factor for shaft speed, K_1

The correction factor for shaft speed, K_1, is calculated using Equation (2):

$$K_1 = \frac{N_C}{N_R} \tag{2}$$

6.5.2 Correction factor for tests where polytropic exponents for specified conditions and test conditions are different, K_2

The correction factor for tests where polytropic exponents for specified conditions and test conditions are different, K_2, can be neglected, except for when testing single-stage reciprocating compressors. In such machines, a change in the polytropic exponent and in the pressure ratio will influence the volume flow rate as the expansion of the gas trapped in the clearance volume is affected. Since the degree of this influence is not fully known, it is important that the compressor be operated as near to the specified pressure ratio as possible.

For differences within the limits given in Table 1, Equation (3) shall apply:

$$K_2 = \frac{1 - E\left(r_C^{1/n_C} - 1\right)}{1 - E\left(r_R^{1/n_R} - 1\right)} \tag{3}$$

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 κ, in which κ is the isentropic exponent).

For pressure ratios below 3, the correction factor is simplified to Equation (4):

$$K_2 = 1 + E\left(r_R^{1/n_R} - r_C^{1/n_C}\right)$$

(4)

For all other compressors where the deviation from specified values and fluctuations from average readings during the test are maintained within the limits of Table 1, $K_2 = 1,0$.

6.5.3   Correction factor for external coolant temperature, K_3

The temperature difference between the external coolant and the gas at their inlet 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 formula for correcting volume flow rate can be given. It is recommended that provided the specified gas and coolant temperatures and the difference between them are maintained within the limits given in Table 1, no correction shall be made. Therefore, the correction factor for external coolant temperature is

$K_3 = 1,0$

For liquid-injected rotary compressors, the volume flow rate is affected by the temperature difference of the liquid injected into the compressor and therefore 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 and sealing 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.

For liquid-injected rotary compressors that use air-cooled exchangers to cool the injected liquid, the temperature of the cooling air approaching the heat exchanger and the temperature of the compressor inlet air will usually be similar. In these circumstances, provided the inlet air temperature remains within ± 10 K of the specified value in Table 1, no correction for volume flow rate shall be made.

$K_3 = 1,0$

For liquid-injected rotary compressors that use water-cooled heat exchangers to cool the injected liquid, the water flow rate can generally be adjusted to approximately maintain the specified liquid injection temperature. Provided the liquid injection temperature is maintained during the test within the limits specified in Table 1, no correction for volume flow rate shall be made.

$K_3 = 1,0$

Where the conditions stated in this subclause cannot be met and for other types of liquid-injected rotary compressor, the correction factor, K_3, shall be individually determined [see 6.4 h)].

6.5.4 Correction of volume flow rate to allow for discharge of condensate formed from vapour component of intake gas flow

Vapour present in the intake gas can condense and be collected as it passes through the compressor at any point between the inlet point and the flow measurement point (i.e. intercooler, aftercooler, etc.). Allowance may be made for such condensate ejected from the compressor during the test when calculating the inlet gas flow using Equation (5):

$$q_{V\text{cd}} = q_{m\text{cd}} \times R_\text{v} \times T_1 / p_1 \tag{5}$$

where

$q_{V\text{cd}}$ is the volume flow rate of condensed water vapour at compressor inlet conditions;

$q_{m\text{cd}}$ is the total mass flow rate of condensate collection;

R_v is the gas constant of water vapour.

Any condensate resulting from water being injected in the gas stream shall not be taken into account.

6.5.5 Correction for deviation in gas constant and compressibility factor

A change in gas constant or compressibility factor can affect the leakage and hence the measured volume flow rate. This influence should be neglected provided the product $R \times Z$ of gas constant, R, and compressibility factor, Z, is maintained within the tolerances given in Table 1.

6.6 Corrected volume flow rate

When the inlet gas has no vapour component which will condense at any temperature and pressure condition obtained in the compressor during the testing process, the corrected volume flow rate is found using Equation (6):

$$q_{V\text{corr}} = K_1 K_2 K_3 \times q_{V\text{R}} \tag{6}$$

where $q_{V\text{R}}$ is the measured volume flow rate calculated from measured results of the test.

$$q_{V\text{R}} = \frac{q_{m\text{R}} \times R_\text{f} \times T_1}{p_1} \tag{7}$$

with

$$R_\text{f} = R_\text{g} \left[1 + \frac{x_\text{f}}{x_\text{f} + 1} \times \left(\frac{R_\text{v}}{R_\text{g}} - 1 \right) \right] \tag{8}$$

When condensed vapour ejected from any point in the compressor is collected and measured during the test, allowance shall be made when determining the equivalent inlet flow rate using Equation (9):

$$q_{V\text{corr}} = K_1 K_2 K_3 \times \left(q_{V\text{R}} + q_{V\text{cd}} \right) \tag{9}$$

where $q_{V\text{cd}}$ is the inlet volume flow rate equivalent to the condensed vapour ejected from the compressor during the test, as calculated using Equation (5).

6.7 Power corrections

6.7.1 Correction factor for shaft speed, K_4 $(= K_1)$

The absorbed power is affected by the shaft speed. It should be assumed that the compressor efficiency remains unchanged for deviations of test shaft speed from the specified shaft speed within the limits given in Table 1.

Using Equation (10), the correction factor for shaft speed, K_4 $(= K_1)$, is then:

$$K_4 = \frac{N_C}{N_R} \tag{10}$$

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

The specified pressure ratio can normally be maintained within ± 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, $\kappa + 1{,}40$).

If the inlet pressure, polytropic exponent and the pressure ratio deviate from the figures specified, then the correction methods given in Equations (11) to (13) shall be used. The correction factor for inlet pressure, polytropic exponent and pressure ratio, K_5, is:

a) for single-stage machines, cooled and uncooled:

$$K_5 = \frac{p_{1C}}{p_{1R}} \tag{11}$$

b) for multi-stage compressors with intercoolers:

$$K_5 = \frac{p_{1C}}{p_{1R}} \times \frac{\lg r_C}{\lg r_R} \tag{12}$$

c) if the pressure ratio during the test is held within ± 0,2 %, the power input correction for all displacement compressors can be simplified to:

$$K_5 = \frac{p_{1C}}{p_{1R}} \tag{13}$$

6.7.3 Correction factor for isentropic exponent, K_6

If the isentropic exponent deviates from the figure specified in the contract, then the correction methods in Equation (14) shall be used for single-stage reciprocating compressors, cooled and uncooled, with negligible leakage losses past the piston(s). The correction factor for isentropic exponent, K_6, is given as Equation (14):

$$K_6 = \frac{\left[n/(n-1) \right]_C}{\left[n/(n-1) \right]_R} \times \frac{r_C^{\left(\frac{n-1}{n}\right)_C} - 1}{r_R^{\left(\frac{n-1}{n}\right)_R} - 1} \times K_2 \tag{14}$$

NOTE   The actual polytropic exponent varies during the compression process.

If no test results are available, the isentropic exponent should be used (for air, $\kappa = 1,4$). If the polytropic exponent deviates from the value specified in the contract, then the correction methods below shall be used.

6.7.4 Correction factor for humidity in multi-stage compressors, K_7

If in a multi-stage compressor, vapour has condensed in and has been discharged from the intercoolers, decreasing quantities of vapour are compressed in the following stages. The correction factor for humidity in multi-stage compressors, K_7, is given as Equation (15):

$$K_7 = 1 + \frac{R_v}{R_g} \times \frac{z-1}{z} \times \left[\frac{T_{1wR}}{T_{1R}} \left(x_{1R} - \frac{1}{z-1} \sum_{i=2}^{z} x_{iR} \right) - \frac{T_{1wC}}{T_{1C}} \times \left(x_{iC} - \frac{1}{z-1} \sum_{i=2}^{z} x_{iC} \right) \right] \tag{15}$$

where x is the mixing ratio of the gas at the inlet of any stage.

The mixing ratio may be calculated from the partial pressure of the vapour.

6.7.5 Correction factor for external coolant inlet temperature, K_8

The temperature difference between the external coolant and the gas at their inlet points will affect the gas temperature in the compressor cylinders as well as in the intercoolers. As this influence varies with the compressor type, size and shaft speed, no general formula for correcting power can be given. It is recommended that provided the specified gas and coolant temperatures and the difference between them are maintained within the limits given in Table 1, no correction shall be made.

For liquid-injected type rotary compressors, the inlet air temperature, the temperature of the injected liquid, and the difference between them all affect the absorbed power. In particular the temperature of the injected liquid has a significant influence on viscosity and hence on internal leakage and hydraulic losses.

For liquid-injected rotary air compressors which use air-cooled heat exchangers to cool the injected liquid, the temperature of the cooling air approaching the heat exchanger and the temperature of the compressor inlet air will usually be similar. In these circumstances, provided the inlet air temperature remains within $\pm$ 10 K of the specified value, no correction for power shall be made. Therefore, the correction factor for external coolant inlet temperature, K_8, shall be made.

$K_8 = 1,0$

For liquid-injected rotary air compressors which use water-cooled heat exchangers to cool the injected liquid, the water flow rate can generally be adjusted to approximately maintain the specified liquid injection temperature. Provided the liquid injection temperature is maintained during the test within limits specified in Table 1, no correction for power shall be made.

$K_8 = 1,0$

Where the conditions stated above cannot be met and for other types of liquid-injected rotary compressors, the correction factor, K_8, shall be individually determined [see 6.4 h)].

6.8 Corrected power

The corrected power is given as Equation (16):

$$P_{corr} = K_4 K_5 K_6 K_7 K_8 \times P_R \tag{16}$$

If a test motor is used, the characteristics of the motor shall be referenced in the report.

NOTE   For packaged compressors only, the input power to the motor is corrected in this way. The other components in the total power consumption figure are then added to arrive at the total corrected input power figure.

If practical, the mechanical losses, P_{me}, shall be identified individually (e.g. by measuring oil volume flows and temperatures to bearings and seals). The correction for suction pressure shall be as given in Equation (17):

$$P_{corr} = \left[\left(P_r - P_{me} \right) \times K_5 + P_{me} \right] \times K_4 K_6 K_7 K_8 \tag{17}$$

6.9 Corrected specific energy requirement

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

7 Uncertainty of measurement

The information on uncertainty of measurement in Annex G shall be used.

8 Comparison of test results with specified values

8.1 General

The test results, corrected to the specified operating conditions in accordance with Clause 6, shall be compared with the guarantee or specified performance.

The comparison shall include:

— comparison of the corrected power consumption (specific power consumption, fuel consumption or efficiency, depending on the terms of the guarantee) with the guaranteed power consumption (specific power consumption, fuel consumption or efficiency);

— comparison of the corrected volume flow rate with the guaranteed volume flow rate at the specified pressure rise (or pressure ratio).

In making the comparison, the following shall be taken into account:

— uncertainty of measurement (see Annex G);

— errors due to the confidence limits in the thermodynamic properties of the gases used;

— errors due to the inaccuracy of the methods used to correct the test results to the guaranteed operating conditions;

— errors due to non-steady conditions during the test;

— any tolerance in the performance of the compressor permitted by the terms of the guarantee.

These errors should be combined to determine the total test uncertainty. This and the manufacturing tolerance should be clearly and separately stated or illustrated in the presentation of the comparison.

In the presentation of the comparison, a conclusion should be included stating whether or not the results of the test indicate that the compressor meets the specification.

The methods of performance comparison described in 8.2 and 8.3 presume that no alternative method to comparison has been agreed on.

