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

**Part 6:
Cryogenic vacuum pumps**

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

Partie 6: Pompes à vide cryogéniques

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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 cryogenic vacuum pumps. This document complements ISO 21360-1, which provides a general description of the measurement of performance data of vacuum pumps. This document takes precedence in the event of a conflict with ISO 21360-1.

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

Part 6: Cryogenic vacuum pumps

1 Scope

This document specifies methods for measuring the volume flow rate, maximum throughput, pumping capacity, base pressure cryogenic vacuum pump, cooldown time and crossover value of cryogenic vacuum pumps.

It is applicable to two-stage, closed-loop gaseous helium cryogenic vacuum pumps, which can be directly flanged to a vacuum chamber.

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 21360-1:2020, *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 terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

base pressure cryogenic vacuum pump

p_b

pressure obtained in the test dome within 24 h of completing cooldown

Note 1 to entry: It is possible that the base pressure is not the lowest pressure obtainable with the cryogenic vacuum pump. The base pressure represents the lowest pressure that can be obtained after reasonable conditioning of the cryogenic vacuum pump and the test dome without any test gas (see 5.5).

Note 2 to entry: For many practical applications (e.g. only cooldown time is tested, see 5.6), base pressure also can be obtained in the cryogenic vacuum pump with a blank-off flange at the entrance.

3.2

cooldown time

time elapsed between starting the cryogenic vacuum pump at room temperature ($293\text{ K} \pm 3\text{ K}$) at a starting pressure as indicated by the manufacturer and the point at which the temperature of the *second stage* (3.6) reaches 20 K

Note 1 to entry: The roughing valve should only be closed when the action of closing does not cause the pressure in the cryogenic vacuum pump to rise to a value above the starting pressure.

3.3

crossover value

q_{cv}

maximum amount of nitrogen gas which can be admitted into the pump over a short time with the temperature of the *second stage* (3.6) remaining $\leq 20\text{ K}$ during the test gas flow

3.4

pumping capacity

q_{pc}

quantity of gas, which has been pumped up to the moment when the volume flow rate has reduced to 50 % of the initial value measured

Note 1 to entry: After having pumped this amount of gas, the pump still can reduce the pressure in the test dome down to a value of $p \leq 10^{-3}\text{ Pa}$ in less than 10 min to ensure that a certain pumping performance is still available.

3.5

maximum throughput

$Q_{\max}$

maximum quantity of condensable gas flow, which a cryogenic vacuum pump can pump

3.6

second stage

lower temperature side cooling station with the cold panels of a closed-loop, two-stage gaseous helium cold head

4 Symbols

Symbol	Designation	Unit
Q	gas throughput of cryogenic vacuum pump	$\text{Pa}\cdot\text{l}\cdot\text{s}^{-1}$ (or $\text{Pa}\cdot\text{m}^3\cdot\text{s}^{-1}$)
$Q_{\max}$	maximum throughput	$\text{Pa}\cdot\text{l}\cdot\text{s}^{-1}$ (or $\text{Pa}\cdot\text{m}^3\cdot\text{s}^{-1}$)
q_{cv}	crossover value	$\text{Pa}\cdot\text{l}$ (or $\text{Pa}\cdot\text{m}^3$)
q_{pc}	pumping capacity	$\text{Pa}\cdot\text{l}$ (or $\text{Pa}\cdot\text{m}^3$)
p_d, p_e	pressures in the test dome for the orifice method	Pa
p_b	base pressure cryogenic vacuum pump	Pa
p_1	vacuum pressure on inlet	Pa
p_2	starting pressure	Pa
D	inner diameter of test dome	m
D_N	nominal diameter of test dome	m
$T_{\max}$	maximum temperature of the second stage	K

5 Test methods

5.1 Test gas

All measurements in this document should be performed with at least 99,9 % (by mass) pure test gas. The test gas should be nitrogen (alternatively dry air), argon and hydrogen.

5.2 Measurement of the volume flow rate (pumping speed)

5.2.1 General

The measurement of volume flow rate is specified in ISO 21360-1.

Pretreatment (see 5.2.2) is recommended before measuring the pumping speed of the test gas (except hydrogen).

