Universität Hamburg

Synchrotron Research Institute

YEREVAN STATE UNIVERSITY

German-Armenian Joint Practical Course
on Accelerator Physics

Vacuum Technology Practice Course

Supervisor Dr. V. Dekhtyarov

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Contents

1. INTRODUCTION

The main idea of this course is to cover all aspects of vacuum science and technology in order to enable engineers, technicians, and scientists to develop and work successfully with the equipment and “environment” of vacuum. Beginners in the field of vacuum should be able to start and experts should be able to deepen their knowledge and find the necessary information and data to continue their work.

1.1 Pressure concept

Due to the bond between its molecular particles the volume occupied by a solid or liquid substance is hardly influenced by ambient conditions (temperature, pressure, etc.). Therefore, this volume is an inherent property of the substance. A gas behaves differently: when a container holds a certain amount of gas, the gas spreads across the complete inner volume of the container and fills it homogeneously. The larger the container, the thinner the gas. The container’s volume V determines volume as well as state of the gas.

The gas in the container exerts a force on the walls of the container (Figure 1). A larger wall area is subject to a larger force than a smaller wall area. Therefore, it is convenient to introduce the term pressure as ***p***. The quantity pressure is defined as the ratio of the force F, exerted perpendicularly to a surface element of the container’s wall, to the area of this surface element ***A***:

$$p = \frac{F}{A} \tag{1}$$

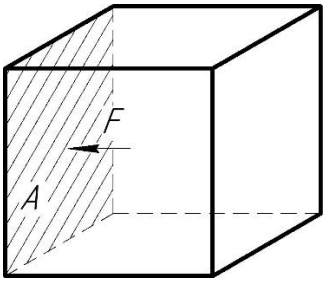


Figure 1 Pressure exerted to the walls of a container by a gas.

In vacuum technology, the term pressure usually refers to absolute pressure (based on an ideal vacuum). Pressure is an important quantity when describing the gas state.

The word **vacuum** typically means a dilute gas or the corresponding state at which the pressure or density is lower than that in the surrounding atmosphere (ISO 3529/1). DIN 28400/1, on the other hand, defines vacuum as a state where pressure is smaller than 30 kPa (300 mbar), which is the lowest pressure that may exist on the surface of the earth.

The defining equation (1) shows that pressure is a derived quantity. The unit of pressure in the International System of Units (SI) is given by

$$p = \frac{F}{A} = \frac{Newton}{meter^2} = Pascal = Pa \qquad (2)$$

One pascal (unit symbol Pa), therefore, is the pressure at which a force of 1 N (1 $kg \cdot m \cdot s^{-2}$) is exerted perpendicularly to a flat surface of 1 m^2.

A number of additional pressure units are in use; the most important once are listed in Table 1.

According to SI, the only additional unit accepted besides Pa is bar (and mbar). The unit mmHg is often used in medicine (for blood pressure, internal eye pressure). In the United States, the units torr and, for higher pressures, psi are common in vacuum technology.

A certain pressure value, corresponding approximately to the pressure of atmospheric air at sea level, that is, normal atmosphere, has been defined as **standard pressure p_n** (ISO 554, ISO 3529/1, DIN 1343):

$$pn = 101325\ Pa = 1013.25\ \text{mbar} \qquad (3)$$

In vacuum-technology applications, where the value of negative pressure with respect to ambient pressure is of interest (e.g., lifting devices with a vacuum sucker), the term relative vacuum is also used. At normal pressure, the relative vacuum is 0%, whereas it is 100% in an ideal vacuum. For any pressure p, relative vacuum is calculated according to

$$\text{Relative vacuum} = \frac{pn - p}{pn} \times 100\% \qquad (4)$$

Table 1 Pressure units according to ISO 3529/1.

Unit	Unit, definition	Conversion symbol
bar	Bar	$1\ \text{bar} = 10^5\ \text{Pa}$
mbar	millibar	$1\ \text{mbar} = 100\ \text{Pa}$
Torr	Torr 1=760 of standard pressure p_n	$1\ Torr = \frac{101325}{760} Pa = 133.322\ Pa \approx \frac{4}{3}\ mbar$
mmHg	Millimeters of mercury = the pressure exerted at the bottom of a vertical column of mercury, 1 mm deep, at standard acceleration due to gravity and at 0 °C	$1\ mmHg = 133.322\ Pa$

μ	Micron = micrometers of mercury = the pressure exerted at the bottom of a vertical column of mercury, 1 μm deep, at standard acceleration due to gravity and at 0°C	$1\ \mu mHg = 0.133322\ Pa$
psi	Pound-force per square inch pressure due to weight (at standard acceleration due to gravity) of one American pound to an area of one square inch	$1\ psi\ \approx 6894.76\ Pa$

Standard acceleration due to gravity is $g_n = 9.80665\ m \cdot s^{-2}$.

