INTERNATIONAL STANDARD

ISO 5302

First edition
2003-07-15

Vacuum technology — Turbomolecular pumps — Measurement of performance characteristics

Technique du vide — Pompes turbomoléculaires — Mesurage des caractéristiques fonctionnelles

Reference number
ISO 5302:2003(E)

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Published in Switzerland

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Foreword

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ISO 5302 was prepared by Technical Committee ISO/TC 112, *Vacuum technology*, Subcommittee SC 3, *Vacuum pumps — Performance*.

Vacuum technology — Turbomolecular pumps — Measurement of performance characteristics

1 Scope

This International Standard specifies methods for the measurement of performance characteristics of turbomolecular pumps. It is applicable to all sizes and all types of turbomolecular pumps

a) with mechanical or magnetic bearings, and

b) with or without an additional drag stage.

NOTE Since turbomolecular pumps are backed by primary pumps, their performance cannot be completely defined without having the following in addition to the curve of the volume flow rate against suction pressure:

— the throughput curve,

— the compression ratio curve, and

— the curve for the variation in inlet pressure,

over the whole of the range concerned and for various gases.

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 3529-2, *Vacuum technology — Vocabulary — Part 2: Vacuum pumps and related terms*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3529-2 and the following apply.

3.1
critical backing pressure
p_c
maximum backing pressure p_2 while the pump still has a compression rate $p_2/p_1 \geqslant 2$ and the purge gas flow is on

NOTE p_1 is the (high) vacuum pressure on inlet.

3.2
maximum throughput
Q_{max}
highest gas load, in pascal litres per second (Pa·l/s) [millibar litres per second (mbar·l/s)], that can be pumped continuously without damage or destruction of the pump

NOTE The limiting parameter depends on the design of the pump. In most cases it will be given as a maximum temperature at a defined location. The value of Q_{max} depends on the gas pumped, the backing pump used, and the conditions of cooling, etc.

3.3
volume flow rate
q_V
volume of gas which, under ideal conditions, flows from the test dome through the pump inlet per unit time

NOTE 1 For practical reasons, however, the volume flow rate of a given pump and for a given gas is conventionally taken as equal to the quotient of the throughput of this gas and of the equilibrium pressure at a given point. The units adopted for the volume flow rate are cubic metres per hour (m^3/h) or litres per second (l/s).

NOTE 2 The term “pumping speed” and symbol “S” are sometimes used instead of “volume flow rate”.

3.4
ultimate pressure
value towards which the pressure in the test dome approaches asymptotically

NOTE 1 It is the lowest pressure obtainable with the pump.

NOTE 2 It is recommended not to give ultimate pressure values in the manufacturer's specification. Therefore, no procedure to measure the ultimate pressure is given in this International Standard. However, if the manufacturer lists the ultimate pressure, the operating conditions under which the measurement is made should be stated.

3.5
minimum operational pressure
p_0
pressure obtained in the dome 48 h after the bake-out procedure

3.6
compression ratio
K_{eff}
ratio of the backing pressure p_2 to the inlet pressure p_1 of the turbomolecular pump

$$K_{eff} = p_2/p_1$$

NOTE To obtain the compression rate at zero flow rate, K_0, for a given gas, the partial pressure of this gas in the outlet duct should be at least 90 % of p_2.

3.7
maximum working pressure
p_{1max}
highest pressure on the inlet side that the turbomolecular pump and the driving device can withstand without being damaged