When the pressure remains stable within ± 3 % (for hydrogen ± 5 % is acceptable) for the following minute, the average value per minute can be regarded as valid p_1 .

If several test gases are used, without regenerating the pump completely, the gases should be used in the following order: hydrogen, nitrogen (alternatively dry air), argon.

If during measurement more than 30 % of the pumping capacity as indicated by the manufacturer is admitted, the cryogenic vacuum pump should be regenerated.

The test pump should be directly flanged to the test dome (see 5.7.2, Figure 1) or the quick-acting valve (see 5.7.2, Figure 2). When using the test dome described in ISO 21360-1:2020, Figure 3, the cold surfaces of the test pump shall not protrude into the test dome. Specifically, for cryogenic vacuum pumps with cold surfaces extending beyond the pump inlet flange used in some applications (e.g. semiconductor industry), flanges or pipe adapters should be used to facilitate the connection between the test pump and the test dome to prevent the cold surfaces from protruding into the test dome.

5.2.2 Pretreatment procedure

A quantity of the test gas given by $\alpha \cdot q_v$ is admitted into the cryogenic vacuum pump during the pretreatment. Where, q_v is the nominal volume flow rate of the pump and α ($\alpha = 1$ Pa·s) is a proportionality factor determining the quantity of gas to be admitted into. The inlet pressure should be within the measuring pressure range and the operational time should not exceed 60 min.

The pressure shall be measured by the ion gauge, when the pressure change is at least one order below the measured pressure range in which the volume flow rate shall be measured, or if the pressure change satisfies $\frac{\Delta p}{\Delta t} < 30 p_1$ (Pa·h⁻¹), the measurement of volume flow rate can be started.

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

The throughput method is one of the most widely used methods for vacuum pumps. It is applicable to all pressure ranges and pump sizes where flow meters for gas throughput measurements are available with sufficient accuracy. The type of test dome shall be in accordance with ISO 21360-1:2020, Figure 1. The complete volume flow rate shall be measured by the throughput method specified in ISO 21360-1:2020, 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 shall be measured by the orifice method specified in ISO 21360-1:2020, 5.2.

5.2.5 Measurement of water vapour volume flow rate (pumping speed)

Due to the difficulties of obtaining stable water vapour flow and measuring the pressure of the water vapour, the value of water vapour volume flow rate should normally be calculated by [Formula \(A.1\)](#).

5.3 Maximum throughput measurement

5.3.1 General

The maximum throughput is the maximum quantity of gas ($\text{Pa}\cdot\text{l}\cdot\text{s}^{-1}$ or $\text{Pa}\cdot\text{m}^3\cdot\text{s}^{-1}$), flowing from the test dome through the cryogenic vacuum pump inlet flange, that the pump can withstand while maintaining a given temperature of the second stage. The maximum temperature, T_{max} , depends on the gas species and is set at 20 K for condensable gases (Ar, N₂, O₂ etc.). Therefore, the maximum throughput is the throughput which causes the temperature of the second stage to rise to and remain stable at $T_{\text{max}}=20$ K. The measurement of the maximum throughput is to verify the parameters given by the manufacturer. Therefore, the measurement process is non-destructive and should not be used to obtain the limit value.

5.3.2 Measurement method

The maximum throughput shall be measured using the throughput method specified in [5.2.3](#). When the temperature of the second stage reaches 20 K and should remain stable, the measured flow rate is the maximum throughput of the test gas. The recommended test gas is argon.

5.3.3 Measurement setup

For this measurement, the test dome shall be the same as that for the volume flow rate measurement by the throughput method specified in ISO 21360-1:2020, 5.1.2 to 5.1.3. The test dome shall be clean and dry. In addition, the temperature of the second stage shall be measured with a sensor which can measure to an accuracy of $\pm 0,5$ K at 20 K.

5.3.4 Measuring procedure

Measuring procedure of the maximum throughput shall be the same as that of the volume flow rate measurement by the throughput method after complete regeneration but without pretreatment. Connect the pump to the test dome, which can establish a constant gas flow and of measuring the pressure, p_1 , in the test dome.