8.2 Comparison of measured performance curves with guarantee points

8.2.1 Compressors with no possibility of performance adjustment

If it is not possible to adjust the speed or geometry of the compressor, the guarantee comparison for volume flow rate, q_V, and specific energy, P/q_V, is carried out as shown in Figure 1.
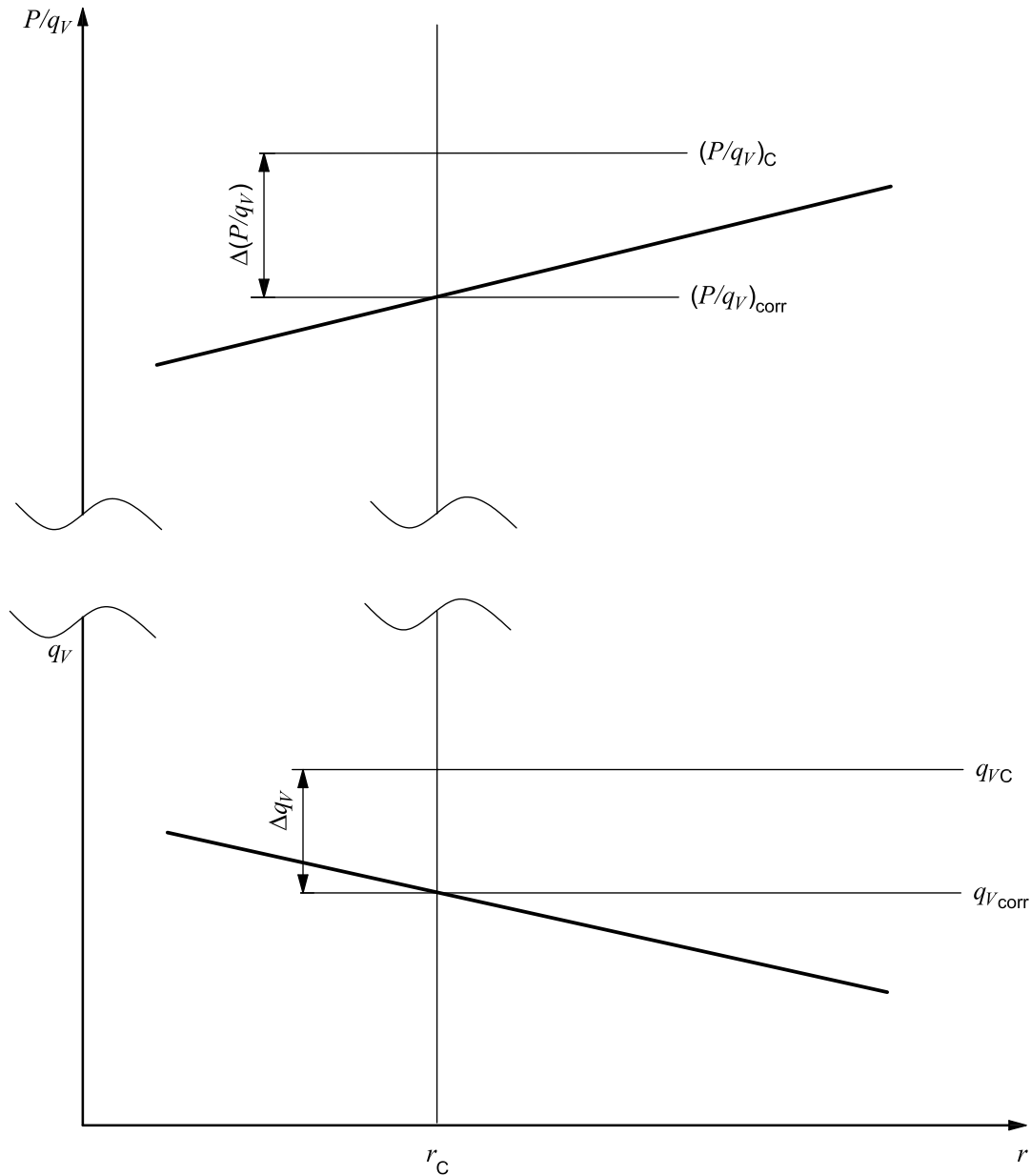
Figure 1 — Guarantee comparison of measured performance curve for compressors with no possibility of performance adjustment

8.2.2   Compressors with possibility of adjusting the performance curve

In this case, the guarantee comparison can be made directly for volume flow rate, q_V, using the performance curve which passes through the guarantee point. This performance curve can be recorded directly or be interpolated from adjacent performance curves in the permissible range. The guarantee comparison for specific energy, P/q_V, is made as shown in Figure 2.
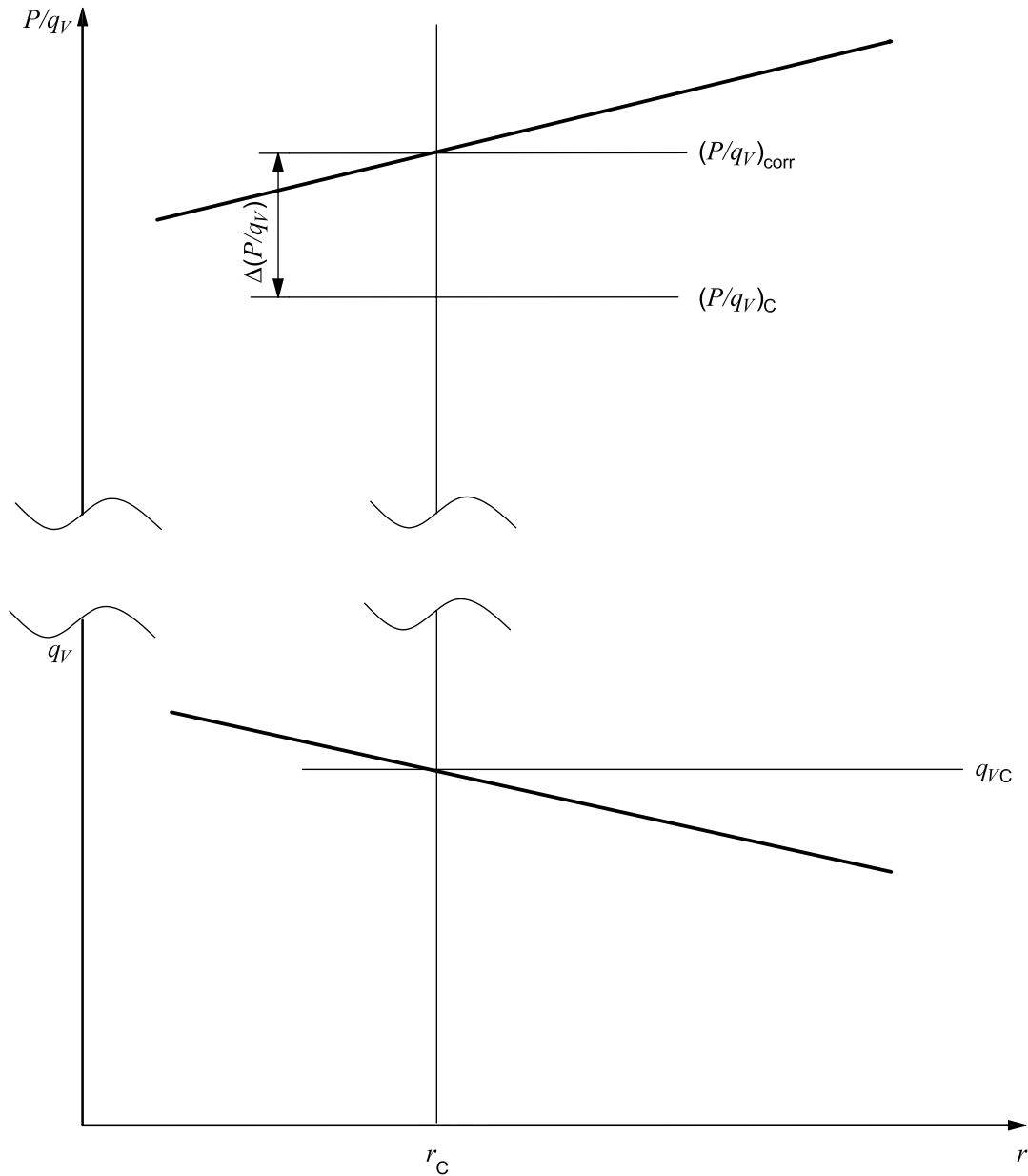
Figure 2 — Guarantee comparison of measured performance curve for compressors with possibility of adjusting performance curve

8.3   Comparison of single measuring points with single guarantee points

8.3.1   Compressors with no possibility of performance adjustment

Equations (18), (19) and (20) provide a means of comparing the corrected value of specific energy, $(P/q_V)_{corr}$, determined at the test pressure ratio, r_R, with the contractual requirements at the specified pressure ratio, r_C (see Figure 3). This assumes that the compressor efficiency remains unaltered within the range $0{,}95 r_C \leqslant r_R \leqslant 1{,}05 r_C$.

$$\left(\frac{P}{q_V} \right)_{corr,\,C} = \left(\frac{P}{q_V} \right)_{corr} \times K_9 \tag{18}$$

where for single-stage displacement compressors with or without cooling and multi-stage compressors without intercooling, the correction factor for pressure ratio, K_9, is given as Equation (19):

$$K_9 = \frac{r_C^{(\kappa - 1/\kappa)_C} - 1}{r_R^{(\kappa - 1/\kappa)_C} - 1} \tag{19}$$

For multi-stage displacement compressors with intercoolers, Equation (20) applies:

$$K_9 = \frac{\ln r_C}{\ln r_R} \tag{20}$$

where

r_R is the measured pressure ratio;

r_C is the contractual pressure ratio.

See Figure 3.
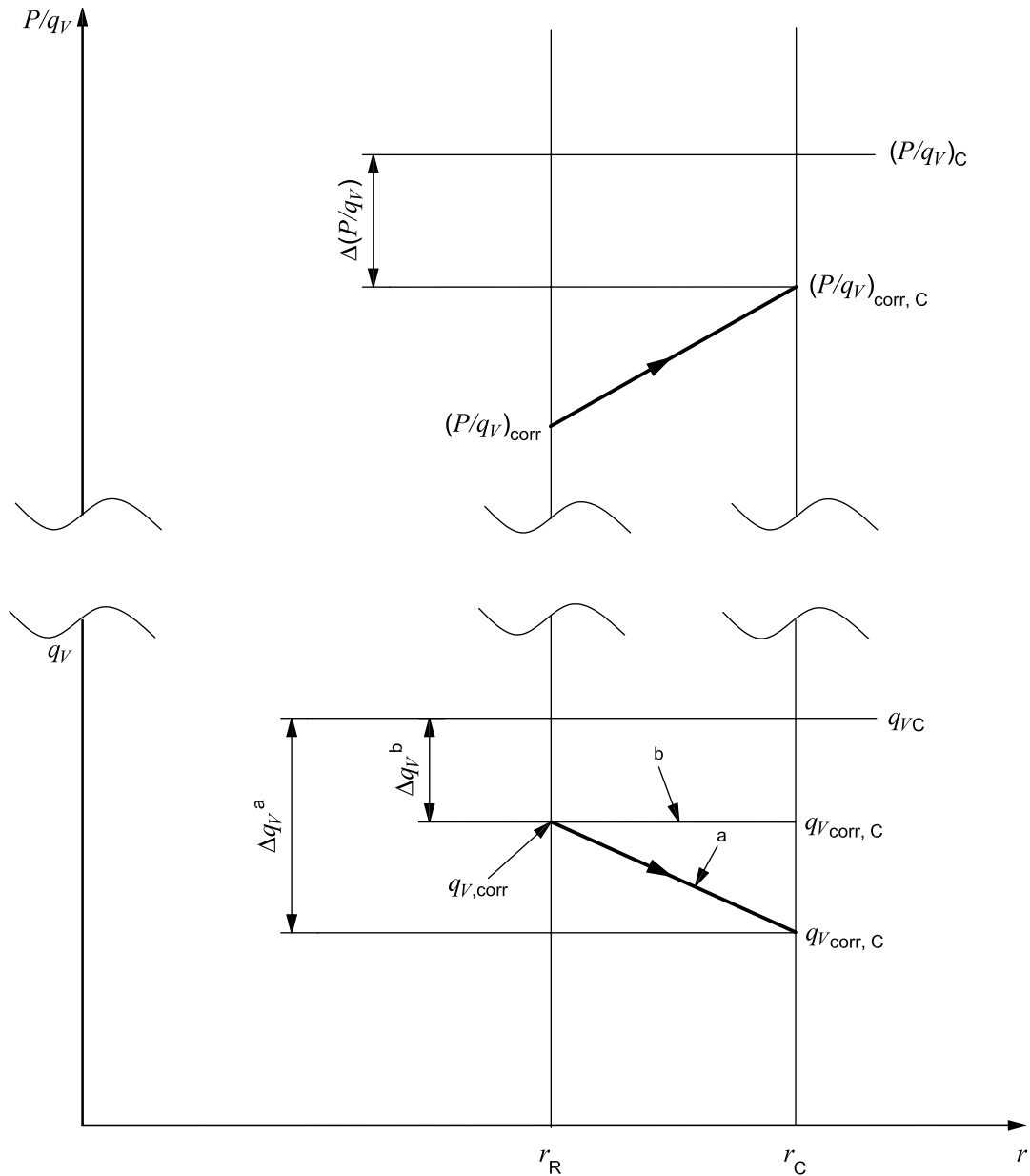
a   Single-stage piston compressors (with clearance volume).

b   Multi-stage compressors with back expansion (piston compressors), displacement compressors without back expansion (rotary type compressors).