1.2 Gas laws

For a proper understanding of phenomena in gases, more especially at low pressures, it is essential to consider these phenomena from the point of view of the kinetic theory of gases. This theory rests essentially upon two fundamental assumptions. The first of these postulates is that matter is made up of extremely small particles or molecules, and that the molecules of the same chemical substance are exactly alike as regards size, shape, mass, and so forth. The second postulate is that the molecules of a gas are in constant motion, and this motion is intimately related to the temperature. In fact, the temperature of a gas is a manifestation of the amount or intensity of molecular motion [2].

In the case of monatomic molecules (such as these of the rare gases and vapors of most metals) the effect of increased temperature is evidenced by increased translational (kinetic) energy of the molecules. In the case of diatomic and polyatomic molecules increase in temperature also increases rotational energy of the molecule about one or more axes, as well as, vibrational energy of the constituent atoms with respect to mean positions of equilibrium. However, in the following discussion only the effect on translational energy will he considered.

According to the kinetic theory a gas exerts pressure on the enclosing walls because of the impact of molecules on these walls. Since the gas suffers no loss of energy through exerting pressure on the solid wall of its enclosure, it follows that each molecule is thrown back from the wall with the same speed as that with which it impinges, but in the reverse direction; that is, the impacts are perfectly elastic.

A gas completely fills an available volume and shows a number of macroscopic properties: it has a temperature and exerts a temperature-dependent pressure to the

walls. An equation of state (see [2] for details) connects the state quantities pressure, volume, and temperature. Additionally, a gas is capable of conducting frictional force between surfaces in motion (viscosity), transferring thermal energy between surfaces with unequal temperatures (thermal conductivity), and can influence spreading of molecular particles (diffusion).

These different properties of a gas can be explained easily by considering the microscopic behavior of individual gas particles (atoms, molecules), by means of the kinetic theory of gases. This theory is based on the conception that a gas consists of a very large number of tiny particles that move thermally (kinetics). The moving particles hit the walls of the container and one another. All collisions are assumed elastic, that is, the total energy is conserved. During a collision, however, velocities of the colliding particles change with respect to value and direction, following the mechanical laws of collisions. The kinetic theory of gases derives the macroscopic properties of a gas from the microscopic motion of individual particles.

In its simplest form, the kinetic theory of gases assumes that gas particles are small, hard spheres with a fixed diameter, and which remain practically unaltered during a collision, such as billiard balls. This conception often already yields good understanding of reality and is used in this chapter. When further developing the model, soft spheres can be assumed that deform like rubber balls during a collision and additionally attract one another mutually when they come close.

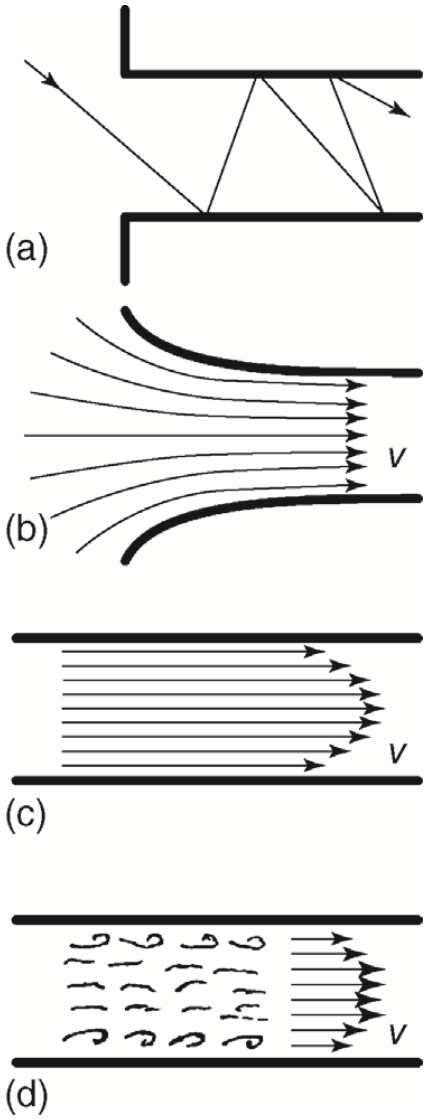


Figure 2 Different types of gas flows. (a) Molecular flow. (b–d) Different types of viscous flows: gas-dynamic (intake flow), laminar, and turbulent.

Gas flow patterns play an important role in vacuum technology. When a vessel is evacuated, the gas that initially filled the vessel flows to the pump through tubes. During operation of the vessel, gas released by components (desorption) or supplied to the process flows from high-pressure to low-pressure regions. Knowledge of flow patterns is vital for designing vacuum systems intelligently and understanding their performance characteristics.

