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EUROPEAN COMMITTEE OF MANUFACTURERS OF COMPRESSORS, VACUUM PUMPS AND PNEUMATIC TOOLS COMITE EUROPEEN DES CONSTRUCTEURS DE COMPRESSEURS, POMPES A VIDE ET OUTILS A AIR COMPRIME EUROPAISCHES KOMITEE DER HERSTELLER VON VERDICHTERN, VAKUUMPUMPEN UND DRUCKLUFTWEKZEUGEN	PN5ASRCC/5

VACUUM PUMPS
Acceptance Specifications
Refrigerator Cooled Cryopumps
Part 5

GENERAL SECRETARIAT

British Compressed Air Society
33/34 Devonshire Street
LONDON
W1N 1RF
Tel: 071 935 2464
Fax: 071 935 3077

Vacuum Pumps

Acceptance Specifications

Part V Refrigerator Cooled Cryopumps

FOREWORD

PNEUROP, the coordinated assembly of manufacturers of compressors, vacuum pumps and pneumatic tools from eleven European countries - Austria, Belgium, France, Germany, Great Britain, Italy, Liechtenstein, Luxemburg, the Netherlands, Sweden, Switzerland - decided to set up a committee "Vacuum Technique" with the object to create acceptance specifications covering the scope of relevant vacuum pumps. Since 1967 five parts of those specifications were published. The committee "Vacuum Technique" being under German chairmanship (Secretariat: Fachgemeinschaft Kompressoren und Vakuumpumpen im VDMA, Postfach 71 08 64, D-6000-Frankfurt am Main-71) now presents this publication and thanks all delegates for their active cooperation. Very helpful advise and support by experts from manufacturers in the USA is acknowledged gratefully.

Frankfurt am Main, July 1989

6.0.1 INTRODUCTION

The purpose of this recommendation is to ensure that the measurement of the performance characteristics of cryopumps is as far as possible carried out according to uniform procedures and under uniform conditions. It is hoped, that this will result in measurements carried out by different manufacturers' or in different laboratories and the information provided in manufacturers literature being genuinely comparable. It should be emphasized that throughout this paper the term "cryopump" refers only to refrigerator cooled cryopumps - in accordance with 6.0.2 "Scope".

Since cryopumps are capture pumps and do not pass pumped gases to a primary pump, the performance characteristics are independent of the roughing pump size. However, deterioration of performance for certain gas species can occur if the period of rough pumping during starting becomes too long due to a roughing pump of insufficient size. To avoid this possibility, the roughing pump used for the tests should be sized such that the cryopump manufacturers' starting pressure is reached within 40 minutes of opening the roughing valve and that the roughing line is fitted with a trap against back-streaming of oil vapour. Alternatively, oil free rough pumping methods could be used.

Some of the following tests may result in the accumulation of dangerous quantities of gas.

For the duration of the measurements outlined in this specification, the user should avoid excessive handling of the equipment and the effects of sunshine or draughts should be reduced by appropriate screening. Errors resulting from a change in atmospheric pressure can be neglected providing the test time is adequately short.

Cryopumps can be mounted in any orientation but for the purposes of this acceptance specification the preferred orientation shall be with the cryopump axis vertical and the test dome on top of the pump.

6.0.2 SCOPE

These acceptance specifications refer to refrigerator cooled cryogenic vacuum pumps which can be directly flanged to a vacuum chamber with the cold surfaces not protruding into the chamber.

These acceptance specifications are recommended for the following gases:

a) dry air (nitrogen)
b) argon
c) hydrogen

If a manufacturer lists the volume rate of flow (pumping speed) or other technical data for water vapour, it must be stated whether this is a calculated value. If not, the operating conditions under which the measurement of those values were obtained must be indicated.

The following criteria are subject to these specifications:

- Volume rate of flow (pumping speed)
- Maximum throughput
- Pumping capacity
- Ultimate pressure
- Cool down time
- Cross over
- Refrigeration capacity.

These acceptance specifications should only be used for newly manufactured pumps. In the case of pumps that have been used before on a system, it is possible that permanent changes in performance due to unknown gas and vapour loads will make a direct comparison invalid, even if carried out according to these acceptance specifications.

6.1 Volume rate of flow (Pumping speed) Definition

Under ideal conditions, the volume rate of flow is the volume of gas which flows from the test dome through the pump inlet per unit time. For practical reasons, however, the volume rate of flow (pumping speed) of a given pump for a given gas is conventionally taken as the quotient of the throughput of this gas and of the equilibrium pressure at a given point. The unit adopted for the volume rate of flow (pumping speed) is the litre per second ($\ell \cdot s^{-1}$).

Method of measurement

Method for inlet pressures $> 1 \cdot 10^{-6}$ mbar and/or flow rates $> 2 \cdot 10^{-4}$ mbar$\cdot \ell \cdot s^{-1}$

The method adopted for the measurement of the volume rate of flow (pumping speed) S is the steady pressure method for which gas throughput is measured by a flowmeter. If q_{pV} is the gas throughput thus measured at atmospheric pressure and p is a pressure held constant and measured using a pressure gauge in a determined area of the test dome, the volume rate of flow (pumping speed) is obtained by the relationship:

$$S = \frac{q_{pV}}{p - p_0} \text{ in } \ell \cdot s^{-1} \qquad (1)$$

Method for inlet pressures $\leq 1 \cdot 10^{-6}$ mbar and/or flow rates $\leq 2 \cdot 10^{-4}$ mbar$\cdot \ell \cdot s^{-1}$

The method adopted for the measurement of the volume rate of flow (pumping speed) is the "standard conductance" method in which a thin orifice plate divides the test dome into two chambers. If pressure is measured in each chamber by pressure gauges having the same sensitivity, the volume rate of flow (pumping speed) is then given by:

$$S = C\left(\frac{p_1 - p_{10}}{p_2 - p_{20}} - 1\right) \text{ in } \ell \cdot s^{-1} \qquad (2)$$

Where C is the calculated conductance taking account of the dome orifice size and of the gas nature. For p_1 and p_2 see figure 2.