4 Symbols and abbreviated terms

Symbol	Designation	Unit
C	conductance	m^3/s (=10^3 l/s)
d	orifice diameter	m
D	nominal diameter of test dome	m
K_{eff}	compression ratio of vacuum pump	—
$K_{eff,a}$, $K_{eff,b}$	special values of compression ratio	—
K_0	compression ratio at zero throughput	—
L	thickness of orifice wall	m
M	molecular mass of gas	kg/mol
p_0	minimum operational pressure on inlet	Pa (or mbar)
p_1	(high) vacuum pressure on inlet	Pa (or mbar)
p_{1max}	maximum working pressure on inlet	Pa (or mbar)
p_2	vacuum pressure in backing line	Pa (or mbar)
p_a, p_b	special values of pressure	Pa (or mbar)
p_c	critical backing pressure	Pa (or mbar)
Q	throughput of vacuum pump	Pa·l/s (or mbar·l/s)
Q_0	leakage gas load	Pa·l/s (or mbar·l/s)
Q_T	test gas load	Pa·l/s (or mbar·l/s)
Q_{max}	maximum throughput	Pa·l/s (or mbar·l/s)
Q_1, Q_2	special values of throughput	Pa·l/s (or mbar·l/s)
R	ideal gas constant	N·m/mol·K
q_V	volume flow rate	l/s
q_{V0}	volume flow rate at K_{eff} = 1	l/s
q_{VB}	volume flow rate of backing pump	l/s
q_{Vx}	maximum expected volume flow rate (see 6.3)	l/s
T	absolute temperature	K

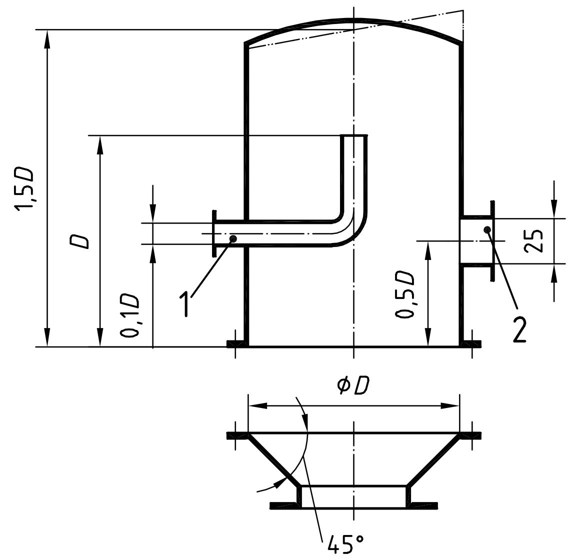
5 Apparatus for volume flow rate (pumping speed) measurement

5.1 Test dome for the throughput method: Inlet pressures > 10^{-4} Pa (10^{-6} mbar)

For these measurements, use a test dome as shown in Figure 1 with the same nominal diameter D as that of the pump inlet. The face of the dome opposite the inlet flange may be flat, conical or slightly curved with the same average height above the flange as the flat face. The test dome shall be fitted with a device for bake-out ensuring uniform heating of the dome to achieve the minimum operational pressure.

For pumps with an inlet flange diameter less than the nominal diameter DN 100, the diameter of the dome shall correspond to DN 100. The transition to the pump inlet flange shall be made through a 45° taper fitting as short as possible according to Figure 1.

Dimensions in millimetres



Key

1 gas inlet

2 vacuum gauge connection

Figure 1 — Test dome

5.2 Test dome for the standard conductance method: Inlet pressures $< 10^{-4}$ Pa (10^{-6} mbar)

The test dome shall be cylindrical and of the shape shown in Figure 2. The dome shall be fitted with a device for bake-out that ensures uniform heating of the dome to achieve the minimum operational pressure.

The diameter of the thin wall orifice plate shall be chosen according to the expected flow rate and shall be such that the ratio of the pressures measured at p_a and p_b lies between 3 and 50. Care shall be taken to ensure that at the inlet pressure p_1 the mean free path of the gas particles is not smaller than the orifice diameter d.

For pumps with an inlet flange diameter less than the nominal diameter DN 100, the diameter of the dome shall correspond to DN 100. Then the transition to the pump inlet flange shall be made through a 45° taper fitting according to Figure 1.

For pumps with an inlet flange diameter greater than DN 100, the nominal diameter D of the dome shall be equal to the actual diameter of the inlet flange.

5.3 Pressure gauges

Total pressure measurements shall be made using pressure gauges calibrated to within 5 % accuracy for pressures greater than 10^{-4} Pa (10^{-6} mbar), or within 10 % for pressures less than this value.

It is recommended that after completion of the tests, the calibration of the vacuum gauge(s) is checked, for example by comparison with a reference gauge *in situ*.

With the test dome (5.2), the pressure gauge agreement may be ensured by fitting at B a gas admission pipe leading to the pump orifice in the lower part of the dome (see Figure 2). The adjustable valve for gas admission in this pipe line shall be opened so as to obtain approximately the desired pressure. After stabilization, the pressure gauges at the points shown shall give the same readings (p_a and p_b). If not, the required correction can be deduced.