The test should be started at least 3 h after the cryogenic vacuum pump completing cooldown. The test gas is admitted into the test dome by the flow meter and the gas inlet valve or mass flow controllers until the temperature of the second stage reaches $20\text{ K} \pm 3\text{ K}$ and remains stable for 15 min. Record the flow rate, and the temperature. Change the flow, but only sufficiently to stabilize the temperature of the second stage in the range of 17 K to 23 K. In such a manner, record at least six stabilized temperatures and flow rates. The temperature of the first and the second stage shall equilibrate for ≥ 15 min prior to each reading. Of the six data points, at least two points of the temperature of the second stage measurements shall be taken above 20 K, and at least two points of the temperature of the second stage measurements shall be taken below 20 K. With a minimum of six data points, least squares curve fit a linear relation between throughput and the maximum temperature of the second stage. The maximum throughput is the throughput value at 20 K.

5.4 Pumping capacity measurement

5.4.1 General

Argon and hydrogen are recommended to represent condensable and adsorbable gases, respectively.

5.4.2 Measurement setup

For this measurement, the test dome shall be the same as that for the volume flow rate measurement by the throughput method specified in ISO 21360-1:2020, 5.1.2 to 5.1.3. The test dome shall be clean and dry.

5.4.3 Measuring procedure

A constant throughput of test gas, smaller than the maximum throughput, shall be admitted continuously. Check the throughput and inlet pressure regularly.

In case of argon, the gas flow should be admitted into and interrupted by the recovery method to make sure that the pressure in the test dome still can be reduced to less than 1×10^{-3} Pa in 10 min or less. Also, the inlet pressure shall be less than twice of the initial pressure p_1 . If this is not possible, the pumping capacity has been exceeded and the test should be stopped. The cumulative amount of the test gas pumped for each successive measurement shall be calculated.

In case of hydrogen, the gas flow should be admitted into the test dome continuously until the inlet pressure of the test dome increases to twice of the initial pressure p_1 . If the pressure in the test dome shall reduce to less than 1×10^{-3} Pa in 10 min or less, calculate the cumulative amount of the test gas pumped during the test period. If this is not possible, the pumping capacity has been exceeded and the test should be stopped and repeated.

The procedure of the recovery method shall be as follows:

- a) introduce some constant gas flow for a certain period;
- b) stop introducing, and confirm that the pressure decreases below the criteria within a certain period;
- c) repeat a) and b).

The test conditions (gas type, flow rate, introduction period, stopping period, and threshold value) shall be specified in the test report.

5.5 Measurement of base pressure cryogenic vacuum pump

The complete measurement of base pressure shall be in accordance with ISO 21360-1:2020, 5.4. However, the pressure shall be measured within 24 h from completing cooldown. This pressure is not the ultimate pressure.

5.6 Measurement of cooldown time

5.6.1 General

The cooldown time is defined as that time elapsed between starting the cryogenic vacuum pump at room temperature at a starting pressure as indicated by the manufacturer and the point at which the temperature of the second stage reaches 20 K. If the cryogenic vacuum pump cannot start at room temperature, report the starting temperature.

NOTE Cooldown time can be affected by ambient humidity.

5.6.2 Measurement setup

To determine the cooldown time, the test dome according to the setup of volume flow rate measurement by the throughput method shall be fitted to the pump.

NOTE For the cooldown time measurement, a blank-off flange can be used optionally. The test is conducted using a blank-off flange at the entrance of the cryogenic vacuum pump. The blank-off flange is constructed of polished stainless steel. The test method is reported.

5.6.3 Measuring procedure

Before the test, the cryogenic vacuum pump shall be regenerated with a roughing pump to meet the pre-vacuum requirement of the cryogenic vacuum pump indicated by the manufacturer. Close the roughing valve and start the cryogenic vacuum pump (the refrigerator shall be turned on). Record the time of the temperature of the second stage from room temperature to 20 K.

5.7 Measurement of crossover value

5.7.1 General

The nitrogen gas equivalent to the estimated the crossover value shall be admitted into the cryogenic vacuum pump via the test dome by quick-acting valve. The test gas should be pumped within 3 s. If the temperature of the second stage maintains ≤ 20 K, the amount of gas that has been admitted is the crossover value.