Figure 3 — Guarantee comparison for compressors with no possibility of adjusting the performance

The corrected inlet volume flow rate, q_{V1corr}, determined at the test pressure ratio, r_R, can similarly be compared with the contractual value, q_{VC}, at the contractual pressure ratio, r_C, as given in Equations (21) and (22):

a)   for single-stage piston compressors (with clearance), Equation (21) applies:

$$q_{Vcorr,C} = q_{Vcorr} \times \frac{1 - E\left(r_C^{1/n_C} - 1\right)}{1 - E\left(r_R^{1/n_R} - 1\right)}$$
(21)

b) for multi-stage compressors with back expansion (piston compressors) and displacement compressors without back expansion (rotary type compressors), assuming constant volumetric efficiency and no alteration of the suction volume flow is applied, Equation (22) applies:

$$q_{V\text{corr, C}} = q_{V\text{corr}} \qquad (22)$$

8.3.2 Compressors with possibility of adjusting the performance curve

In this case, alteration of speed or compressor geometry (e.g. built-in volume ratio or swept volume adjustment) provides a means of adjusting q_V to q_{VC} at the specified pressure ratio, r_C. See Figure 4.

The specific energy, $P/q_{V\text{corr}}$, for the volume flow, q_{VC}, is adjusted to the specified pressure ratio, r_C, assuming constant efficiency within the limits of Table 1, as given in Equation (23):

$$\left(\frac{P}{q_V}\right)_{\text{corr, C}} = \left(\frac{P}{q_V}\right)_{\text{corr}} \times K_9 \qquad (23)$$

K_9 is calculated according to 8.3.1.

8.4 Uncertainties and manufacturing tolerances

For uncertainties and manufacturing tolerances, see G.6.

8.5 Special information

8.5.1 Linking design tolerances

If, for a guarantee point, a variation in design is claimed for the volume flow or for the pressure ratio, all other guarantee points are shifted similarly in the same ratio.
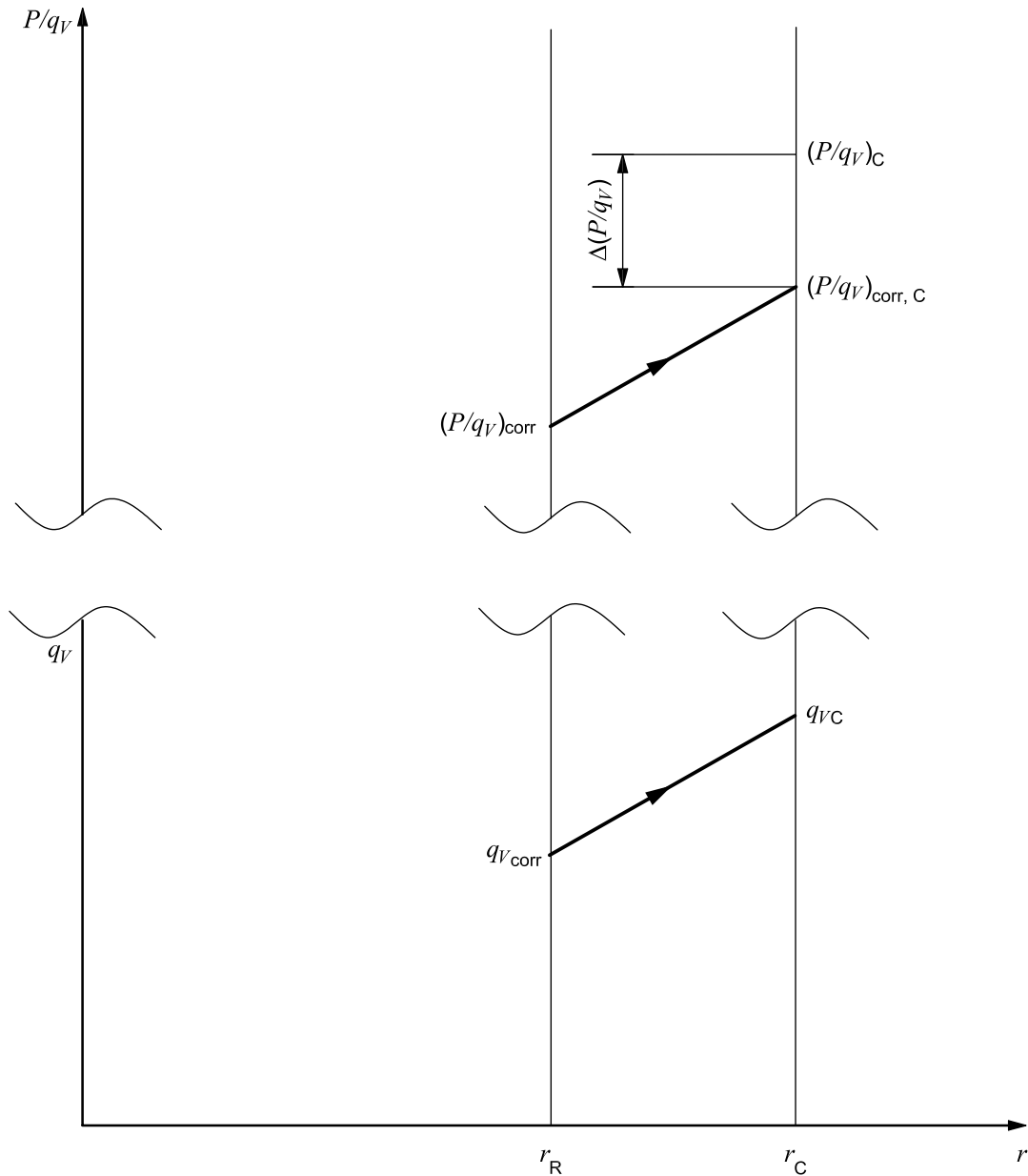
Figure 4 — Guarantee comparison for compressors with possibility of adjusting the performance

8.5.2   Linking guarantee points

The percentage variations, Δ^*, from the guarantee values are calculated from the differences of quantity, Δ, by applying Equation (24):

$$\Delta^*_{av} = \frac{\sum\limits^{n} \Delta^*_i \times C_i}{\sum\limits^{n} C_i} \tag{24}$$

The weighted mean variation is formed.

The relevant values of C_i are the evaluation coefficients assigned to the guarantee points (weights). If they are not agreed in the supply contract, they are made equal to 1.

NOTE   When, because of operational conditions that are not the supplier's responsibility, not all the operational points are checked, the guarantees of the relevant points are regarded as being fulfilled.

9   Test report

After completion of the acceptance test, a test report shall be completed recording all the necessary information on the procedure and the results of the test. It shall specify the following:

a)   the test data, the place of the test and the names of the supervisor and other participants;

b)   the following technical data:

   1)   for the compressor

      i)   the owner, site and purpose of installation, manufacturer,

      ii)   the type and serial number,

      iii)   the year of manufacture, and

      iv)   a short technical description giving operational data, auxiliaries and their drive and any other special features (intercooling and lubricating system, etc.);

   2)   for the driving unit, generally the same items specified for the compressor, but in particular those which are essential for establishing the specified performance;

c)   the conditions and scope of the guarantees according to the contract;

d)   the programme of the procedure and diagram of the test arrangement indicating location of measuring points, instruments used and their calibration records;

e)   a record of the test run together with a table of the average values of the important readings and the time they were taken. If possible, a record of the maximum and minimum readings. Copies of the log sheets and of any readouts from an automatic recorder, as well as duplicates of the gas analysis, etc.;

f)   an indication of any unscheduled occurrence which was noted during the test;

g)   the formulae used for the calculation of the results, with due regard to the propagation of the mean uncertainties as they influence the final results;

h)   a statement of the method used for converting the test results to specified conditions with reference to the tables and charts used (see Clause 8); a clear definition of the reference process chosen;

i)   a comparison of the actual performance with the guaranteed values or data and a statement of whether the contract values have been met or not.

Annex A
(normative)

Acceptance test for liquid-ring compressors

A.1 Additional definitions

The definition of particular relevance to this annex is the definition of a liquid-ring compressor (see 3.1.12).

A.2 Measuring equipment, methods and accuracy

See Clause 5.

A.3 Test procedure

See 6.1 to 6.3; however, Table 1 is replaced by Table A.1 for liquid-ring compressors.

Table A.1 — Maximum deviations from 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	$\pm 5\,K$

Whenever the pressure ratio is used as the basis for correction, it shall be within $\pm 2\,\%$ of the specified value.

Whenever the relative vapour pressure is used as the basis for correction, it shall be as close as possible to the specified value.

A.4 Correction of test results to specified conditions

Whenever the test conditions deviate from the specified conditions, a correction of the intake volume flow rate and the power absorbed or specific energy requirement shall 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.

A.5 Inlet volume flow rate corrections

A.5.1 Correction factor for shaft speed

The correction factor for shaft speed, K_1, is given as Equation (A.1):

$$K_1 = \frac{N_C}{N_R} \tag{A.1}$$

A.5.2 Correction factor for working liquid temperature

The correction factor for working liquid temperature, K_{10}, is given as Equation (A.2):

$$K_{10} = \frac{p_{1C} - p_{LC}}{p_{1R} - p_{LR}} \times \frac{T_{LR}}{T_{LC}} \tag{A.2}$$

where

p_{1C} is the specified absolute inlet pressure, in megapascal (bar);

p_{LC} is the partial pressure of the working liquid at its specified temperature, in megapascal (bar);

p_{1R} is the measured absolute inlet pressure, in megapascal (bar);

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

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

T_{LC} is the specified absolute temperature of the working liquid, in kelvin.

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

A.5.3 Correction factor for gas inlet temperature

The correction factor for gas inlet temperature, K_{11}, is given as Equation (A.3):

$$K_{11} = \frac{T_{1C}}{T_{1R}} \tag{A.3}$$

where

T_{1C} is the specified absolute inlet gas temperature, in kelvin;

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

A.6 Corrected inlet volume flow rate

The corrected volume flow rate, $q_{V\text{corr}}$, is given as Equation (A.4):

$$q_{V\text{corr}} = K_1 K_{10} K_{11} \times q_{V\text{R}} \tag{A.4}$$

where $q_{V\text{R}}$ is the measured volume flow rate calculated from observed results of the test.

A.7 Power correction

The correction factor for shaft speed, K_{12} is given as Equation (A.5):

$$K_{12} = \left(\frac{N_C}{N_R} \right)^2$$
(A.5)

where

N_C is the specified shaft speed;

N_R is the measured shaft speed during the test.

A.8 Corrected shaft power

The corrected shaft power, P_{corr}, is given as Equation (A.6):

$$P_{corr} = K_{12} \times P_R$$
(A.6)

where P_R is the measured absorbed power.

A.9 Corrected specific energy requirement

The corrected specific energy requirement is obtained by dividing the corrected shaft power by the corrected volume flow rate (see A.6 and A.8).

A.10 Uncertainty of measurement

See Annex G.

A.11 Comparison with specified values

See Clause 8.

A.12 Test report

See Clause 9.

Annex B
(normative)

Simplified acceptance test for bare displacement compressors

B.1 General

B.1.1 Air or nitrogen

This subclause applies to bare displacement air compressors of all types.

a) Such compressors are configured without drive motor or engine and generally only incorporate essential ancillary equipment, e.g. interstage coolers in the case of multi-stage compressors.

b) This subclause defines and describes acceptance tests for bare displacement air compressors which are constructed to design specifications which include performance data, i.e. volume flow rate, inlet and discharge pressure, specific energy consumption and speed, published in the manufacturer's sales documentation.

c) For compressors that are designed to inspire atmospheric air from their immediate surroundings, the performance data usually relate to a normal ambient air inlet pressure.

d) Only measurements necessary to verify the performance of a single set of conditions shall be taken.

e) The test conditions shall be as close as is reasonably possible to the specified conditions and the deviations from these shall not exceed the limits indicated in Table B.1.

f) The compressor under test shall be deemed acceptable provided the results obtained do not differ from the specified performance by more than the allowances given in Table B.2.