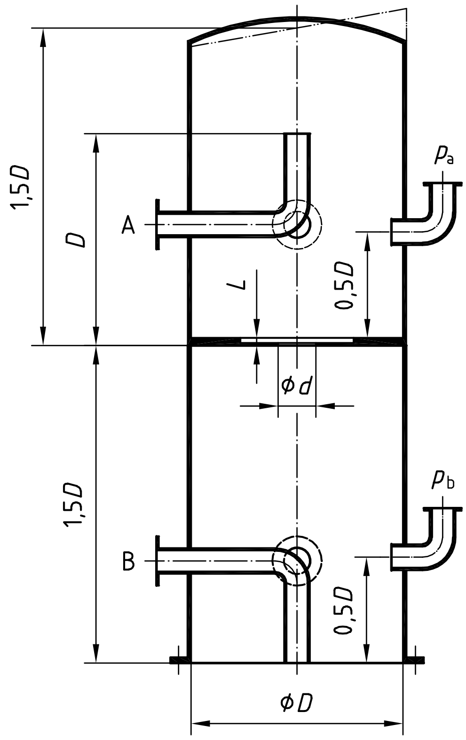


Figure 2 — Test dome

6 Test methods and procedures

6.1 Principle

Measurements are made with 99,9 % (by mass) pure test gas: nitrogen, hydrogen, helium and argon.

6.2 Measurement of partial pressures

For measurements of backing pressure, a pressure gauge with a trap may be used. For measurements of inlet pressure, a partial pressure gas analyser supplemented by a total pressure gauge may be used.

Partial pressure gas analysers used at the pump inlet shall have sufficient resolving power in the mass range from 1 to 100.

6.3 Size of backing pump

The effective volume flow rate, q_V, of a turbomolecular pump depends on the volume flow rate q_{V0} at zero pressure difference ($p_1 = p_2$), the compression ratio K_0 at zero rate of throughput ($Q = 0$) and the volume flow rate $q_{V\mathrm{B}}$ of the backing pump according to the relationship

$$q_V = q_{V0}\left(\frac{K_0 - q_V / q_{V\mathrm{B}}}{K_0 - 1}\right) \quad (1)$$

which may be solved to give

$$q_V = \frac{q_{V0}}{1 - 1/K_0 + q_{V0}/\left(K_0 \cdot q_{V\mathrm{B}}\right)} \quad (2)$$

See Annex A for the derivation of these equations.

For small values of K_0 (e.g. for hydrogen, $K_0 \approx 1\,000$), the volume flow rate of the turbomolecular pump is influenced by the size of the backing pump. This influence may be regarded as small if a backing pump is used with a volume flow rate $q_{V\text{B}}$ deduced from

$$\frac{q_{V\text{x}}}{q_{V\text{B}}} < 0{,}05\, K_0 \qquad \text{or} \qquad q_{V\text{B}} > 20\left(\frac{q_{V\text{x}}}{K_0}\right) \tag{3}$$

for the whole pressure range, where $q_{V\text{x}}$ is the expected maximum volume flow rate of the turbomolecular pump.

From Equation (3), the choice of a suitable backing pump may be made for a gas with known value of K_0 from the specification of the turbomolecular pump.

6.4 Volume flow rate (pumping speed)

Under ideal conditions, the volume flow rate is the volume of gas which flows from the test dome through the pump inlet per unit time. For practical reasons, however, the volume flow rate of a given pump and for a given gas is conventionally taken as equal to the quotient of the throughput of this gas and of the equilibrium pressure at a given location.

The units adopted for the volume flow rate q_V are cubic metres per hour (m^3/h) or litres per second (l/s).

6.5 Methods of measurement of volume flow rate (pumping speed)

6.5.1 Method for inlet pressures > 10^{-4} Pa (10^{-6} mbar): Throughput method

The method adopted for the measurement of the volume flow rate q_V is the steady pressure method for which the gas throughput, Q, is measured outside the dome. If the pressure p_1 in the test dome, which is measured by a vacuum gauge in the determined area (Figure 1), is held constant, the volume flow rate q_V is obtained by the relationship

$$q_V = \frac{Q}{p_1 - p_0} \tag{4}$$

where p_0 is the minimum operational pressure in the test dome (see 6.9).