Note: The pressures indexed with o are the respective equilibrium pressures in the test dome chambers just before gas admittance.

The orifice conductance may be calculated using the following formula:

$$C = \sqrt{\frac{R \cdot T \cdot \pi}{32 \cdot M}} \cdot \frac{d^2}{1 + \frac{\ell}{d}} \qquad (3)$$

R	=	Ideal gas constant	$N \cdot m \cdot mol^{-1} \cdot K^{-1}$
T	=	Absolute temperature	K
M	=	Gas molecular mass	$kg \cdot mol^{-1}$
ℓ	=	Thickness of the orifice wall	m
d	=	Orifice diameter	m
C	=	Conductance	$m^3 \cdot s^{-1}$ $(=10^3 \ \ell \cdot s^{-1})$

The term $1+\frac{\ell}{d}$ is a corrective-factor defined as transmission probability.

The formula should be applied with consistent units as given in the following example:

$$R = 8.314 \ Nm \cdot mol^{-1} \cdot K^{-1} = 8.314 \ kg \cdot m^2 \cdot s^{-2} \cdot mol^{-1} \cdot K^{-1}$$

$$M_{air} = 28.8 \cdot 10^{-3} kg \cdot mol^{-1}$$

$$T = 293 \ K = 20°C$$

Therefore for air at 20°C:

$$C_{air} = 91 \frac{d^2}{1 + \frac{\ell}{d}} m^3 \cdot s^{-1} = 91000 \frac{d^2}{1 + \frac{\ell}{d}} \ell \cdot s^{-1} \qquad (3a)$$

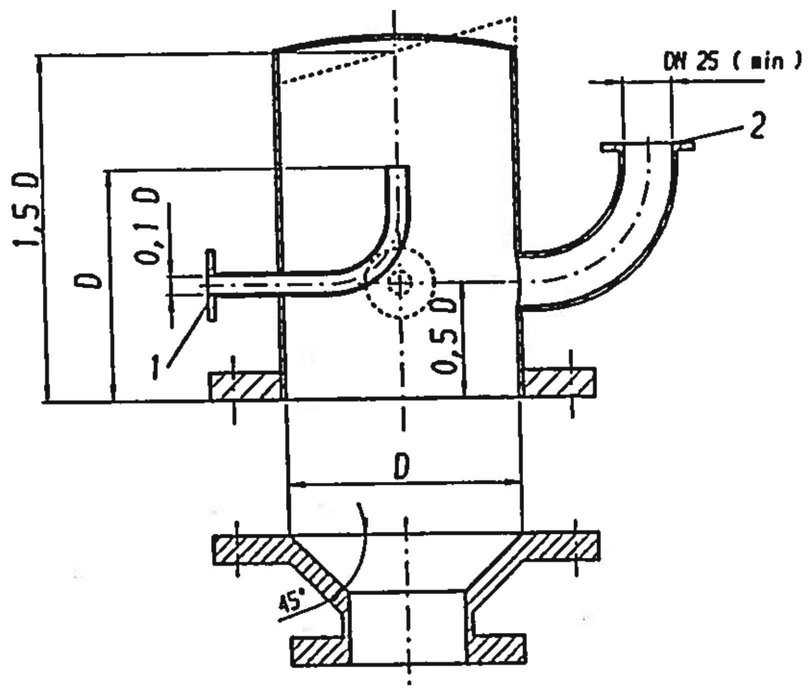
Test dome for measuring the volume rate of flow (pumping speed) at pressures $> 1 \cdot 10^{-6}$ mbar and/or flow rates $> 2 \cdot 10^{-4}$ mbar·ℓ·s^{-1}

For measurement a test dome as shown in fig. 1 with the same diameter D as that of the pump inlet is to be used. The top of the dome may be flat, conical curved or sloping with the same average height above the flange as for the flat face.

For pumps with an inlet flange diameter less than 100 mm a dome should be used with a diameter of 100 mm. The transition piece to the pump inlet flange should be made through a 45° taper fitting as short as possible as shown in figure 1.

The test dome must be constructed in such a way that it can be fitted with a heating device for bake-out ensuring uniform heating of the dome to max. 120°C.