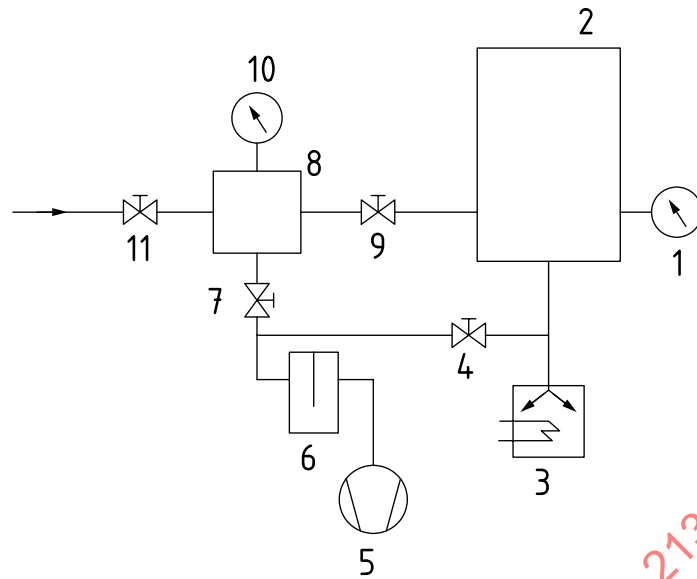
NOTE This test method is intended to verify the data given by the manufacturer, therefore it is not a destructive test, and the measuring procedure is not normally used to determine the limit parameter values of the transit capacity. It is normally tested with nitrogen.

5.7.2 Measurement setup

The measurement setup is shown in [Figure 1](#) using the test dome shown as in ISO 21360-1:2020, Figure 1. In order to avoid the temperature change of the test gas during expansion, the volume ratio of the test dome to the charging chamber shall not be less than 10:1. The valve between the charging chamber and the test dome shall have enough flow conductivity and be fully opened quickly enough to admit 98 % gas load into the test dome within 3 s.

Alternatively, the dome itself may be used as the charging chamber. The measurement setup is shown in [Figure 2](#). In this case, a quick-acting valve shall be used to isolate the cryogenic vacuum pump from the test dome. The gas load is injected into the pump by opening the valve isolating the dome from the cryogenic vacuum pump. The valve shall be fully opened quickly enough to lead 98 % gas load into the test dome within 3 s.

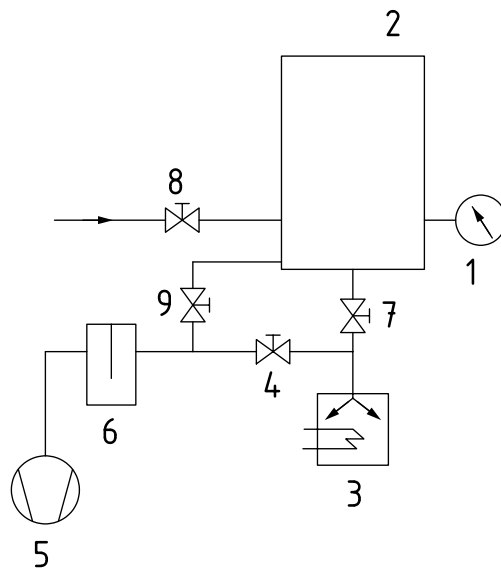
Temperature measuring system which have less than 0,1 s response time is recommended for detecting temperature variation sensitively.



