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Vacuum technology — Standard methods for measuring vacuum-pump performance —

Part 4:
Turbomolecular vacuum pumps

Technique du vide — Méthodes normalisées pour mesurer les performances des pompes à vide —

Partie 4: Pompes à vide turbomoléculaires

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Foreword

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This document was prepared by Technical Committee ISO/TC 112, *Vacuum technology*.

A list of all parts in the ISO 21360 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document specifies methods for measuring the performance data of turbomolecular vacuum pumps. This document complements ISO 21360-1, which provides a general description of the measurement of performance data of vacuum pumps.

The methods described here are well known from existing national and international standards. The aim in drafting this document was to collect together suitable methods for the measurement of performance data of turbomolecular vacuum pumps. This document takes precedence in the event of a conflict with ISO 21360-1.

Vacuum technology — Standard methods for measuring vacuum-pump performance —

Part 4: Turbomolecular vacuum pumps

1 Scope

This document, in conjunction with ISO 21360-1, specifies methods for the measurement of performance characteristics of turbomolecular vacuum pumps. It is applicable to all sizes and all types of turbomolecular vacuum pumps, including those

— with mechanical or magnetic bearings;

— with or without an additional drag stage(s) or other pumping stages on the shaft;

— with one or more inlet ports.

Since turbomolecular vacuum pumps are backed by primary pumps, their performance cannot be completely defined by the volume flow rate curve. Also, the driving device and the backing pressure of the turbomolecular vacuum pump is important to the performance.

The following completes the performance characteristics:

— information about throughputs and backing pressure of the turbomolecular vacuum pump;

— the compression ratio curve (compression ratio vs backing pressure of turbomolecular vacuum pump).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 21360-1:2012, *Vacuum technology — Standard methods for measuring vacuum-pump performance — Part 1: General description*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 21360-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
critical backing pressure
p_c
maximum backing pressure p_3 on the outlet that the vacuum pump and the driving device can withstand for continuous operation without being damaged or overloaded while the pump still has a compression ratio $p_3/p_1 > 10$ and the purge gas flow is off

Note 1 to entry: p_1 is the (high) vacuum pressure on inlet. The rotational speed of the turbomolecular vacuum pump can be reduced at this working point. The value of p_c depends on the rotational speed and the type of gas, therefore both shall be named together with the value of p_c.

Note 2 to entry: Measurement with purge gas leads to different results (during pumping light gases at the inlet the use of heavy purge gas will influence the performance regarding critical backing pressure p_c). Therefore, the purge gas flow has to be zero.

3.2
maximum throughput
Q_{max}
highest gas load that can be pumped continuously without damage or destruction of the pump

Note 1 to entry: Given in pascal litres per second (Pa l/s), millibar litres per second (mbar l/s) or standard cubic centimetres per minute (sccm).

Note 2 to entry: The limiting parameter depends on the design of the pump. In most cases it will be given as a maximum temperature at defined locations. The value of Q_{max} depends on, for example, the gas pumped, the backing pump used, the rotational speed and the conditions of cooling. If the Q_{max} is stated in the units Pa l/s or mbar l/s, then the test dome temperature shall also be documented, because this value depends on the gas temperature. This is not the case if the Q_{max} value is stated in the unit sccm.

3.3
volume flow rate
q_V

$$q_V = \frac{dV}{dt} \tag{1}$$

where

V is the volume;

t is time.

EXAMPLE In the context of the ISO 21360 series, the volume flow rate is the volume of gas per unit time which, under ideal conditions, flows from the test dome through the pump inlet.

Note 1 to entry: For practical reasons, the volume flow rate of a given pump and for a given gas is conventionally considered to be equal to the quotient of the throughput of this gas and of the equilibrium pressure at a given location. The volume flow rate is expressed in cubic metres per hour or litres per second.

Note 2 to entry: The term “pumping speed” and symbol “S” are often used instead of “volume flow rate”.

[SOURCE: ISO 21360-1:2012, 3.1]

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

Note 1 to entry: This ultimate pressure is always lower than the base pressure p_{b1}.

Note 2 to entry: It is the lowest pressure obtainable with the pump.

Note 3 to entry: It is recommended that ultimate pressure values are not given in the manufacturer's specification. Therefore, no procedure to measure the ultimate pressure is given in this document. However, if the manufacturer lists the ultimate pressure, the operating conditions and measurement time durations under which the measurement is made should be stated.

3.5
base pressure turbomolecular pump
p_{b1}
pressure obtained in the dome 48 h after the bake-out procedure

Note 1 to entry: That is the conditioning of the vacuum pump and the test system without any test gas (see 5.6).