Table B.1 — Maximum deviations from specified values during an acceptance test

Inlet pressure	$\pm$ 10 %
Discharge pressure	$\pm$ 2 %
External coolant quantity	$\pm$ 10 %
Inlet temp. of external air coolant	$\pm$ 10 K
Inlet temp. of external liquid coolant	$\pm$ 5 K
Liquid injection temperature	$\pm$ 5 K

Table B.2 — Maximum deviations permissible at test

Volume flow rate at specified conditions $(m^3/s) \times 10^{-3}$	Volume flow rate %	Specific energy requirement %	Power requirement (at zero volume flow rate or at pressure ratio of 1) [a] %
$0 < q_V \leqslant 8,3$	± 7	± 8	± 10
$8,3 < q_V \leqslant 25$	± 6	± 7	± 10
$25 < q_V \leqslant 250$	± 5	± 6	± 10
$q_V > 250$	± 4	± 5	± 10
NOTE The tolerance values in this table cover and include manufacturing tolerances of the compressor and tolerances relating to the measurements taken during the test.			
[a] Where specified, the manufacturer shall state the method used.			

NOTE   Compressors of this type are usually manufactured in batches or in continuous production quantities and the performance guarantee offered by the manufacturer to the purchaser is implicit in the information stated in the relevant sales data.

B.1.2 Process gases

This subclause applies to bare displacement process gas compressors of all types (compressor stages) and to any type of bare displacement air compressors with a power requirement above 800 kW. Such bare air compressors typically compress air which is used as a process gas rather than for a compressed air system. This subclause therefore cannot be applied to regular compressed air or nitrogen compressors, where B.1.1 applies.

This subclause can only be used under the following circumstances.

a) Contractual agreements are agreed between both parties to use this subclause.

b) Evidence and experience with the type of compressor under test shall be available to justify the use of this subclause.

c) The test report shall include the justification for applying this subclause, including the deviation from the contractually agreed process parameters, e.g. power or composition of gas or pressure ratio, which require the use of this subclause.

d) Such compressors are configured without drive motor or engine and generally only incorporate essential ancillary equipment, e.g. interstage coolers in the case of multi-stage compressors.

e) This subclause defines and describes acceptance tests for bare displacement compressors as described in this subclause, constructed to design specifications which include performance data, i.e. volume flow rate, inlet and discharge pressure and specific energy consumption.

f) Only those measurements necessary to verify the performance of a single set of conditions ("guarantee point") to meet the specification shall be taken.

g) The test conditions shall be as close as reasonably possible to the specified conditions and the deviations from these shall not exceed the limits specified in Table B.3.

h) Experience shows that the power requirements of this type of packaged compressor frequently exceed the test bench capabilities of the manufacturers, especially in cases with high inlet pressures.

i) In cases where due to high inlet pressures the power requirement of the test would exceed 800 kW, it is therefore sufficient to fulfil only the pressure ratio condition of Table B.3, rather than the absolute inlet and discharge pressure conditions. In addition, tests with the specified speed but with atmospheric inlet pressure should then be carried out.

j) 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.

k) If the acceptance test is not carried out with the gas specified, the conversion method to be used shall be identified. If the isentropic exponent of the process gas specified is more than 7 % smaller than the isentropic exponent of the medium used for the test, thermal problems can occur if the pressure ratio is kept within the limits given by Table B.3. In such cases, it is therefore admissible to deviate from the specified pressure ratio by − 40 % to + 20 %.

l) The compressor under test will be deemed acceptable provided the results obtained do not differ from the specified performance by more than the allowances given in Table B.2.

NOTE   Compressors of this type are usually manufactured in batches and the performance guarantee offered by the manufacturer to the purchaser is implicit in the information stated in the relevant sales data.

Table B.3 — Maximum deviations from specified values during an acceptance test

Speed	± 20 %
Inlet pressure	Not specified [a]
Pressure ratio	± 20 % [b]
Discharge pressure	Not specified [a]
Coolant temperature	As for B.1
Liquid injection temperature	± 10 K
[a] If the specified inlet and discharge pressures cannot be provided, it is sufficient to fulfil the pressure ratio condition alone.	
[b] This can be exceeded if the isentropic exponent of the specified medium is more than 7 % smaller than the isentropic exponent of the test medium.	

B.2 Methods of measurement

B.2.1 General

All measurement points shall be as specified in this International Standard.

B.2.2 Methods of determining volume flow rate

The measurement of volume flow rate shall be carried out according to the methods in 5.6 and recorded in a test report.

B.2.3 Method of determining condensate rate

B.2.3.1   General

Volume flow rate may be calculated assuming complete removal of moisture from the inlet air.

If the bare compressor has no means of condensing moisture from the air being compressed, no correction shall be made for moisture content. If the bare compressor has a means of condensing and ejecting moisture, for example intercooler(s) and aftercooler(s), correction of the volume flow rate may be made either by collection and measurement of the condensate ejected during the test according to B.4.2.1 or entirely by calculation according to B.4.2.3.

B.2.3.2 Collection and measurement of condensate

Before and after the acceptance test, which shall be carried out with the compressor running at the specified test conditions, the condensate shall be drained from all ejection positions before the standard discharge point in such a way that the steady state of the compressor's running is not disturbed.

The average mass rate of condensate ejection during the test shall be calculated by dividing the mass of condensate drained after the test by the time between the draining operations. The condensate correction factor, K_{13}, shall then be determined as shown in B.4.2.3.

B.2.4 Methods of determining shaft power

B.2.4.1 General

Displacement compressors shall be tested on a fixed test rig using an electric motor as the means of providing shaft power. One of the following methods of determining shaft power may be used:

a) computing the shaft power from measurements of the speed of the compressor shaft (B.2.4.2) and the torque applied to it (B.2.4.3), while running steadily at the specified test conditions

b) determining the output shaft power from a calibrated drive motor by measurement of the input electrical power to the motor (B.2.4.4) using the previously determined operating characteristics of efficiency and, when appropriate, power factor for the motor.

B.2.4.2 Measurement of shaft speed

Shaft speed shall be determined by using methods that have the same accuracy as that stated in 5.5.

B.2.4.3 Measurement of torque

Precision torque meters having a certified calibration and an accuracy of 2 % or better at all measurement values shall be used but not below one third of their rated torque.

B.2.4.4 Measurement of electrical power

Precision instruments shall be used to measure power, voltage and current with their coils connected so that a voltage drop in the cables will not affect the measurement.

For three-phase motors the two-wattmeter method or other method of similar accuracy shall be used (see IEC 60051-1). Current and voltage transformers shall be chosen to operate as near to their rated loads as possible so that their ratio error is minimized.

B.2.4.5 Transmission losses

The manufacturer shall state the value of any external drive transmission losses. Allowance for transmission loss shall not be made for drive gears which are an integral part of the compressor being supplied, as is the case with many oil-injected rotary screw air ends.

B.3 Test procedure and report

Preliminary tests may be performed to determine whether or not the compressor is in suitable condition for the acceptance test to be conducted and to check the measuring instruments.

After a preliminary test has been carried out, this test may, by agreement, be considered the acceptance test, provided all requirements for an acceptance test have been met.

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

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

Where a verification is required it shall be demonstrated, in conjunction with the test, that the compressor is also capable of producing the specified discharge pressure, provided the inlet pressure be within the limits specified in Table B.1 and in the case of process gases, Table B.3.

The test report shall be short and simple without tolerance calculations and with only the essential corrections cited.

B.4 Computation of test results

B.4.1 General

Test conditions are never exactly consistent with the specified conditions. Therefore, before test results and specified performance values are compared, corrections shall be applied to the measured values of volume flow rate and shaft power.

Provision is made, within the limits specified in B.1.1 e), for adjustment of the volume flow rate for deviations of shaft speed and formation of condensate and adjustment of shaft power for deviations of shaft speed and inlet pressure.

B.4.2 Volume flow rate correction

B.4.2.1   General

The corrected volume flow rate, $q_{V\text{corr}}$, is calculated using Equation (B.1):

$$q_{V\text{corr}} = K_1 K_{13} \times q_{V\text{R}} \tag{B.1}$$

where

$\quad K_1$ is the correction factor for shaft speed (see B.4.2.2);

$\quad K_{13}$ is the correction factor for condensed water vapour at the specified free air conditions (see B.4.2.3).

B.4.2.2   Shaft speed correction factor

It may be assumed that the compressor volumetric efficiency, compressor mechanical efficiency and drive motor efficiency all remain unchanged for deviations of the test shaft speed from the specified speed within the limits given in B.1.1 e).

The correction factor, K_1, is then given as Equation (B.2):

$$K_1 = \frac{N_\text{C}}{N_\text{R}} \tag{B.2}$$

B.4.2.3 Condensate formation correction factor

When condensate ejected during the test is collected and measured, an allowance for this, K_{13}, may be calculated using Equation (B.3):

$$K_{13} = 1 + \frac{q_w \times R_v \times T_1}{q_{VR} \times p_1}$$ (B.3)

As an alternative to the collection and measurement of condensate, Equation (B.4) may be used to calculate the correction factor, K_{13}:

$$K_{13} = \frac{p_1}{p_1 - p_{vs} \times \varphi \times \left(1 - \dfrac{R_g}{R_v}\right)}$$ (B.4)

where

p_{vs} is the saturated vapour pressure of water at the temperature at the standard inlet point;

φ is the relative vapour pressure at the standard inlet point;

$\left(1 - \dfrac{R_g}{R_v}\right)$ may be taken as 0,378 for air.

The manufacturer shall state which correction method was used, together with the appropriate values.

B.4.3 Shaft power correction

B.4.3.1 General

The corrected shaft power, P_{corr}, is calculated using Equation (B.5):

$$P_{corr} = K_4 K_5 \times P_R$$ (B.5)

where

K_4 is the correction factor for shaft speed as expressed by $\dfrac{N_C}{N_R}$;

K_5 is the correction factor for inlet pressure as expressed by $\dfrac{p_{1C}}{p_{1R}}$.

B.4.3.2 Inlet pressure correction factor

Provided the deviation in inlet pressure is maintained within the limits specified in Table B.1, the correction for inlet pressure, K_5, is calculated using Equation (B.6):

$$K_5 = \frac{p_{1C}}{p_{1R}}$$ (B.6)

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B.4.4 Calculation of specific energy requirement

The specific energy requirement, $e_{V\text{corr}}$, of the compressor is calculated using Equation (B.7)

$$e_{V\text{corr}} = \frac{P_{\text{corr}}}{q_{V\text{corr}}}$$

(B.7)

B.4.5 Comparison with specified values

Corrected to the specified pressure ratio r_C, the specific energy requirement $e_{V\text{corr, C}}$ of the compressor is calculated using Equation (B.8):

$$e_{V\text{corr, C}} = e_{V\text{corr}} \times K_6$$

(B.8)

For single-stage displacement compressors with or without cooling and multi-stage compressors without intercooling, Equation (B.9) applies:

$$K_6 = \frac{\left[\kappa/(\kappa-1)\right]_C}{\left[\kappa/(\kappa-1)\right]_R} \times \frac{r_C^{\left(\frac{\kappa-1}{\kappa}\right)_C} - 1}{r_R^{\left(\frac{\kappa-1}{\kappa}\right)_R} - 1}$$

(B.9)

For multi-stage displacement compressors with intercoolers, Equation (B.10) applies:

$$K_6 = \frac{\ln r_C}{\ln r_R}$$

(B.10)

Annex C
(normative)

Simplified acceptance test for electrically driven packaged displacement compressors

C.1 General

C.1.1 Air or nitrogen

This subclause applies to any packaged air compressor which incorporates a displacement compressor of any type driven by an electric motor.

a) Such packaged compressors are usually fully piped and wired and generally include starting equipment and all ancillary items necessary for their effective operation as a complete self-contained air compressor installation.

b) For compressors supplied without a main drive motor, a test can be performed using a test motor with known characteristics; speed correction shall only be done in this case.

c) This subclause defines and describes acceptance tests for electrically driven packaged air compressors, of standard types, constructed to design specifications which include performance data, i.e. volume flow rate, inlet and discharge pressure, specific energy consumption and no-load power.

d) For compressors that are designed to inspire atmospheric air from their immediate surroundings, the performance data usually relate to a normal ambient air inlet pressure.

e) Only measurements necessary to verify the performance of a single set of conditions shall be taken.

f) The test conditions shall be as close as is reasonably possible to the specified conditions and the deviations from these shall not exceed the limits indicated in Table C.1.

g) The compressor under test shall be deemed acceptable provided the results obtained do not differ from the specified performance by more than the allowances given in Table C.2.

NOTE   Compressors of this type are usually manufactured in batches or in continuous production quantities and the performance guarantee offered by the manufacturer to the purchaser is implicit in the information stated in the relevant sales data.