FIGURE 1 Test Dome

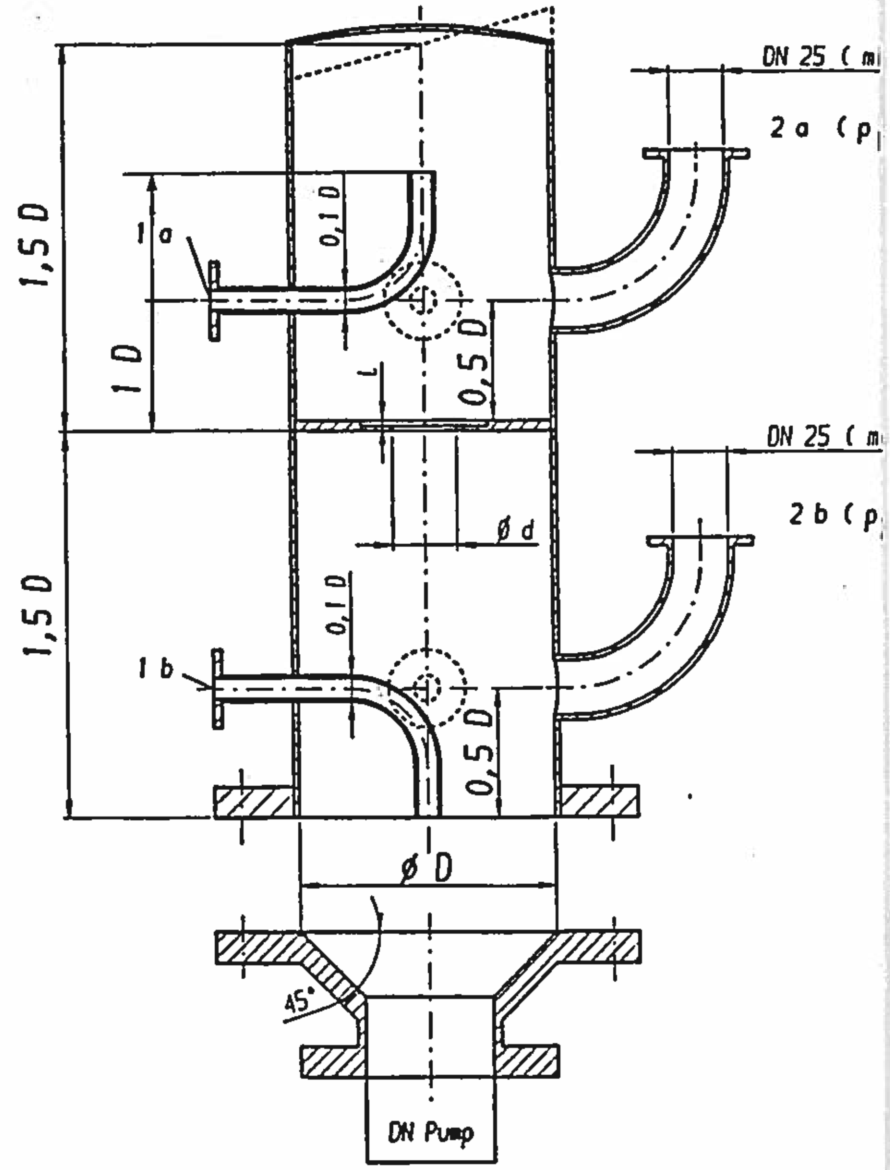


1 Gas inlet 2 Vacuum gauge connection

Test dome for measuring the volume rate of flow (pumping speed) at pressures $\leqq 1 \cdot 10^{-6}$ mbar and/or flow rates $\leqq 2 \cdot 10^{-4}$ mbar·ℓ·s^{-1}

For measurement a test dome as shown in fig. 2 with the same diameter D as that of the pump inlet is to be used. The upper part of this test dome corresponds to that shown in fig. 1. For pumps with an inlet flange diameter less than 100 mm a dome should be used with a diameter of 100 mm. The transition to the pump inlet flange should be made through a 45° taper fitting as short as possible as shown in fig. 2. The diameter of the orifice in the thin plate should be chosen according to the expected flow rate and the diameter D of the dome. It should be such that its value lies between 0.05 D and 0.1 D and that the ratio of the pressure measured at p_1 and p_2 is greater than 10. The test dome must be constructed in such a way that it can be fitted with a heating device for bake-out ensuring heating of the dome to max. 120°C.

FIGURE 2 Test Dome



1 Gas inlet

2 Vacuum gauge connection

The test dome is equipped with two Bayard Alpert gauges referring to table A of the Annex.

One may ensure pressure gauge agreement by fitting at 1b a gas admission pipe directed to the pump inlet in the lower part of the dome (figure 2). The adjustable valve for gas admission in this pipe line should be opened so as to obtain the desired pressure. After stabilization, pressure gauges for p_1 and p_2 should indicate the same values; otherwise necessary corrective factors must be applied.

Procedure for measurement

For measuring the volume rate of flow (pumping speed), the test dome, the pressure gauge and a flow meter shall be fitted according to the illustration in fig. 3. A suitable variable gas inlet valve shall be fitted between the test dome and the flow meter. For measuring the volume rate of flow at pressures less than $1 \cdot 10^{-6}$ mbar a test dome according to fig. 2 is used with an additional Bayard Alpert gauge and gas inlet valve for calibration, as described in the previous section. Prior to the commencement of the rate of flow measurement the assembly shall be leak tested.

During the measurement the pump should be run under the conditions prescribed by the manufacturer. The ambient temperatures shall be 293 K $\pm$ 3 K and kept constant during measurement to within $\pm$ 1 K.

If the temperature of the test dome deviates by more than 3 K from that of the flow meter or one or both from the standard temperature (293 K) a correction must be applied according to the following equation:

$$S_0 = S \frac{T_2}{T_1} \sqrt{\frac{T_0}{T_2}} \qquad (4)$$

When using a vertical measuring tube (Burette) or a calibrated capillary:

$$S_0 = S \frac{T_0}{\sqrt{T_1 \cdot T_2}} \qquad (5)$$

Where:

	S_0	corrected volume rate of flow (pumping speed) $(\ell \cdot s^{-1})$
	S	measured volume rate of flow (pumping speed) $(\ell \cdot s^{-1})$
	T_0	standard temperature (293 K)
	T_2	temperature of the test dome (K)
	T_1	temperature of the flow meter (K)

Initially the cryopump and the test dome are evacuated by means of a roughing pump. When the starting pressure indicated by the manufacturer of the cryopump is reached, the cryopump is switched on. The roughing pump continues to evacuate the system until the roughing pump valve can be closed without the system pressure rising to a value above the starting pressure. At this point the roughing valve must be closed and left shut for the duration of the tests. Then pumping is continued with only the cryopump until its operating temperature (second stage lower than 20 K) is reached and until the pressure is at least one decade below the pressure range in which the volume rate of flow (pumping speed) measurement shall be carried out.