3.6
effective compression ratio
K_{eff}
ratio of the backing pressure p_3 to the inlet pressure p_1 of the turbomolecular vacuum pump

$$K_{eff} = \frac{p_3}{p_1} \quad (2)$$

3.7
compression ratio
K_0
maximum compression ratio without gas load through the turbomolecular vacuum pump, wherein p_{b3} is the base pressure of the backing pump and p_{b1} is the base pressure of the turbomolecular vacuum pump

$$K_0 = \frac{p_3 - p_{b3}}{p_1 - p_{b1}} \quad (3)$$

4 Symbols and abbreviated terms

Symbol	Designation	Unit
K_{eff}	compression ratio of vacuum pump	—
K_0	maximum compression ratio of vacuum pump at zero throughput	—
p_{b1}	base pressure turbomolecular pump	Pa (or mbar)
p_{b3}	base pressure of backing pump	Pa (or mbar)
p_1	(high) vacuum pressure on inlet	Pa (or mbar)
p_3	vacuum pressure in backing line	Pa (or mbar)
p_c	critical backing pressure	Pa (or mbar)
Q	throughput of vacuum pump	Pa l/s (or mbar l/s) or sccm
Q_{max}	maximum throughput	Pa l/s (or mbar l/s) or sccm
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	l/s
T	absolute temperature	K

5 Test methods

5.1 Test gas

All measurements in this clause should be performed with at least 99,9 % (by mass) pure test gas. Test gas for, for example, nitrogen, hydrogen, helium and argon.

5.2 Volume flow rate measurement (pumping speed)

5.2.1 General

Volume flow rate measurement methods for turbomolecular vacuum pumps are specified in ISO 21360-1:2012, 5.1 and 5.2. If no other descriptions or experimental arrangements are shown, those of ISO 21360-1 shall be used.

5.2.2 Size of backing pump

The effective volume flow rate, q_V, of a turbomolecular vacuum pump depends on the volume flow rate q_{V0} at zero pressure difference ($p_1 = p_3$), the compression ratio K_0 at zero rate of throughput ($Q = 0$) and the volume flow rate q_{VB} of the backing pump according to Formula (4).

$$q_V = q_{V0}\left(\frac{K_0 - q_V / q_{VB}}{K_0 - 1}\right) \tag{4}$$

which may be solved to give Formula (5).

$$q_V = \frac{q_{V0}}{1 - 1/K_0 + q_{V0}/(K_0 \cdot q_{VB})} \tag{5}$$

NOTE See Annex A for the derivation of Formulae (4) and (5).

For small values of K_0 (e.g. for hydrogen, $K_0 \approx 1\ 000$), the volume flow rate of the turbomolecular vacuum 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_{VB} deduced from Formula (6).

$$\frac{q_{VX}}{q_{VB}} < 0{,}05 \cdot K_0 \text{ or } q_{VB} > 20 \cdot \left(\frac{q_{VX}}{K_0}\right) \tag{6}$$

for the whole pressure range, where q_{VX} is the expected maximum volume flow rate of the turbomolecular vacuum pump.

From Formula (6), 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 vacuum pump.

Check that the backing pump still has this calculated pumping speed at the working point of Q_{max}.

5.2.3 Volume flow rate (pumping speed) measurement by the throughput method

The throughput method is the one most used for vacuum pumps and is applicable to all pressure ranges and pump sizes where flow meters for gas throughput measurements are available with sufficient accuracy.

The complete volume flow rate measurement by throughput method is specified in ISO 21360-1:2012, 5.1.

5.2.4 Volume flow rate (pumping speed) measurement by the orifice method

This method is recommended for low gas throughputs where no suitable gas flow meters are available. The complete volume flow rate measurement by orifice method is specified in ISO 21360-1:2012, 5.2.

5.3 Maximum throughput measurement

5.3.1 Measurement method

For at least two sizes of backing pump, measure the throughput Q as a function of the backing pressure p_3 while the pump is operated under conditions as specified by the manufacturer. The test dome shown in ISO 21360-1:2012, Figure 1 shall be used. Suitable sensors should be provided to monitor the limiting parameter(s) (see 3.2, Note 2 to entry). When the maximum throughput Q_{max} is reached, all monitored values shall become stable and shall not exceed the prescribed limit for a minimum time of 4 h. One of the backing pumps should preferably be smaller than the other, with a throughput as proposed by the manufacturer and the other pump about 5 to 10 times larger.

This procedure is intended to verify the data given by the pump manufacturer and so it is non-destructive. However, it shall not be used to find the limit.

5.3.2 Test procedure

Connect the pump to the test dome, which is capable of establishing a constant gas flow and of measuring the inlet pressure p_1. The backing line is equipped with a vacuum gauge to measure the backing pressure p_3. Increase the gas load on the high vacuum side stepwise. The readings of the sensors shall be stable before they are recorded. If one sensor reading passes the prescribed limit, close the gas inlet valve and the test shall be regarded as having failed. With the maximum throughput Q_{max}, the test shall run for a minimum time of 4 h with all readings well within the limits, and the pump temperature drift over time should not exceed 1 K/h.