Table C.1 — Maximum deviations from specified values during an acceptance test

Inlet pressure	$\pm$ 10 %
Discharge pressure	$\pm$ 2 %
External coolant quantity	$\pm$ 10 %
Inlet temp. of external air coolant [a]	$\pm$ 10 K
Inlet temp. of external liquid coolant [a]	$\pm$ 5 K
Liquid injection temperature	$\pm$ 5 K
[a] For multi-stage compressors with inter coolers, the difference between gas inlet temperature and external coolant temperature shall be limited to $\pm$ 2 K in the case of liquid and $\pm$ 4 K for air.	

Table C.2 — Maximum deviations permissible at test

Volume flow rate at specified conditions	Volume flow rate	Specific energy requirement	Power requirement (at zero volume flow rate or at pressure ratio of 1) [a]
$(m^3/s) \times 10^{-3}$	%	%	%
$0 < q_V \leqslant 8,3$	± 7	± 8	± 10
$8,3 < q_V \leqslant 25$	± 6	± 7	± 10
$25 < q_V \leqslant 250$	± 5	± 6	± 10
$q_V > 250$	± 4	± 5	± 10
NOTE The tolerance values in this table cover and include manufacturing tolerances of the compressor and tolerances relating to the measurements taken during the test.			
[a] Where specified, the manufacturer shall state the method used.			

C.1.2 Process gases

This subclause applies to packaged displacement process gas compressors of all types (compressor stages) and to any type of packaged displacement air compressor with a power requirement above 800 kW. Such packaged air compressors typically compress air which is used as a process gas rather than for a compressed air system. This subclause therefore cannot be applied for regular compressed air or nitrogen compressors, where C.1.1 applies.

This subclause can only be used under the following circumstances.

a)   Contractual agreements are agreed between both parties to use this subclause.

b)   Evidence and experience with the type of compressor under test shall be available to justify the use of this subclause.

c)   The test report shall include the justification for applying this subclause.

d)   Such packaged compressors are usually fully piped and wired and generally include starting equipment and all ancillary items necessary for their effective operation as a complete self-contained air compressor installation.

e)   This subclause defines and describes acceptance tests for packaged displacement compressors as described in this subclause, constructed to design specifications which include performance data, i.e. volume flow rate, inlet and discharge pressure and specific energy consumption.

f)   Only those measurements necessary to verify the performance of a single set of conditions ("guarantee point") to meet the specification shall be taken.

g)   The test conditions shall be as close as reasonably possible to the specified conditions and the deviations from these shall not exceed the limits specified in Table C.3.

h)   Experience shows that the power requirements of this type of packaged compressors frequently exceed the test bench capabilities of the manufacturers, especially in cases with high inlet pressures.

i)   In cases where due to high inlet pressures the power requirement of the test would exceed 800 kW, it is sufficient to fulfil only the pressure ratio condition of Table C.3, rather than the absolute inlet and discharge pressure conditions. In addition, tests with the specified speed but with atmospheric inlet pressure should then be carried out.

j)   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.

k) If the acceptance test is not carried out with the gas specified, the conversion method to be used shall be identified. If the isentropic exponent of the process gas specified is more than 7 % smaller than the isentropic exponent of the medium used for the test, thermal problems can occur if the pressure ratio is kept within the limits given by Table C.3. In such cases, it is therefore admissible to deviate from the specified pressure ratio by − 40 % to + 20 %.

l) The compressor under test will be deemed acceptable provided the results obtained do not differ from the specified performance by more than the allowances given in Table C.2.

NOTE   Compressors of this type are usually manufactured in batches and the performance guarantee offered by the manufacturer to the purchaser is implicit in the information stated in the relevant sales data.

Table C.3 — Maximum deviations from specified values during an acceptance test

Speed	± 20 %
Inlet pressure	Not specified [a]
Pressure ratio	± 20% [b]
Discharge pressure	Not specified [a]
Coolant temperature	As for C.1
Liquid injection temperature	± 10 K

[a]   If the specified inlet and discharge pressures cannot be provided, it is sufficient to fulfil the pressure ratio condition alone.

[b]   This can be exceeded if the isentropic exponent of the specified medium is more than 7% smaller than the isentropic exponent of the test medium.

C.2 Methods of measurement

C.2.1 General

All measurement points shall be as specified in this International Standard.

C.2.2 Methods of determining volume flow rate

The measurement of volume flow rate shall be carried out according to the methods specified in 5.6 and recorded in a test report.

C.2.3 Method of determining condensate rate

If the compressor package has no means of condensing moisture from the gas being compressed, no correction shall be made for moisture content. If the compressor has a means of condensing and ejecting moisture, for example intercooler(s) and aftercooler(s), correction of the volume flow rate may be made either by collection and measurement of the condensate ejected during the test according to C.2.3.1 or entirely by calculation according to C.4.2.3.

C.2.3.1   Collection and measurement of condensate

Before and after the acceptance test, which shall be carried out with the compressor running at the specified test conditions, the condensate shall be drained from all ejection positions before the standard discharge point in such a way that the steady state of the compressor's running is not disturbed.

The average mass rate of the condensate ejection during the test shall be calculated by dividing the mass of condensate drained after the test by the time between the draining operations. The condensate correction factor, K_{13}, shall then be determined as shown in C.4.2.3.

C.2.4 Measurement of packaged compressor power input

Electrically driven packaged compressors shall be assembled as a complete unit in accordance with the supplied specification for the acceptance test. The measurement of the total electrical power supplied to the package shall be carried out when it is running at the specified speed, ambient conditions, supply voltage and frequency. One of the following methods of determining the input electrical power may be used:

a) the double element wattmeter method, which gives a direct indication of the electrical kilowatt/input;

b) a computation based on the separate measurements of voltage, current and power factor of the electrical supply.

Precision instruments shall be used to measure power, voltage and current with their coils connected so that a voltage drop in the cables will not affect the measurement. Current and voltage transformers shall be chosen to operate as near to their rated loads as possible so that their ratio error is minimized (see IEC 60051-1).

C.3 Test procedure and report

Preliminary tests may be performed to determine whether or not the package is in suitable condition for the acceptance test to be conducted and to check the measuring instruments.

After a preliminary test has been carried out, this test may, by agreement, be considered the acceptance test, provided all requirements for an acceptance test have been met.

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

Before readings are taken, the package shall be run long enough to ensure that steady-state conditions are reached and the provisions of 6.2 i) are observed.

Where a verification is required it shall be demonstrated, in conjunction with the test, that the compressor is also capable of producing the specified discharge pressure, provided the inlet pressure is within the limits specified in Table C.1 and, in the case of process gases, Table C.3.

The test report shall be short and simple without tolerance calculations and with only the essential corrections cited.

If a test motor is used then the characteristics of that motor shall be mentioned in the report.

C.4 Computation of test results

C.4.1 General

Test conditions are never exactly consistent with the specified conditions. Therefore, before test results and specified performance values are compared, corrections shall be applied to the measured values of volume flow rate and shaft power.

C.4.2 Volume flow rate correction

C.4.2.1 General

The corrected volume flow rate, $q_{V\text{corr}}$, is calculated using Equation (C.1):

$$q_{V\text{corr}} = K_1 K_{13} \times q_{V\text{R}} \tag{C.1}$$

where

K_1 is the correction factor for shaft speed (see C.4.2.2);

K_{13} is the correction factor for condensed water vapour at the specified free air conditions (see C.4.2.3).

C.4.2.2   Shaft speed correction factor

This correction is only required when the electric motor drive is not supplied. It may be assumed that the compressor volumetric efficiency, compressor mechanical efficiency and drive motor efficiency all remain unchanged for deviations of the test shaft speed from the specified speed, within the limits given in Table C.1.

The correction factor, K_1 is then as given in Equation (C.2):

$$K_1 = \frac{N_C}{N_R} \qquad\qquad (C.2)$$

C.4.2.3   Condensate formation correction factor

When condensate ejected during the test is collected and measured, an allowance for this, K_{13}, may be calculated using Equation (C.3):

$$K_{13} = 1 + \frac{q_w \times R_v \times T_1}{q_{VR} \times p_1} \qquad\qquad (C.3)$$

where q_w is the rate of flow of coolant.

As an alternative to the collection and measurement of condensate, Equation (C.4) may be used to calculate the correction factor, K_{13}:

$$K_{13} = \frac{p_1}{p_1 - p_{vs} \times \varphi \times \left(1 - \dfrac{R_g}{R_v}\right)} \qquad\qquad (C.4)$$

where

p_{vs} is the saturated vapour pressure of water at the temperature at the standard inlet point;

φ is the relative vapour pressure at the standard inlet point;

$\left(1 - \dfrac{R_g}{R_v}\right)$ may be taken as 0,378.

The manufacturer shall state which correction method was used, if any, together with the appropriate values.

C.4.3 Packaged compressor power input correction

C.4.3.1   General

The packaged compressor power input, P_{Pcorr}, is calculated using Equation (C.5):

$$P_{Pcorr} = K_4 K_5 \times P_{PR} \qquad\qquad (C.5)$$

where

K_4 is the correction factor for the shaft speed, as expressed by $\dfrac{N_C}{N_R}$;

K_5 is the correction factor for inlet pressure and pressure ratio (see 6.7.2).

It is recognized that some elements of the total electrical power input to a packaged compressor are independent of shaft speed and ambient pressure, e.g. the power input to a separately driven cooling fan and power consumed by regulation systems. However, it is unusual for the electrical power for these functions to exceed 10 % of the total input power to the package. In these circumstances, the use of the corrections is considered valid for production test purposes.

C.4.3.2 Inlet pressure correction factor

Provided the deviation in inlet pressure is maintained within the limits specified in Table C.1, the correction for inlet pressure, K_5, is calculating using Equation (C.6):

$$K_5 = \frac{p_{1C}}{p_{1R}} \tag{C.6}$$

C.4.4 Calculation of specific energy requirement

The specific energy consumption, e_{VPcorr}, of the packaged compressor is found using Equation (C.7):

$$e_{VPcorr} = \frac{P_{Pcorr}}{q_{Vcorr}} \tag{C.7}$$

C.4.5 Comparison with specified values

Corrected to the specified pressure ratio, r_C, the specific energy requirement, $e_{VPcorr,\,C}$, of the packaged compressor is calculated using Equation (C.8):

$$e_{VPcorr,\,C} = e_{VPcorr} \times K_6 \tag{C.8}$$

with K_6 calculated according to B.4.5.

Annex D
(normative)

Simplified acceptance test for internal combustion engine-driven packaged displacement compressors

D.1 General

D.1.1 Air or nitrogen

This subclause applies to any packaged air compressor which incorporates a displacement air compressor of any type driven by an internal combustion engine.

a) Such packaged air compressors are usually fully piped and wired and generally include all ancillary items necessary for their effective operation as a complete self-contained air compressor unit.

b) This subclause defines and describes acceptance tests for engine-driven packaged air compressors of standard types constructed to specifications determined by the manufacturer and which are sold against performance data, i.e. volume flow rate, inlet and discharge pressure, specific fuel consumption and speed, published in the manufacturer's sales documentation.

c) Such compressors are designed to inspire atmospheric air from their immediate surroundings and the performance data offered by the manufacturer usually relate to a normal ambient air inlet pressure.

d) Only those measurements necessary to verify the performance at a single set of conditions offered by the manufacturer in standard sales documentation shall be taken.

NOTE 1   If a manufacturer specifies the performance of engine-driven package compressors by stating the performance of the bare air end at a specified speed and pressure and indicates power and/or fuel consumption by reference to the engine maker's technical data, and does not carry out an acceptance test to this simplified code on the complete package, such a machine cannot be presented as having been tested in accordance with this simplified code.

e) The test conditions shall be as close as is reasonably possible to the specified conditions and the deviations from these shall not exceed the limits specified in Table D.1.

f) The compressor under test will be deemed acceptable provided the results obtained do not differ from the specified performance by more than the allowances given in Table D.2.

NOTE 2   Compressors of this type are usually manufactured in batches or in continuous production quantities and the performance guarantee offered by the manufacturer to the purchaser is implicit in the information stated in the relevant sales data.