For measurement the variable gas inlet valve is opened and test gas is admitted to the dome so as to produce the required pressure in the test dome.

The volume rate of flow (pumping speed) of the cryopump can be influenced immediately after regeneration by short duration sorption effects. To make the volume rate of flow (pumping speed) measurement independent from these effects the pump should be conditioned. (This is not recommended in the case of the volume rate of flow (pumping speed) measurements for hydrogen). For conditioning purposes a quantity of the test gas given by:

$$pV = a \cdot S_0 \text{ in mbar} \cdot \ell \qquad (6)$$

will be admitted, where S_0 ($\ell \cdot s^{-1}$) is the expected volume rate of flow (pumping speed) of the pump and a = 0.01 mbar·s is a proportionality factor determining the quantity of gas to be admitted. The inlet pressure for conditioning shall be within the range to be measured and shall be chosen so that, as a rule, the inlet valve can be closed after 60 minutes. If the pressure falls by at least one decade below the pressure range to be measured or if the pressure reduction is

$$\frac{\Delta p}{\Delta t} \leqq 0.3 \cdot p \ (\text{mbar} \cdot h^{-1}) \qquad (7)$$

the measurement can be started. The calculation of the volume rate of flow (pumping speed) is made by using formula (1) or (2).

The volume rate of flow (pumping speed) shall be measured at different inlet pressures (at least 2 measurements within one decade) beginning from the lowest pressure. For each measured point the following values shall be ascertained:

atmospheric pressure	P_a (mbar)
inlet pressure	p (mbar)
volume of gas pumped	V (l)
measurement time	t (s)
temperature of the test dome	T_2 (K)
temperature of the flow meter	T_1 (K)
equilibrium pressure	p_0 (mbar)

The inlet pressure and the volume of the gas pumped shall be measured simultaneously. If the measurement of the gas flow takes more than 60 s, the pressure is to be checked at least 3 times or every 60 seconds and the mean value is to be used for evaluation.

If the highest and the lowest measured values of the volume rate of flow (pumping speed) differ by more than 10 % from the mean, the measurement must be repeated.

If several test gases are used, without regenerating the pump completely, it is recommended to use the gases in the following order:

hydrogen - nitrogen or air - argon.

If during measurement more than 30 % of the capacity of the pump as indicated by the manufacturer is admitted, it is recommended to regenerate the pump prior to the following measurement.

Type designation

If the volume rate of flow (pumping speed) is used in reports and technical specifications this value must not be greater than 10 % above the average value measured at 10^{-5} mbar.

6.2 Maximum throughput

Definition

The maximum throughput is the maximum quantity of gas in pressure-volume units per unit time, flowing from the test dome through the cryopump inlet flange, that the pump can withstand whilst maintaining a given second stage temperature. This temperature T_{max} depends on the gas species and is set at 20 K for condensable gases (Ar, N_2, O_2 etc.). Therefore the maximum throughput is the throughput which causes the second stage temperature to rise to and remain stable at T_{max} = 20 K. The unit adopted for the throughput is the millibar litre per second ($mbar \cdot \ell \cdot s^{-1}$).

Method of measurement

The method adopted for the measurement of the throughput is the steady pressure method, for which the throughput is measured outside the dome at atmospheric pressure.

Measuring apparatus
Test dome

The same as that for volume rate of flow (pumping speed) measurement at inlet pressures $\geq 1 \cdot 10^{-6}$ mbar (see fig. 1).

Temperature measurement

The temperature of the second stage shall be measured with a sensor chosen from table C. The sensor location should be as close as possible to the cold head second stage.

Equipment for measuring the throughput

The equipment can be chosen in accordance with Table B.

Pressure gauges

It is desired to quote the test dome pressure at which the measurement is carried out. Suitable pressure gauges should be chosen in accordance with Table A.

Procedure for measuring maximum throughput

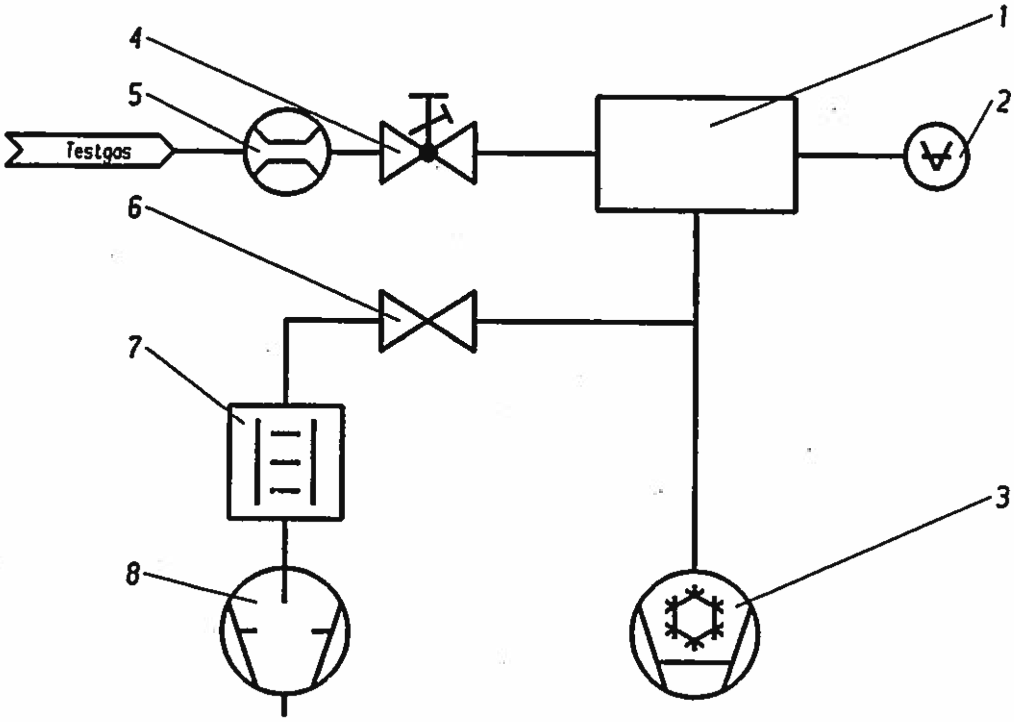
The pump is prepared in the same manner as for the measurement of volume rate of flow (pumping speed) but without pre-conditioning.