5.4 Critical backing pressure measurement

The complete critical backing pressure measurement method is specified in ISO 21360-1:2012, 5.5 and the definition of this critical backing pressure is given in 3.1.

The critical backing pressure measurement is defined without an effective gas flow through the turbomolecular vacuum pump. This means the gas inlet valve 5 stays closed. Therefore the critical backing pressure value is only valid to "zero"-throughput applications.

For any other applications with nameable gas loads through the turbomolecular vacuum pump, other backing pressures will limit the pump operation.

5.5 Measurement of compression ratio

The complete compression ratio measurement method and experimental setup is specified in ISO 21360-1:2012, 5.5.

To reduce the amount of any other gas at the turbomolecular vacuum pump outlet, the use of another turbo-pump or a diffusion pump as a backing pump is strongly recommended. This lowers the outlet pressure p_3 to $< 10^{-2}$ Pa (10^{-4} mbar). The use of a cold trap is not recommended, due to misleading effects to the results.

To obtain the compression ratio 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_3.

NOTE It could be difficult to achieve this 90 % partial-pressure-condition at the outlet, especially if dry backing pumps are used, due to their low compression ratio for light gases.

The compression ratio can be influenced by production tolerances and pump temperature during the measurement. If partial pressure measurements are used, this should be stated. If extrapolation has been used to determine theoretical maxima, this should also be stated.

5.6 Measurement of base pressure

The complete measurement of base pressure is specified in ISO 21360-1:2012, 5.4. This pressure is **not** the ultimate pressure.

5.7 Vibration measurement

5.7.1 General

The vibration of the turbomolecular vacuum pump shall be measured in a direction radial to the motor axis, in the frequency range from 10 Hz to five times the normal rotational speed of the pump, running under normal conditions with no gas load. Both the vibration acceleration and vibration velocity shall be recorded.

5.7.2 Test apparatus

The turbomolecular vacuum pump shall be freely mounted, in a vertical and/or horizontal position following the manufacturer's operating instructions, on a sheet of rubber at least 4 mm thick on a solid vibration-free base, in order to have a decoupling of the test pump to the base. The base may be a concrete block of at least five times the mass of the pump but no less than 100 kg.

WARNING — Provisions shall be made for the safety of personnel in the area.

The inlet flange of the pump shall be blanked off with a standard flange and seal. The vibration measurement head(s) shall be mounted on the pump in a plane at a right angle to the rotor axis. This plane shall not be more than a tenth of the largest dimension of the pump, away from the centre of mass of the pump.

In preparing the pump with the test equipment, the mass of the pump with its blanking flange shall not increase by more than 3 %. No additional masses shall be connected to the pump during the tests.

The pump shall be connected to the backing pump by a flexible hose at least 750 mm long and bent by more than 90°.

5.7.3 Test procedure

Before taking a measurement, the pump shall be run under normal operating conditions without gas load for at least 30 min. While measurements are taken, the backing pump shall be switched off.

6 Test report

The test report should contain the following measurements:

— volume flow rate measurement (pumping speed, 3.3);

— compression ratio measurement (3.7);

— maximum throughput measurement (3.2);

— critical backing pressure measurement (3.1);

— base pressure measurement (3.5);

— vibrational measurement (5.7).

The test report shall contain the following general information about the tested pump:

- the type and article/serial number of the turbomolecular pump;
- the type and article/serial number of the driving device;
- flange type and size, nominal rotational speed and maximum power consumption of the turbomolecular pump;
- ambient temperature.

6.1 Volume flow rate measurement

- used method (throughput or orifice method):
  - if orifice method is used: geometry of orifice;
  - if orifice method is used: the value of the standard conductance and the formula used for the calculation;
- size of test dome;
- rotational speed;
- used backing pump or backing pressure;
- used cooling method and data;
- measured gas types;
- amount of purge gas, if used;
- diagram: pumping speed vs inlet pressure.

6.2 Compression ratio measurement

- rotational speed;
- used backing pump;
- used cooling method and data;
- measured gas types;
- diagram: compression ratio vs backing pressure.

6.3 Maximum throughput measurement

- rotational speed;
- used backing pump (dry/wet) or backing pressure;
- used cooling method and data;
- measured gas types;
- amount of purge gas, if used;
- value of maximum throughput.

6.4 Critical backing pressure measurement

- rotational speed;

— used cooling method and data;
— measured gas types;
— value of critical backing pressure.

6.5 Base pressure measurement

— rotational speed;
— used cooling method and data;
— used backing pump or backing pressure;
— value of base pressure.

6.6 Vibrational measurement

— rotational speed;
— documentation of test apparatus;
— direction of vibration measurement;
— position of vibration measurement;
— diagram: vibration data vs frequency range.