Table D.1 — Maximum deviations from specified values during an acceptance test

Inlet pressure	$\pm$ 10 %
Discharge pressure	$\pm$ 2 %
External coolant quantity	$\pm$ 10 %
Coolant temperature	$\pm$ 10 K
Liquid injection temperature	$\pm$ 5 K

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Table D.2 — Maximum deviations permissible at test

Volume flow rate at specified conditions $(m^3/s) \times 10^{-3}$	Volume flow rate %	Specified fuel consumption %
$0 < q_V \leqslant 8,3$	± 7	± 8
$8,3 < q_V \leqslant 25$	± 6	± 7
$25 < q_V \leqslant 250$	± 5	± 6
$q_V > 250$	± 4	± 5
NOTE The tolerance values in this table cover and include manufacturing tolerances of the compressor and tolerances relating to the measurements taken during the test.		

D.1.2 Process gases

This subclause applies to any packaged process gas compressor which incorporates a displacement compressor of any type driven by an internal combustion engine and to any packaged air compressor with high inlet pressures which incorporates a displacement compressor of any type driven by an internal combustion engine. Air compressors with high inlet pressures typically compress air which is used as a process gas rather than for a compressed air system. This subclause therefore cannot be applied for regular compressed air or nitrogen compressors, where D.1.1 applies.

This subclause can only be used under the following circumstances.

a) Contractual agreements between both parties to use this subclause.

b) Evidence and experience with the type of compressor under test shall be available to justify the use of this subclause.

c) The test report shall include the justification for applying this subclause.

d) Such process gas compressors are supplied by the manufacturer fully piped and wired and generally include all ancillary items necessary for their effective operation as a complete self-contained process gas compressor unit.

e) This subclause defines and describes acceptance tests for engine-driven packaged compressors, as described above, which are constructed to design specifications which include performance data, i.e. volume flow rate, inlet and discharge pressure and specific energy consumption.

f) Only those measurements necessary to verify the performance of a single set of conditions ("guarantee point") agreed upon between the customer and the manufacturer shall be taken.

g) The test conditions shall be as close as reasonably possible to the specified conditions and the deviations from these shall not exceed the limits specified in Table D.3.

Experience shows that process gas compressors are quite often operated with high inlet pressures. The provision of high volume flows of high pressure test media frequently exceeds the test bench capabilities of the manufacturers. In cases with high inlet pressures, it is therefore sufficient to fulfil only the pressure ratio condition of Table D.3 rather than the absolute inlet and discharge pressure conditions. In addition, tests with the specified speed but with atmospheric inlet pressure should then be carried out.

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.

If the acceptance test is not carried out with the gas specified, the conversion method to be used shall be identified. If the isentropic exponent of the process gas specified is more than 7 % smaller than the isentropic exponent of the medium used for the test, thermal problems can occur if the pressure ratio is kept within the limits given by Table D.3. In such cases it is therefore admissible to deviate from the specified pressure ratio by $- 40$ % to $+ 20$ %.

The compressor under test will be deemed acceptable provided the results obtained do not differ from the specified performance by more than the allowances given in Table D.2.

NOTE 1   If a manufacturer specifies the performance of engine-driven package compressors by stating the performance of the bare compressor at a specified speed and pressure and indicates power and/or fuel consumption by reference to the engine maker's technical data, and does not carry out an acceptance test to this simplified code on the complete package, such a machine cannot be presented as having been tested in accordance with this simplified code.

NOTE 2   Compressors of this type are usually manufactured in batches and the performance guarantee offered by the manufacturer to the purchaser is implicit in the information stated in the relevant sales data.

Table D.3 — Maximum deviations from specified values during an acceptance test

Speed	$\pm$ 20 %
Inlet pressure	Not specified [a]
Pressure ratio	$\pm$ 20 % [b]
Discharge pressure	Not specified [a]
Coolant temperature	$\pm$ 10 K
Liquid injection temperature	$\pm$ 10 K
[a] If the specified inlet and discharge pressures cannot be provided, it is sufficient to fulfil the pressure ratio condition alone.	
[b] This can be exceeded if the isentropic exponent of the specified medium is more than 7 % smaller than the isentropic exponent of the test medium.	

D.2 Specific definitions

Definitions of particular relevance to this annex are 3.1.8 (fuel consumption) and 3.1.20 (specific fuel consumption).

D.3 Methods of measurement

D.3.1 Methods of determining volume flow rate

The measurement of volume flow rate (see 5.6) shall be carried out according to the methods given in this International Standard and recorded in a test report (see Clause 9).

D.3.2 Method of determining condensate rate

If the package compressor has no means of condensing moisture from the gas being compressed, no correction shall be made for moisture content. If the compressor has a means of condensing and ejecting moisture, for example intercooler(s) and aftercooler(s), correction of the volume flow rate may be made either by collection and measurement of the condensate ejected during the test according to D.5.2.1 or entirely by calculation according to D.5.2.3.

D.3.2.1   Collection and measurement of condensate

Before and after the acceptance test, carried out with the compressor running at the specified test conditions, the condensate shall be drained from all ejection positions before the standard discharge point in such a way that the steady state of the compressor's running is not disturbed.

The average mass rate of condensate ejection during the test shall be calculated by dividing the mass of condensate drained after the test by the time between the draining operations. The condensate correction factor, K_{13} shall then be determined as shown in D.5.2.3.

D.3.3 Measurement of fuel consumption

D.3.3.1 General

The measurement of the fuel consumption of the package will be carried out when the compressor is running steadily and continuously at the specified speed, ambient pressure and pressure ratio and temperature conditions, and with the specified fuel having the correct calorific value.

The mean fuel consumption of the engine shall be determined by weighing or by measuring the volume of fuel consumed during the test in accordance with the requirements of ISO 3046-1.

D.3.3.2 Variable speed combustion engine-driven compressors

For variable speed combustion engine-driven compressors, performance measurement should be carried out at:

— maximum volume flow rate;

— three or more volume flow rates evenly spaced between the minimum and maximum volume flow rate;

— minimum volume flow rate;

— no load power.

NOTE 1   If the measured value of no load power is equal to or less than 1 % of full load power, the manufacturer can state "not significant" or "0" on the test report.

NOTE 2   The maximum and minimum volume flow rates are as specified by the manufacturer.

D.3.4 Measurement of shaft speed

Shaft speed shall be determined by using methods that have the same accuracy as that stated in 5.5.

D.4 Test procedure and report

Preliminary tests may be performed to determine whether or not the compressor is in suitable condition for the acceptance test to be conducted and to check the measuring instruments.

After a preliminary test has been carried out, this test may, by agreement, be considered the acceptance test, provided all requirements for an acceptance test have been met.

During the test, no adjustments other than those required to maintain the test conditions and those required for normal operation of the compressor shall be made.

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

Where a verification is required it shall be demonstrated, in conjunction with the test, that the compressor is also capable of producing the specified discharge pressure, provided the inlet pressure is within the limits specified in Table D.1.

The test report shall be short and simple without tolerance calculations and with only the essential corrections cited.

D.5 Computation of test results

D.5.1 General

Test conditions are never exactly consistent with the specified conditions. Therefore, before test results and specified performance values are compared, corrections shall be applied to the measured values of volume flow rate and shaft power.

Provision is made within the limits specified in Table D.1 for adjustment of the volume flow rate for deviations of shaft speed and formation of condensate and adjustment of shaft power for deviations of shaft speed and inlet pressure.

D.5.2 Volume flow rate correction

D.5.2.1   General

The corrected volume flow rate, $q_{V\text{corr}}$, is calculated using Equation (D.1):

$$q_{V\text{corr}} = K_1 K_{13} \times q_{V\text{R}} \tag{D.1}$$

where

   K_1 is the correction factor for shaft speed (see D.5.2.2);

   K_{13} is the correction factor for condensed water vapour at the standard inlet conditions (see D.5.2.3).

D.5.2.2   Shaft speed correction factor

It may be assumed that the compressor volumetric efficiency, compressor mechanical efficiency and drive motor efficiency all remain unchanged for deviations of the test shaft speed from the specified speed within the limits given in D.1.1 e).

The correction factor, K_1, is then given as Equation (D.2)

$$K_1 = \frac{N_\text{C}}{N_\text{R}} \tag{D.2}$$

where

   N_C is the specified shaft speed;

   N_R is the measured shaft speed.

D.5.2.3   Condensate formation correction factor

When condensate ejected during the test is collected and measured, an allowance, K_{13}, for this may be calculated using Equation (D.3):

$$K_{13} = 1 + \frac{q_\text{w} \times R_\text{v} \times T_1}{q_{V\text{R}} \times p_1} \tag{D.3}$$

where q_w is the rate of flow of coolant.

As an alternative to the collection and measurement of condensate, Equation (D.4) may be used to calculate the correction factor, K_{13}

$$K_{13} = \frac{p_1}{p_1 - p_{vs} \times \varphi \times \left(1 - \dfrac{R_g}{R_v}\right)}$$ (D.4)

where

P_{vs} is the saturated vapour pressure of water at the pressure and temperature at the standard inlet point;

φ is the relative vapour pressure at the standard inlet point;

$\left(1 - \dfrac{R_g}{R_v}\right)$ may be taken as 0,378.

The manufacturer shall state which correction method was used, together with the appropriate values.

D.5.3 Packaged compressor fuel consumption correction

D.5.3.1   General

The packaged compressor corrected fuel consumption, F_{Pcorr}, is calculated using Equation (D.5):

$$F_{Pcorr} = K_4 K_5 \times F_{PR}$$ (D.5)

where

K_4 is the correction factor for shaft speed, as expressed by $\dfrac{N_C}{N_R}$;

K_5 is the correction factor for inlet pressure, as expressed by $\dfrac{p_{1C}}{p_{1R}}$.

It is recognized that some elements of the fuel consumption of a packaged compressor are independent of the shaft speed and ambient pressure, e.g. the fuel consumption attributable to the auxiliary drives. However, it is unusual for the power absorbed in this way to exceed 10 % of the total output power of the engine. In these circumstances, the use of the corrections is considered valid for the production test purposes.

D.5.3.2   Inlet pressure correction factor

Provided the deviation in inlet pressure is maintained within the limits specified in D.1.1 e), the correction for inlet pressure, K_5, is given as Equation (D.6):

$$K_5 = \frac{p_{1C}}{p_{1R}}$$ (D.6)

D.5.4 Calculation of specific fuel requirement

The corrected specific fuel consumption, b_{corr}, of the packaged compressor is given as Equation (D.7):

$$b_{corr} = \frac{F_{Pcorr}}{q_{Vcorr}}$$ (D.7)

D.5.5 Comparison with specified values

Corrected to the specified pressure ratio, r_C, the specific fuel consumption, $b_{corr, C}$, of the package compressor is given as Equation (D.8):

$$b_{corr, C} = b_{corr} \times K_6 \qquad\qquad (D.8)$$

with K_6 calculated according to B.4.5.

Annex E
(normative)

Acceptance test for electrically driven packaged displacement variable speed drive compressors

E.1 Introduction

Fixed point measurements were chosen in this International Standard to validate the performance of a variable speed drive compressor because it is almost impossible at this time to develop a set of varying conditions that would be representative of all possible conditions that a compressor can encounter in use. The fixed points that are required in this annex, and which are specified in E.2, can be used to generate a curve that will provide a performance curve.

This method of determining performance will allow uniform comparison of similarly specified compressors and is consistent with the practice used to determine performance in other industries with related technologies, such as refrigeration and air conditioning.

E.2 General

This annex applies to any electrically driven, variable speed drive (e.g. variable frequency drive, direct current drive and switched reluctance), packaged compressor which incorporates a displacement compressor of any type driven by an electric motor.

Such packaged compressors are usually fully piped and wired and generally include starting equipment and all ancillary items necessary for their effective operation as a complete self-contained compressor installation.

This annex defines and describes acceptance tests for electrically driven packaged compressors of standard types which are constructed to design specifications which include performance data, i.e. volume flow rate, inlet and discharge pressure, specific energy consumption and no-load power.

For compressors that are designed to inspire atmospheric air from their immediate surroundings, the performance data usually relate to a normal ambient air inlet pressure.

Performance measurements shall be carried out at:

— maximum volume flow rate;

— three or more volume flow rates evenly spaced between the minimum and maximum volume flow rate;

— minimum volume flow rate;

— no load power.

NOTE 1   If the measured value of no load power is equal to or less than 1% of full load power, the manufacturer can state "not significant" or "0" on the test report.

NOTE 2   The maximum and minimum volume flow rates are as specified by the manufacturer.

The test conditions shall be as close as is reasonably possible to the specified conditions and the deviations from these shall not exceed the limits indicated in Table C.1.