The arrangement of the measuring apparatus is shown in fig. 3. When twice the manufacturers quoted cool-down time has elapsed gas is introduced to the test dome through the adjustable gas inlet valve until a second stage temperature of 20 K is reached.

For tests considered as valid, this temperature must remain steady to within 1 K during all the measurements and for 10 minutes after the last measurement. If temperature unsteadiness is due to a transient cause, time should be allowed for the temperature to stabilize and the test repeated.

At least five measurements must be made, from which the maximum and the minimum value must be eliminated. The quoted maximum throughput is then the arithmetic mean of the remaining values. For the test to be valid the maximum difference between the mean value and the remaining measured ones must be lower than 10 %. If this is not the case the test must be repeated.

FIGURE 3   Maximum throughput measurement apparatus



1	Test dome	5	Flowmeter
2	Vacuum gauge	6	Roughing valve
3	Cryopump	7	Foreline trap
4	Gas inlet valve	8	Roughing pump

6.3 Pumping capacity

The pumping capacity is the quantity of gas (in mbar·ℓ), which has been pumped up to the moment, where the volume rate of flow (pumping speed) has reduced to 50 % of the initial value measured according paragraph 6.1. After having pumped this amount of gas, the pump must still be able to reduce the pressure in the test dome down to a value of $p < 1 \cdot 10^{-5}$ mbar in less than 10 min to ensure, that a certain pumping performance is still available. The following tests may result in the accumulation of dangerous quantities of gas in the pump and appropriate precautions should be taken.

The test is run at constant throughput, so that a decrease of 50 % in volume rate of flow (pumping speed) is indicated by a corresponding increase of 100% in pressure at the test dome. Even with a possible non constant volume rate of flow (pumping speed) this method will lead to reasonable results. In case of increasing volume rate of flow (pumping speed) the pump will show better performance resulting in a higher capacity and vice versa.

The pumping capacity depends on the kind of gas and its temperature and on the working (inlet) pressure. It is recommended to take Argon as representative for the type of condensable gases, and Hydrogen for adsorbable gases.

The pumping capacity is measured with a regenerated pump. The measurement equipment is the same as in 6.1. The test gas is admitted continuously, throughput and inlet pressure should be checked regularly. In case of argon the recommended gas flow should not exceed the manufacturers' specified maximum throughput. In case of hydrogen the inlet pressure should be $5 \cdot 10^{-5}$mbar (corrected, not nitrogen equivalent) at the start of the test.

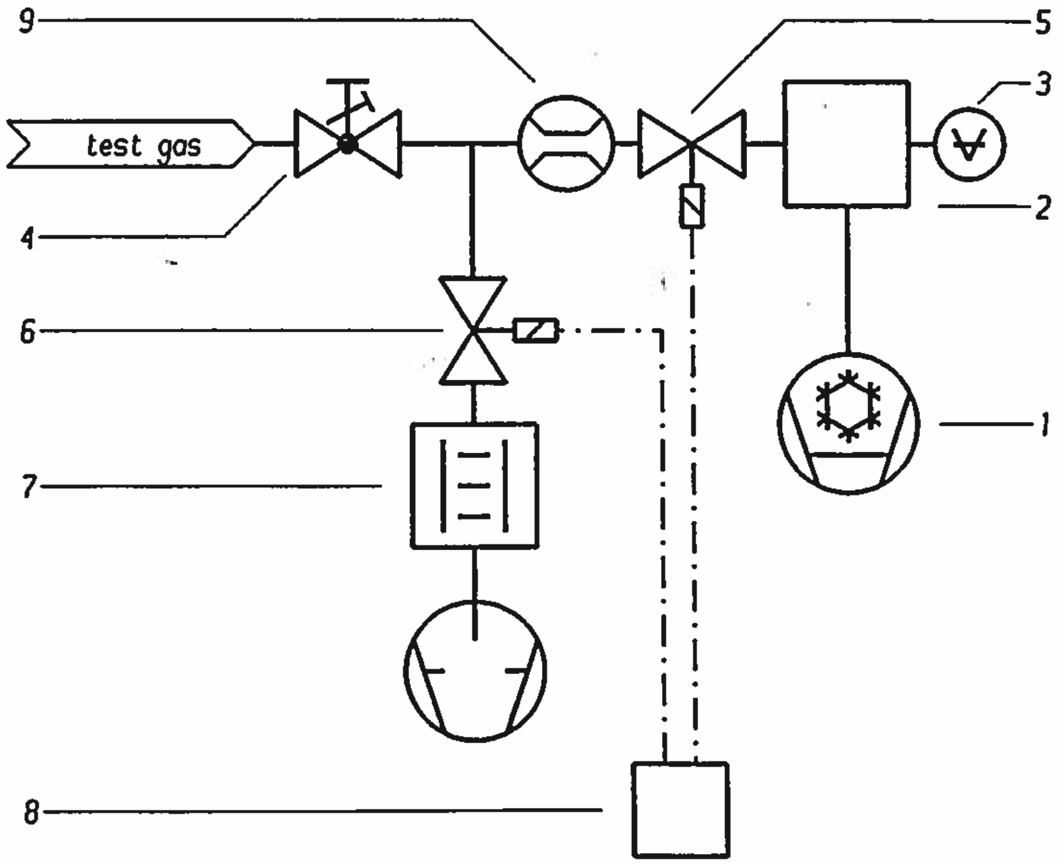
Whenever it seems reasonable the gas admission should be interrupted to make sure, that the pump is still able to lower the test dome pressure down to $< 1 \cdot 10^{-5}$mbar in 10 min or less. In case this is not possible, the pumping capacity has been exceeded and the test should be stopped.