Key

- 1 vacuum gauge
- 2 throughput method test dome
- 3 cryogenic vacuum pump
- 4 roughing valve
- 5 roughing pump
- 6 cold trap (optional)
- 7 vacuum valve
- 8 charging chamber
- 9 quick-acting valve
- 10 vacuum gauge
- 11 charging valve

Figure 1 — Crossover measurement setup



Key

- 1 vacuum gauge
- 2 throughput method test dome
- 3 cryogenic vacuum pump
- 4 roughing valve
- 5 roughing pump
- 6 cold trap (optional)
- 7 quick-acting valve
- 8 charging valve
- 9 vacuum valve (optional)

Figure 2 — Crossover measurement setup (the dome is used as the charging chamber)

5.7.3 Measuring procedure

The cryogenic vacuum pump and the test dome shall be in equilibrium state. Fill the charging chamber V_a with nitrogen up to a suitable pressure p_a (the ratio of the estimated crossover to the volume V_a of the charging chamber). The nitrogen temperature in the charging chamber should be kept in equilibrium with the ambient temperature for ≥ 5 min, record the chamber pressure and the temperature of the second stage. Open the quick-acting valve and then monitor the temperature of the second stage and the pressure in the test dome. This test can be regarded as valid if the maximum temperature of the second stage $T_{\max} \leq 20$ K during the test. If the temperature of the second stage is higher than 20 K, the crossover value should be reduced. Repeat the measurements 3 times. Record the gas quantity $q_{cv} = p_a V_a$ when the temperature of the second stage is the highest. This value shall be regarded as the crossover value.

The tests shall be conducted on a completely regenerated cryogenic vacuum pump. The cryogenic vacuum pump should not regenerate each time between the three measurements.

6 Test report

6.1 Content

The test report shall contain the following general data on the general information (see 6.2), the pump parameters (see 6.3), the test equipment and conditions (see 6.4), the operational parameters (see 6.5) and the pump performance (see 6.6).

6.2 Report on general information

The test report shall contain the following general information:

- a) the data of the test and the place at which the test was conducted;
- b) statement that the data in this document were obtained according to ISO 21360-6:2023;
- c) the method used for the test of the volume flow rate, maximum throughput, pumping capacity, base pressure cryogenic vacuum pump, cooldown time and crossover value of cryogenic vacuum pump;
- d) the uncertainty of the test determined in accordance with ISO 21360-1:2020.

6.3 Report on pump parameters

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

- a) the type and the article/serial number of the cryogenic vacuum pump;
- b) the flange type and size of the cryogenic vacuum pump;
- c) the type and the article/serial number of the cold head and helium compressor.

6.4 Report on test equipment and conditions

The test report shall contain the following general information about the test equipment and conditions:

- a) the type and operational conditions of vacuum gauges used;
- b) the type of seals used upstream from the inlet flange of the test pump;
- c) D (inner diameter of the test dome) and flange type;
- d) ambient temperature, humidity, and atmosphere pressure;
- e) type, operational conditions, the article/serial number, and calibration traceability of flow meter, temperature sensor, and vacuum gauge used.

6.5 Report on operational parameters

All measurement reports shall contain the following items:

- a) the inlet pressure of test pump p_1 ;
- b) test gas species;
- c) starting pressure p_2 .

6.6 Report on pump performance

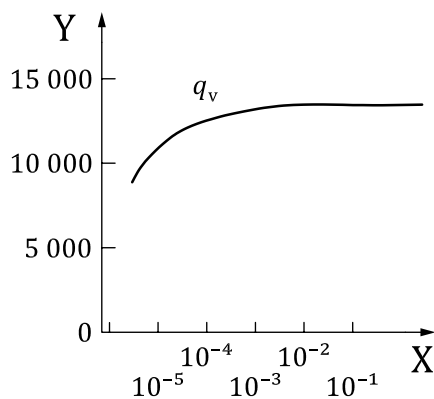
All measurement reports shall contain the following items, if applicable:

- a) volume flow rate (test gas: nitrogen, argon, hydrogen);

NOTE The logarithmic coordinates of the pressure p_1 and the volume flow rate q_v can be plotted according to [Figure 3](#) (optional);

- b) maximum throughput (test gas: argon);
- c) pumping capacity (test gas: argon, hydrogen);
- d) base pressure cryogenic vacuum pump;

- e) cooldown time;
- f) crossover value (test gas: nitrogen).



Key

- X inlet pressure, Pa
- Y volume flow rate, $\text{l}\cdot\text{s}^{-1}$

Figure 3 — Volume flow rate (pumping speed) vs inlet pressure curve of cryogenic vacuum pump