The compressor under test shall be deemed to be acceptable provided the results obtained do not differ from the specified performance by more than the allowances given in Table C.2 for air or nitrogen or Table C.3 for process gases.

NOTE 3   Compressors of this type are usually manufactured in batches or in continuous production quantities and the performance guarantee offered by the manufacturer to the purchaser is implicit in the information stated in the relevant sales data.

E.3 Methods of measurement

The methods identified in Annex C shall be applied.

E.4 Test procedure and report

The procedure and reporting shall be as identified in Annex C, for all performance measurements specified in E.2.

E.5 Computation of test results

The computation of test results shall be done as identified in Annex C.

Annex F
(informative)

Reference conditions

The compressor shall operate at full load.

The compressor reference standard inlet conditions shall be as follows:

Inlet air pressure   100 kPa [1 bar] (a);

Inlet air temperature   20 °C;

Relative water vapour pressure   0

Cooling water temperature   20 °C

When the intended service of the compressor requires a different pressure, the test should be carried out at that pressure, which should be stated together with the declared specific energy requirement figure. Such pressures should be in accordance with ISO 5941.

Annex G
(normative)

Uncertainty of measurement

G.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 95 % confidence limit) constitutes a criterion of the accuracy of the particular measurement.

It is assumed that all systematic errors that can occur in the measurement of the individual quantities measured and of the characteristics of the gas, can be compensated by corrections. A further assumption is that the confidence limits in reading and integration errors can be negligible if the number of readings is sufficient.

The (small) systematic errors that can occur are covered by the inaccuracy of measurements.

Quality classifications and limits of error are often invoked for ascertaining the uncertainty 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 uncertainty of the measurement of the individual quantities measured and on the confidence limits of the gas properties are approximations. This approximation can only be improved at a disproportionate expense (see ISO 2602 and ISO 2854).

NOTE   A calculation of the probable error according to this annex is not always necessary.

G.2 Uncertainty of individual measurements

G.2.1 Uncertainty of pressure measurements

G.2.1.1 Precision pressure gauges and electrical pressure transducers

The relative uncertainty, $\tau_{\Delta p}$, of measurement of pressure difference, using a precision pressure gauge is given as Equations (G.1) and (G.2):

$$\tau_{\Delta p} = \frac{\overline{V}_{\Delta p}}{\Delta p} \qquad\qquad (G.1)$$

$$\tau_{\Delta p} = \pm\, G\, \frac{p_E}{p_R} \times 10^{-2} \qquad\qquad (G.2)$$

NOTE   If the quality class of the pressure gauge is $< 0{,}2$, G is still taken as 0,2 in Equation (G.2) to allow for errors in mounting.

G.2.1.2 Liquid columns

When liquid columns are used, the uncertainty 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, $\overline{V}_{\Delta h}$, of $\pm\,0{,}001$ m can be reached.

$$\tau_{\Delta h} = \frac{\overline{V}_{\Delta h}}{\Delta h} \tag{G.3}$$

In the range from $0{,}1\text{ m} < \Delta h < 1{,}0\text{ m}$, the relative uncertainty of measurement, $\tau_{\Delta h}$, is calculated using Equation (G.4):

$$\tau_{\Delta h} = \pm\frac{0{,}001}{\Delta h} \tag{G.4}$$

where Δh is expressed in metres.

At $\Delta h > 1$ m, the relative uncertainty of measurement is $\tau_{\Delta h} = \pm\,0{,}001$ m.

G.2.1.3 Absolute pressure

The relative uncertainty of the absolute pressure, $p = p_0 + \Delta p$, is calculated using Equation (G.5):

$$\tau_p = \sqrt{\left(\frac{p_0}{p} \times \tau_{p_0}\right)^2 + \left(\frac{\Delta p}{p} \times \tau_{\Delta p}\right)^2} \tag{G.5}$$

where

    p_0 is atmospheric pressure;

    Δp is the gauge pressure if not measured absolutely against zero pressure.

G.2.2 Uncertainty of temperature measurements

G.2.2.1 Liquid-in-glass thermometers

The uncertainty of measurement, $\overline{V}_t$, to be inserted is the extended temperature limit obtained by calibration and supplemented by the addition of the failure margins. In most cases, the uncertainty of measurement may be taken from Table G.1.

Table G.1 — Uncertainty of measurement, $\overline{V}_t$, for calibrated liquid-in-glass thermometers

Temperature range °C	Scale division K				
	0,1	0,2	0,5	1	2
− 50 to < − 5	0,6	0,8	1,7	2	4
− 5 to < 60	0,3	0,4	1	1,4	2
60 to < 110	0,5	0,6	1	2	3
110 to < 210	—	1	2	3	4
210 to 310	—	—	3	4	6

G.2.2.2 Thermocouples

If a recent works test certificate of a calibration of the entire equipment used for the fixed points on the temperature scale is available and measurement has been carried out with precision compensation instruments (quality class 0,1), an uncertainty of measurement, $\overline{V}_t$ 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.

G.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 uncertainty of measurement, $\overline{V}_t$, of $\pm 1,0$ K can be applied for temperatures up to 300° C.

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

G.2.3 Uncertainty of flow measurements

The relative uncertainty, τ_{qm} on flow measurements with standardized throttling devices shall be calculated in accordance with a relevant International Standard, for example ISO/TR 3313. If the suppression of pulsations is unsuccessful, corrections should be applied. In that case, the tolerance should be increased by 20 % of the correction.

G.2.4 Uncertainty of shaft-speed measurements

With shaft speed measured by means of calibrated analogue measuring instruments, the relative uncertainty of measurement, τ_N, is given as Equations (G.6) and (G.7):

$$\tau_N = \frac{\overline{V}_N}{N} \tag{G.6}$$

$$\tau_N = \pm\, G\, \frac{N_E}{N_R} \times 10^{-2} \tag{G.7}$$

With shaft speed measured by means of digital measuring instruments, the relative uncertainty of measurement is given as Equation (G.8)

$$\tau_N = \pm \frac{S}{B} \tag{G.8}$$

where

S is the resolution of the instrument: difference of values during the time base of the instrument;

B is the measured value read from the scale.

G.2.5 Uncertainty of power measurements

G.2.5.1 Torque and speed

With torque measurements carried out by means of calibrated dynamometers, the relative uncertainty of measurement, τ_M, is given as Equations (G.9) and (G.10):

$$\tau_M = \frac{\overline{V}_M}{M} \tag{G.9}$$

$$\tau_M = \pm\, G\, \frac{M_E}{M_R} \times 10^{-2} \tag{G.10}$$

When torque measurements are carried out with an electric dynamometer, the uncertainty of measurement indicated by the manufacturer may be used.

The relative uncertainty of the shaft power, τ_{Pco}, is calculated using Equation (G.11):

$$\tau_{Pco} = \pm\, \sqrt{{\tau_M}^2 + {\tau_N}^2} \tag{G.11}$$

G.2.5.2 Electrical drive

G.2.5.2.1 Uncertainty of the two-wattmeter method

The tolerance for a two-wattmeter measurement is a combination of the tolerance for the instrument readings formulated in the normal way and the tolerance for the instrument errors calculated in accordance with the following.

For a two-wattmeter measurement, the relative uncertainty of the measurement of the electric power input, τ_{Pel}, is given as Equations (G.12) and (G.13):

$$\tau_{Pel} = \frac{\overline{V}_{Pel}}{P_{el}} \tag{G.12}$$

$$\tau_{Pel} = \pm\, \sqrt{{G_U}^2 + {G_I}^2 + {G_w}^2 \left(\frac{\alpha_E}{\alpha_1 + \alpha_2}\right)^2 f_t + \left({\Gamma_U}^2 + {\Gamma_I}^2\right) f_r} \times 10^{-2} \tag{G.13}$$

with

$$f_t = \left(1 + \frac{t - 20}{10} \times \frac{\alpha_1}{\alpha_E}\right)^2 + \left(1 + \frac{t - 20}{10} \times \frac{\alpha_2}{\alpha_E}\right)^2 \tag{G.14}$$

$$f_r = \left(3{,}3 \times 10^3\right) \times \left[\left(3K - 1\right)^2 + \left(3K - 2\right)^2\right] \tag{G.15}$$

where (for this subclause)

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

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

G_w is the quality class of the wattmeter, as a percentage;

K is the part load of the first wattmeter, where $K = \dfrac{P_{el1}}{P_{el2}}$;

α is the actual reading of the wattmeter;

α_E is the full-scale reading of one wattmeter;

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

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

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

G.2.5.2.2 Uncertainty of direct current measurement

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

The measuring errors for voltage, τ_U, and current, τ_I, are combined to give Equation (G.16):

$$\tau_{P1C} = \pm\sqrt{\tau_U{}^2 + \tau_I{}^2} \tag{G.16}$$

G.2.5.3 Uncertainty of the results of measurement at the coupling of the prime mover

$$\tau_{Pco} = \frac{\overline{V}_{Pco}}{P_{co}}$$

When the measurements of the power at the coupling are carried out through the medium of the power drawn by an electric motor, the relative uncertainty of measurement, τ_{Pco}, is given as Equations (G.17) and (G.18):

$$\tau_{Pco} = \pm\sqrt{\left[\left(\frac{\overline{V}_{Pel}}{P_{el}}\right)^2 + \left(\frac{\overline{V}_{\eta M}}{\eta_M}\right)^2\right]} \tag{G.17}$$

$$\tau_{Pco} = \pm\sqrt{\tau_{Pel}{}^2 + \tau_{\eta M}{}^2} \tag{G.18}$$

where

$\overline{V}_{Pel}$ is the uncertainty of measurement of the electric power;

$\overline{V}_{\eta M}$ 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.

G.2.5.4 Other drives

For other drives (steam turbines, internal combustion engines, etc.), the relative uncertainty of the shaft power shall be calculated according to the relevant code.

G.2.6 Confidence limits of gas properties

G.2.6.1 General

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 so be compensated, the confidence limits shall be increased.

The information in G.2.6.2 to G.2.6.4 presumes that suitable chemical or physical analyses will be undertaken to determine the composition of the gas.

G.2.6.2   Gas constant

If the gas constant is taken from standard tables, its confidence limits may be neglected. If the conditions of G.2.6.1 are adhered to, the confidence limits, $\overline{V}_R$, of the gas constant may be neglected. If the gas constant is determined from a density measurement carried out with accurate instruments, a relative confidence limit, $\overline{V}_R/R$, of $\pm\,0,5$ % shall be used.

G.2.6.3   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. When estimating the confidence limits of the compressibility factor of the mixture, the data chiefly used are 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.

G.2.6.4   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 isentropic exponents of gases that differ to a large extent from the ideal state. The confidence limits shall be estimated.

G.3   Uncertainty of results of measurement

G.3.1   Relative uncertainty 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 uncertainty of measurement may usually be neglected. The relative uncertainty, τ_res, of the result of measurement is given as Equation (G.19):

$$\tau_\text{res} = \pm\sqrt{\tau_{qV\text{R}}{}^2 + \tau_\text{NR}{}^2 + \tau_{p1\text{R}}{}^2 + \tau_{T1\text{R}}{}^2 + \tau_{Z1\text{R}}{}^2} \tag{G.19}$$

G.3.2   Relative uncertainty of the result of measurement of the pressure ratio

The relative uncertainty, τ_res, of the result of measurement of the pressure ratio is calculated using Equation (G.20):

$$\tau_\text{res} = \pm\sqrt{\tau_{p1\text{R}}{}^2 + \tau_{p2\text{R}}{}^2} \tag{G.20}$$

G.3.3   Relative uncertainty of the result of measurement of the shaft power, the specific energy requirement and the efficiency

For guarantee comparison according to 8.2, the effect of the viscosity of the lubricant on the uncertainty of measurement may usually be neglected.