Fig. 4 shows the recommended equipment to interrupt the gas admission and pumping the test gas flow with a trapped auxiliary pump. It is sufficient to maintain a pressure of 0.01 mbar to 1 mbar with this pump during the period of gas inlet valve closure.

When the initial pressure has increased by 100 % then the gas admission should be stopped to check if the pump can lower the test dome pressure to $< 1 \cdot 10^{-5}$ mbar in 10 min or less.

The volume of the connection between the valves 4, 5, 6 in Figure 4 must not exceed 5 % of the volume of the test dome.

FIGURE 4 Pumping Capacity Measurement Apparatus



1 Cryopump
2 Test dome
3 Vacuum gauge
4 Leak valve
5 Gas inlet valve
6 Valve, opens when 5 closes
7 Roughing pump with trap
8 Valve control
9 Flow meter

6.4 Ultimate operational pressure

Definition of the ultimate operational pressure

The ultimate operational pressure is the pressure measured in the dome after the procedure as described in the following sections.

Measuring apparatus

The same as for volume rate of flow (pumping speed) at inlet pressures $> 1 \cdot 10^{-6}$ mbar (see fig. 1). The test dome shall also be equipped with a bake out device.

Pressure gauges

The test dome shall be equipped with a pressure gauge chosen in accordance with Table A. The gasket between the vacuum gauge flange and the port of the dome shall be metallic.

Measurement of ultimate operational pressure

When assembling the apparatus cleanliness and leak tightness requirements usually required to reach the high vacuum must be met. Prior to the test the cryopump shall be regenerated together with the test dome according to the manufacturer's specifications. In addition to this the adsorbent of the cryo panels may be purged by baking and roughing the cryopump. The same roughing pump with trap as described for the other tests in the preceding paragraphs must be used. During bake out the cryo panel temperatures shall be controlled so as not to exceed the manufacturer specifications. At the end of bake out (not longer than six hours) the cryopump is started. The ultimate operational pressure is defined as the pressure measured by the pressure gauge 24 hours after the cryopump has been started.

6.5. Cooldown time

To determine the cooldown time, the test dome according to fig. 1 is fitted to the pump.

The cooldown time shall be defined as that time elapsed between starting the cryopump at room temperature and at a starting pressure as indicated by the manufacturer and the point at which the cryopump second stage reaches 20 K. The roughing valve should only be closed when by doing so the pressure in the test dome does not rise to a value above the starting pressure.

6.6 Crossover

Definition

The crossover is defined by the maximum amount of nitrogen gas (in mbar·ℓ) which can be admitted to the pump over a short time with the temperature T_2 of the second stage remaining at or below 20 K during the test gas flow.

For the acceptance test the defined amount of gas is admitted to the pump followed by a continuous measurement of test dome pressure and temperature of the pump's second stage.
The following points should be observed for this procedure:

> the ratio of volumes by expansion of the admitted gas should be less than 10:1 in order to avoid excessive temperature changes of the test gas by adiabatic processes,
>
> at least 98 % of the amount of gas should be admitted within 3 s.

For this test (fig. 5) an additional chamber is connected to the test dome with a volume V_a at least 1/10 of the volume of the pump together with the test dome from fig. 1. This smaller volume (V_a) is connected to the test dome by the valve 3 with sufficiently large conductance, which can be opened within 3 s. This valve replaces the inlet valve for throughput measurement. The bent tube inside the test dome will assure a good thermal accomodation of the gas by a number of particle wall collisions.

Care must be taken to ensure that the tests are conducted on a newly regenerated cryopump. The test will be carried out three times:

Test procedure:

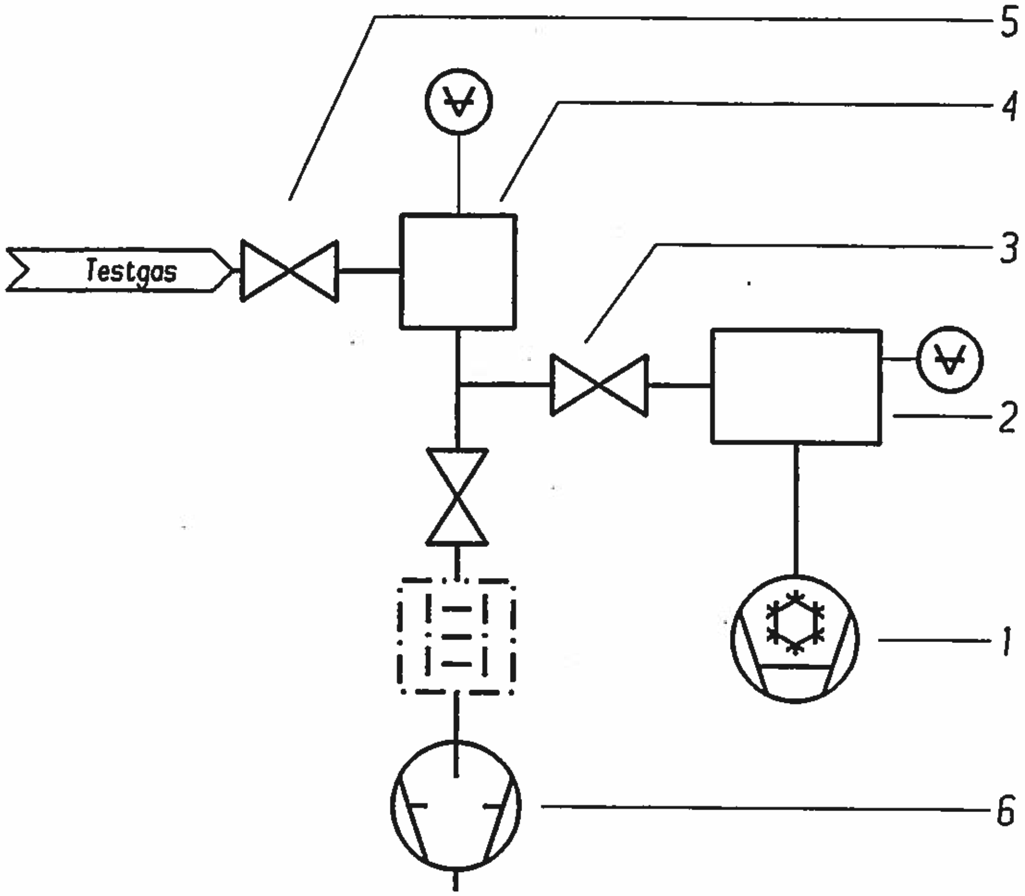
- Make sure that cryopump and test dome are in equilibrium state, valve 3 closed.
- Fill the additional volume V_a with nitrogen up to appropriate pressure p_a
- Wait five minutes to establish ambient temperature in the nitrogen container V_a then read pressure P_a in V_a and temperature T_2 of second stage of cryopump.
- Open valve 3 in less than three seconds. Valve 3 should not be closed during the rest of the test.
- Monitor T_2 and test dome pressure.

The crossover value Q_c is then given by

$$Q_c = V_a \cdot p_a \text{ (mbar}\cdot\ell) \qquad (8)$$

for a maximum temperature $T_{max} \leqq 20$ K of the second stage.

FIGURE 5 Crossover Measurement Apparatus



1	Cryopump	4	Additional volume V_a
2	Test dome	5	Gas supply
3	Valve for gas admittance	6	Roughing pump with optional trap

6.7 Refrigeration capacity

Although refrigeration capacity (cooling power) can not simply be used as a criteria for the assessment of the performance of a cryopump, the following procedure is recommended for measuring the cooling power of the refrigerator. The refrigeration capacity is given for each stage of the cold head usually for one temperature of the stage, with the other stage held at assigned temperature(s). For 2-stage refrigerators the refrigeration capacities (W_{c1}, W_{c2}) are those which maintain steady temperatures of first and second stages at T_1 = 80 K and T_2 = 20 K respectively, when simultaneously loaded.

As the refrigeration capacity is a property of the cold head, all pumping and shielding elements must be demounted before measurement. Electrical heaters, which allow well defined power loads, and temperature sensors according to Table C are installed on the stages. The cold head is placed in a suitable vacuum housing and carefully shielded by superinsulation in order to prevent errors in measured capacities due to radiant heating. Such shielding should take the form of multiple reflective screens each allowed to float at an intermediate temperature or a surrounding screen of thin aluminized plastic foils (typically 30 layers for temperatures down to 10 K).

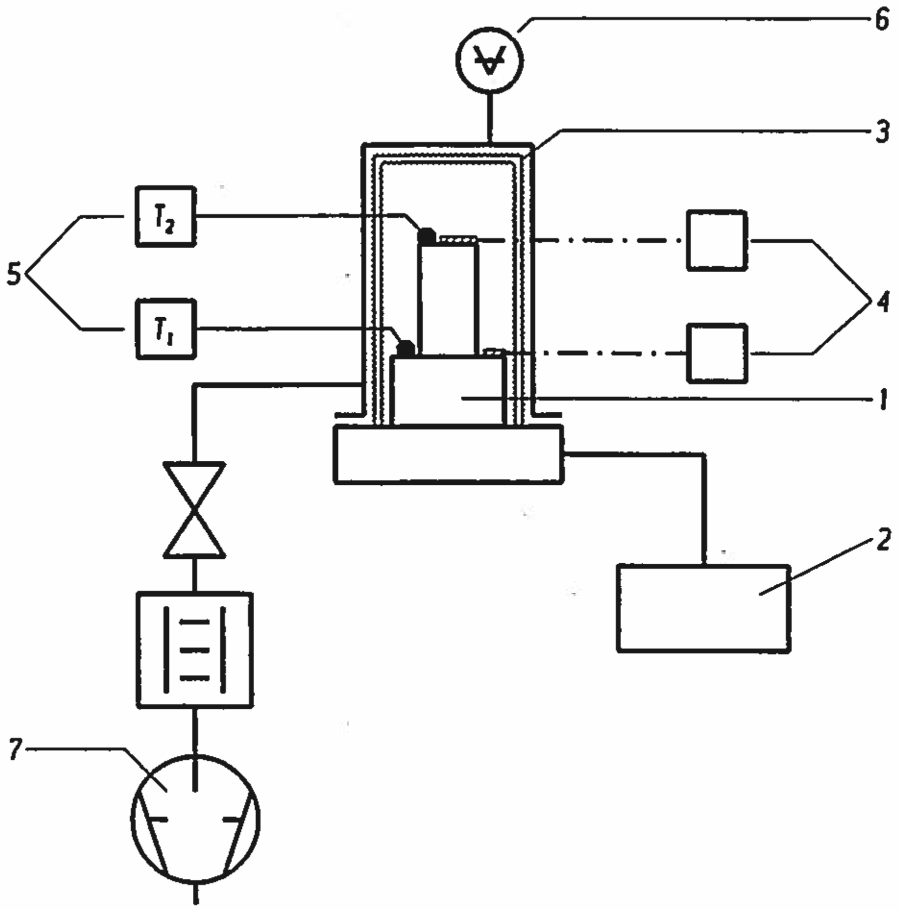
In order to minimize the gas conduction load, the vacuum housing is evacuated and maintained at a pressure $P \leq 10^{-4}$ mbar for the duration of the test by means of a clean vacuum pumping system (for test lay-out see Fig. 6).