This pressure limit may be shifted to lower pressures, if the accuracy of the flow meter is appropriate.

6.5.2 Method for inlet pressures < 10^{-4} Pa (10^{-6} mbar): Standard conductance method

The method adopted for the measurement of the volume flow rate q_V is the steady pressure method known as “standard conductance” method, in which a thin orifice plate divides the test dome (Figure 2) into two volumes. If pressure is measured in each volume by pressure gauges having the same sensitivity, the volume flow rate is then given by

$$q_V = C\left(\frac{p_\text{a} - p_{0\text{a}}}{p_\text{b} - p_{0\text{b}}} - 1\right) \tag{5}$$

where C is the calculated conductance, taking account of the orifice size and the gas properties. Pressures $p_{0\text{a}}$ and $p_{0\text{b}}$ are measured inside the dome before admission of the gas. The conductance of the orifice with diameter d and thickness L may be calculated using the following formula:

$$C = \sqrt{\frac{\pi RT}{32M}}\left(\frac{1}{1 + L/d}\right)d^2 \tag{6}$$

The term $1/(1 + L/d)$ is a correction factor that can be defined as the average throughput probability.

The formula shall be applied with consistent units. Special values such as

$$R = 8{,}314\ \text{N}\cdot\text{m}/(\text{mol}\cdot\text{K})$$

$$M_{\text{air}} = 28{,}8 \times 10^{-3}\ \text{kg/mol}$$

$$T = 293\ \text{K} = 20\ ^{\circ}\text{C}$$

will give

$$C_{\text{air}} = 91\, d^2 \big/ (1 + L/d)\ \text{m}^3/\text{s}$$

or

$$C_{\text{air}} = 91\,000\, d^2 \big/ (1 + L/d)\ \text{l/s}$$

where L and d are measured in metres.

6.6 Test procedures

6.6.1 Procedure for the throughput method: Inlet pressures > 10^{-4} Pa (10^{-6} mbar)

The arrangement of the measuring equipment with the test dome from Figure 1 is given in Figure 3. First, with valve 5 closed, the minimum operational pressure shall prevail in the test dome (see 3.4). Then gas is admitted to the test dome through the adjustable valve 5. Measurements are made with increasing pressures from a threshold value allowing the correct use of the throughput meter 6.

When the required pressure is obtained, wait for at least 5 min. Then measure the pressure, temperature, barometric pressure and either the admitted volume flow rate (when using a flow meter) or the displaced gas volume and time (when using a calibrated burette). If the flow rate remains steady to within ± 1 % for the subsequent 5 min, the measurement at this point may be regarded as valid. If the flow rate is unsteady due to a transient condition, wait until it stabilizes.

If the throughput measurement lasts for more than 60 s, the pressure p_1 in the dome shall be noted at least every minute. If during measurement the pressure varies by more than ± 1 %, the measurement shall be repeated until the readings are stable. Then the throughput is the average of the measured values.

Measurement at three points per pressure decade shall be made up to a value p_1 where the ratio p_2/p_1 becomes 2, or

$$p_2 = 2\, p_1 \qquad (7)$$

6.6.2 Procedure for the standard conductance method: Inlet pressures < 10^{-4} Pa (10^{-6} mbar)

The arrangement of the measuring equipment is given in Figure 4. First, with all valves closed, the minimum operational pressure shall prevail in the test dome (see 6.9). Then the gas is admitted to the test dome through the adjustable valve 5. Take measurements with increasing pressures, beginning from a threshold value of twice that of the minimum operational pressure. When the required pressure p_1 is obtained and remains stable for the following 5 min to within ± 5 %, this point may be regarded as valid.

If pressure is unsteady due to a transient condition, wait until it stabilizes. Measure the pressures p_a and $p_b \equiv p_1$ together with the backing pressure p_2, and the temperature. If during this measurement one of the pressures varies by more than ± 5 %, the measurement shall be repeated until stability is obtained. Then the throughput is calculated from the average of the measured values.