If the power at the coupling with the prime mover is measured, the relative uncertainty, $\tau_{\text{res}P\text{co}}$, of the result of the measurement is given as Equations (G.21), (G.22) and (G.23):

$$\tau_{\text{res}P\text{co}} = \tau_\text{res}\left(P_\text{co}/q_V\right) \tag{G.21}$$

$$\tau_{\mathrm{res}P\mathrm{co}} = \tau_{\mathrm{res}\eta\mathrm{co}} \tag{G.22}$$

$$\tau_{\mathrm{res}P\mathrm{co}} = \pm\sqrt{\tau_{P\mathrm{coR}}{}^2 + \tau_{q_{VR}}{}^2 + \tau_{\mathrm{T1R}}{}^2 + \left(\frac{z-1}{z} \times \tau_{\mathrm{Tw1}}\right)^2 + \varepsilon_2^2 \times \tau_k^2} \tag{G.23}$$

with

$$\varepsilon_2 = \frac{1}{1-k_{\mathrm{R}}} + \frac{1}{k_{\mathrm{R}}} \times \frac{\ln r_{\mathrm{R}}}{1 - r_{\mathrm{R}}{}^{(1-k_{\mathrm{R}})/k_{\mathrm{R}}}} \tag{G.24}$$

G.3.4 Relative uncertainty of the result of measurement of the shaft power, the specific energy requirement and the efficiency

For guarantee comparison according to 8.3, the effect of the viscosity of the lubricant on the uncertainty of measurement may usually be neglected.

If the power at the coupling with the prime mover is measured, the relative uncertainty, τ_{res}, of the result of measurement is given as Equations (G.25), (G.26) and (G.27):

$$\tau_{\mathrm{res}P\mathrm{co}} = \tau_{\mathrm{res}}\left(P_{\mathrm{co}}/q_V\right) \tag{G.25}$$

$$\tau_{\mathrm{res}P\mathrm{co}} = \tau_{\mathrm{res}\eta\mathrm{co}} \tag{G.26}$$

$$\tau_{\mathrm{res}P\mathrm{co}} = \pm\sqrt{\tau_{P\mathrm{coR}}{}^2 + \tau_{q_{VR}}{}^2 + \tau_{\mathrm{T1R}}{}^2 + \left(\frac{z-1}{z} \times \tau_{\mathrm{Tw1}}\right)^2 + \varepsilon_2^2 \times \tau_k^2 \times \varepsilon_1^2 \times \tau_{p1}^2 + \varepsilon_2^2 \times \tau_{p2}^2} \tag{G.27}$$

with

$$\varepsilon_1 = \frac{k_{\mathrm{R}}-1}{k_{\mathrm{R}}} \times \frac{1}{1 - r_{\mathrm{R}}{}^{(1-k/k)}{}_{\mathrm{R}}} \tag{G.28}$$

and ε_2 according to G.3.3.

G.3.5 Determination of measuring uncertainty using the difference method

The uncertainty of measured results, τ_Y, of a result function Y (e.g. steam consumption), particularly in the case of complicated functional interactions, the derivation of which, by means of closed mathematical solutions, is difficult, can be determined using Equations (G.29) and (G.30):

$$\tau_Y = \frac{\overline{V}_Y}{Y} = \pm\sqrt{\sum\left(\frac{\partial Y}{\partial x_i} \times \frac{\overline{V}_{xi}}{Y}\right)^2} = \pm\sqrt{\sum f_{xi}{}^2} \tag{G.29}$$

$$f_{xi} = \frac{Y\left(xi + \overline{V}_{xi}\right) - Y\left(x_i - \overline{V}_{xi}\right)}{2Y\left(x_i\right)} \tag{G.30}$$

For this purpose, the result function, Y, for all measured variables or materials data, x_i, contained therein is calculated using the values increased or decreased by the individual measuring uncertainty, $\overline{V}xi$ and mean relative deviation, f_{xi}, of the result function, Y, calculated from their difference in place of measured value x_i (see Figure G.1).
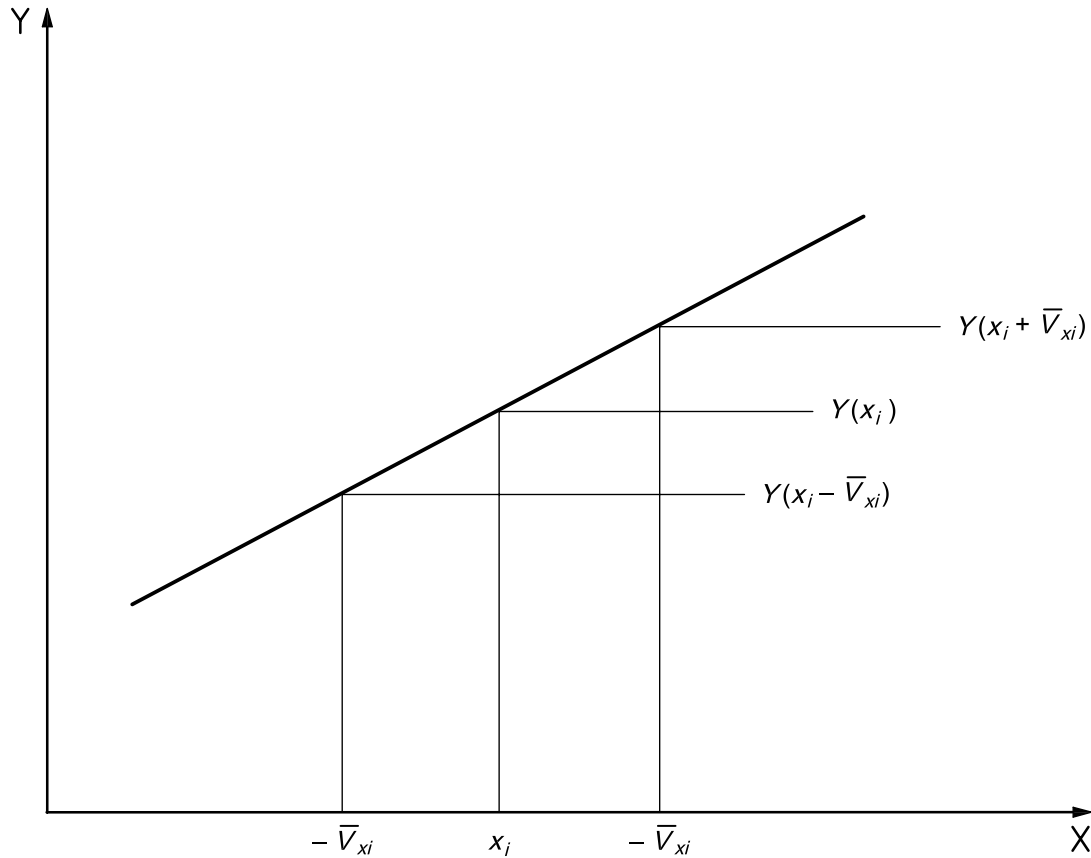
Not for Resale

Figure G.1 — Change in a result function as a function of an individual measuring uncertainty

G.4 Additional tolerances, tolerance for load fluctuation

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 (see Table G.2).

Table G.2 — Tolerance for load fluctuation

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

The tolerance shall be algebraically added to the resulting uncertainty of G.3.

G.5 Relative uncertainty of the result of measurement on a single stage of a multi-stage compressor

G.5.1 General

In the process of building up the total performance curve from the curves of stages measured singly or of groups of curves, the relative uncertainty, τ_{comb}, in the measurement below is as indicated.

G.5.2 Volume flow rate

$$\tau_{\text{comb}q_V} = \pm\left[1 + 0,2\sqrt{(z-1)}\right] \times \frac{\sum \tau_{q_V j}}{z} \tag{G.31}$$

G.5.3 Pressure ratio

$$\tau_{\text{comb}r} = \pm\left[1 + 0,2\sqrt{(z-1)}\right] \times \sum \tau_{rj} \times \frac{\omega_{mj}}{\sum \omega_{mj}} \tag{G.32}$$

G.5.4 Power consumption

$$\tau_{\text{comb}P} = \pm\left[1 + 0,2\sqrt{(z-1)}\right] \times \sum \tau_{Pj} \times \frac{P_j}{\sum P_j} \tag{G.33}$$

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.

G.6 Measurement uncertainties and manufacturing tolerances

G.6.1 Graphical comparison of tolerance of performance curve

Normally, at least two test points will be obtained close to and bridging the guarantee point or each of several guarantee points. The comparison is made as follows.

A chart is constructed in which the parameter to be compared (inlet volume flow, power consumption, specific power consumption, efficiency, etc.) is plotted as the ordinate and the pressure ratio is plotted as the abscissa (see Figure G.2). Each test point is plotted on this chart and around each point is constructed an ellipse, the axes of which indicate the magnitude of the uncertainties in the relevant parameters. Upper and lower curves are drawn tangential to these ellipses. It can be stated, with at least 95 % confidence, that the true performance of the compressor lies within this test band.

The comparison is made by plotting the guaranteed operating point or points on the graph.

The deviation from the guarantee requirement is the distance between the test result band and the guarantee point at the specified pressure ratio, r_C.

In the case of a manufacturing tolerance, m, this value is either subtracted from or added to the guarantee value, as fits the case.

G.6.2 Comparison of a single test result

For this comparison, the uncertainties of result of measurement shall be algebraically added to (or subtracted from) the corrected pressure ratio, r_{corr}, and to the adjusted test result and the manufacturing tolerance will be added to (or subtracted from) the guarantee value. Δ (see Figure G.2) can therefore be found by calculation.
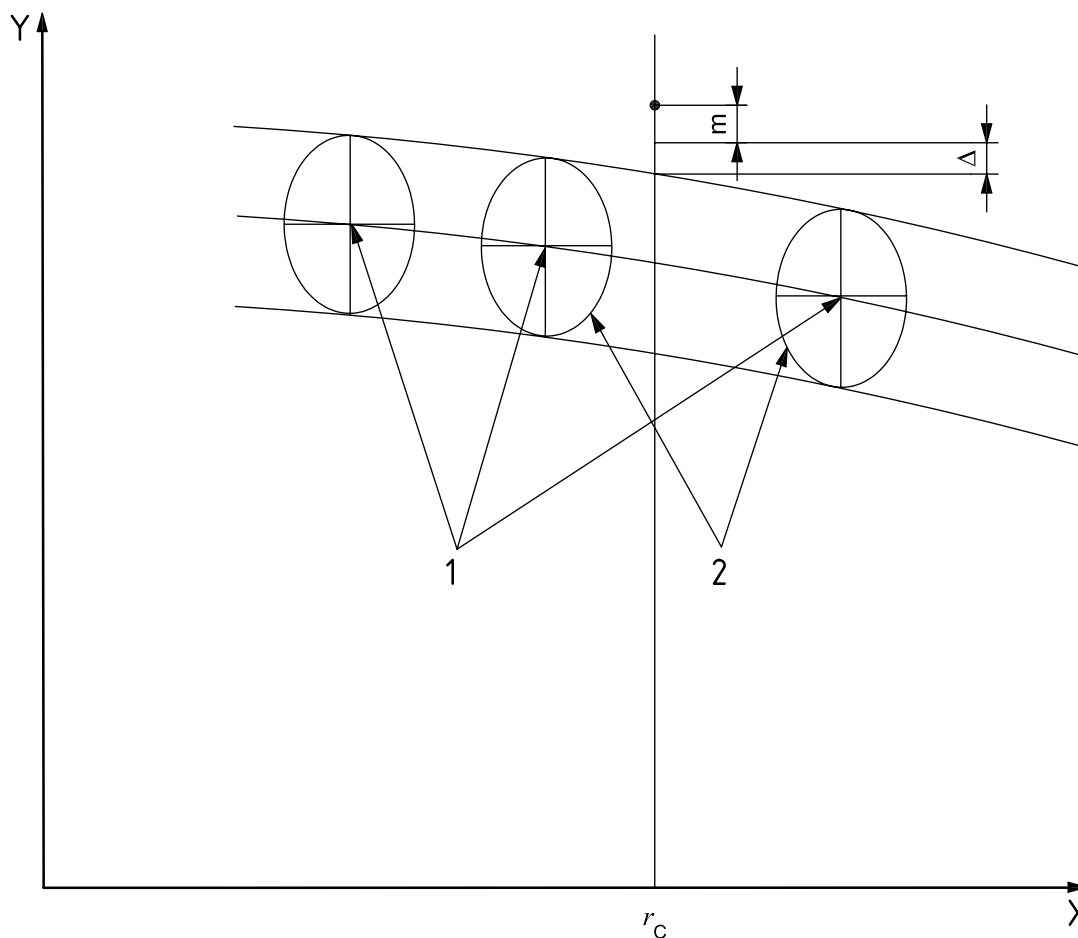
Figure G.2 — Guarantee comparison taking into account measurement uncertainties and manufacturing tolerance

Key

X   pressure ratio, r

Y   volume flow, power consumption, efficiency, etc.

1   test points

2   ellipses representing the test uncertainties

NOTE   The measuring uncertainty ellipses are drawn only if they influence the guarantee comparison. This is not the case if at the guarantee point the deviation is smaller than the length of the relevant half-axis.

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