The cold head should then be run until operational temperatures are reached. The test starts when the temperature of both stages have remained stable for at least 10 minutes. By adjusting the voltage applied to the heaters, the heat input to the two stages can be set to the values (W_{c1}, W_{c2}) specified by the manufacturer. The influence of the connecting wires between heaters and power supply on the measurement should be carefully evaluated.

Refrigeration capacity is the power supplied to the first and second stage at the assigned temperatures; they should be adjusted until the first stage holds steady at 80 K and the second stage at 20 K. The temperatures should remain steady for at least 10 minutes before refrigeration capacities of the stages are measured.

Refrigeration capacity: W_c (Watt) = U (Volt) x I (Ampere)

FIGURE 6 *Refrigeration Capacity Measurement Equipment*



1	*Cold head*	5	*Temperatur measurement*
2	*Compressor*	6	*Vacuum gauge*
3	*Superinsulation*	7	*Vacuum pump with trap*
4	*Power supply for heaters*		

6.8 Test report

The presentation of results shall include the following informations:

1. Type and serial number of pump.

2. A semilogarithmic plot of volume rate of flow (pumping speed) in $\ell \cdot s^{-1}$ versus. log. p in mbar with indication of test gas and the ultimate operational pressure or equilibrium pressure.

3. Value of maximum throughput in mbar$\cdot \ell \cdot s^{-1}$ test gas, inlet pressure, and temperature T_{max} of second stage.

4. Value of pumping capacity in mbar$\cdot \ell$, test gas, inlet pressure in mbar and volume rate of flow (pumping speed) measured at the end of gas admission relative to the initial value in %.

5. Value of ultimate operational pressure.

6. Value of cooldown time to 20 K.

7. Value of crossover given in mbar$\cdot \ell$

8. Value of refrigeration capacity in Watts together with temperature of the cold head for both stages.

ANNEX

Table A Vacuum gauges for cryopumps

Pressure range	Vacuum gauges	Accuracy
≧ 20 mbar	U-tube Diaphragm Calibrated capacitance manometer	± 1 mbar [1)] ± 5 % [2)] ± 2 % [2)]
20 mbar to $1\cdot10^{-2}$ mbar	Mc Leod Calibrated capacitance manometer Pirani	± 5 % [2) 3)] ± 2 % [2)] ± 10 % [2)]
1 mbar to $1\cdot10^{-3}$ mbar	Calibrated capacitance manometer	± 2 % [2)]
10^{-2} mbar to 10^{-6} mbar	Calibrated hot cathode ionization gauge [4)]	± 10 % [2)]
≦ 10^{-4} mbar	Calibrated Bayard Alpert type gauge [4)]	± 10 % [2)]

1) Depending on the method of length measurement; the given accuracy derives from the uncertainty of ± 0.35 mm in length measurement.

2) Of the indicated value.

3) Provided with a vapour trap in form of a U-tube, kept at a temperature between -10 °C and -80 °C throughout the whole measurement.

4) At least in case of hydrogen a correction of the gauge reading is necessary.

Table B Flow measuring equipment

Range	Measuring method	Accuracy
> 1 mbar·ℓ·s^{-1}	Orifice or float type	± 5 %
10 to $1\cdot10^{-3}$ mbar·ℓ·s^{-1}	Burette	± 5 %
3 to $6\cdot10^{-3}$ mbar·ℓ·s^{-1}	Calibrated capillary	± 5 %
All ranges $> 2\cdot10^{-4}$ mbar·ℓ·s^{-1}	Calibrated thermal flow meter	± 10 %
$< 10^{-3}$ mbar·ℓ·s^{-1}	Conductance (according to ISO DIS 3570/I)	± 10 %

Table C Sensors for temperature measurement

Sensor type	Temperature range	Accuracy	Remarks
Pt-resistance	> 30 K	± 1 K 2 wires ± 0,5 K 4 wires	individual calibration curve necessary for T< 60 K
Hydrogen vapour pressure manometer	< 28 K > 14 K	± 0,5 K	
Si-diode	> 4 K	± 0,3 K	individual calibration curve necessary
C-resistor	> 4 K <80 K	± 0,5 K for T<20 K ± 2 K for T>20 K	

Since there is a active research and development in the field of cryo temperature measurement, it may become possible in future to choose other sensor types.