Flow (or flux) is a three-dimensional movement of substance. In a gas, the thermal motion of individual gas particles, as well as macroscopic forces due to local pressure deviations, causes flow. Pressure forces, inertial forces, and frictional forces determine flow behavior. Gravity, however, is usually negligible for gas flow. Usually, the total gas flow through a tube is of interest, but, in certain cases, knowledge of local flow densities in an apparatus is required.

Depending on the prevailing conditions, different types of flows arise. In order to understand flow patterns, it is favorable to consider the different types of flows individually in their pure form.

Depending on pressure and the cross dimensions of a tube, three types of flows can be differentiated:

1. For sufficiently low pressure, the mean free path of gas particles is high, compared with the cross dimensions of the tube. Any mutual particle collision hardly occurs. Each gas particle travels through the tube due to its thermal motion, independent of other particles. However, frequent collisions with the tube walls cause a zigzag route. On average, the paths of many individual particles combine to form the macroscopic flow behavior. This situation is referred to as single-particle motion or molecular flow.
2. Under high pressure, the mean free path of gas particles is much lower than the cross dimensions of the tube. The particles experience frequent mutual

collisions, thereby exchanging momentum and energy continuously. Even a small volume contains many frequently colliding particles. Thus, the gas behaves as a continuum. A flow is the result of local pressure gradients. This situation is referred to as continuum flow or viscous flow.

3. The medium-pressure range is characterized by a transition between molecular and viscous flows. In this transition, collisions of gas particles with the wall occur just about as often as mutual collisions among gas particles. This situation is referred to as transitional flow or Knudsen flow.

Thus, for a particular type of flow to occur, two main criteria can be identified: one criterion is the mean free path of gas particles in relation to the cross dimensions of the tube (for circular cross sections, the diameter). The second criterion is the velocity of flow for given cross dimensions of the tube and internal friction of the gas. Thus, two dimensionless characteristic numbers may be defined to describe these criteria quantitatively.

The situation is different in the case of viscous flow. Here, three types of flows in a tube are differentiated. The length of the tube determines the type of flow (Figure 2, b–d).

1. Initially, the gas has to leave a reservoir (vessel) to reach the entrance of the tube. Subsequently, it streams into the tube (Figure 2, b). Here, the gas accelerates from a quiescent state (velocity of flow equals zero) to a finite velocity of flow. This process requires acceleration energy that is taken from pressure energy (pressure drops) and thermal energy (temperature drops). Thus, as a volume element of gas travels along a path, velocity rises, and simultaneously temperature and pressure drop. For short distances, wall friction is usually negligible. This so-called intake flow is a particular type of gas-dynamic flow.
2. Now, the gas flows through the tube. The velocity of flow at the inlet is approximately constant across the complete cross section. As the gas continues its way through the tube, the gas layers near the walls decelerate, and the velocity of flow drops to zero in the boundary layer at the wall. The thickness of the boundary layer increases along the way. The velocity of flow, the fric-tion behavior of the gas, and the dimensions of the cross section determine the type of flow that develops after a certain intake stretch. For low velocities, all individual volume elements move in the direction of the tube.

Now, the volume elements in the center of the tube move quicker than the volume elements at the boundary of the tube. Thus, a velocity profile develops across the cross section of the tube (Figure 2, c). This type of flow is referred to as laminar flow.

3. If, however, flow velocity is high, frictional forces are high as well because they are determined by flow velocity. A volume element, traveling at higher velocity and some distance from the wall of the tube, is deflected toward the wall by the decelerating action of the slower moving layers near the wall. The deflecting effects increase with friction and thus velocity, whereas the inertia of mass, which tends to preserve the direction of flow, remains unchanged by a change in velocity. Thus, for sufficiently high velocities, deflecting forces dominate and the flow shows turbulences and eddies (Figure 2, d).

1.3 Vacuum levels

The lowest pressure to be obtained, measured and maintained in a vacuum chamber or system determines the main characteristics of the system, the pumps to be used, the gauges and the seals. According to the lowest pressure and the corresponding mean free path vacuum ranges were established.

The low vacuum range includes pressures less than atmospheric and greater than 25 torr. The lower limit of this range was set at that pressure (about one inch of mercury) corresponding to approximately the vapor pressure of water at 25 ^{o}C.

Medium vacuum is considered to be in the range of 25 to 10^{-3} torr. Another classification divides the same range (760 to 10^{-3}) into rough vacuum (760 to 1 torr) and fine vacuum (1 to 10^{-3} torr).

In any case the low vacuum is the range of water vapors and the medium or fine vacuum the range of other vapors (mercury, hydrocarbons, etc.). High vacuum is defined as the condition in a gas-filled space at pressures less than 10^{-3} torr. This range is used to be divided into high, very high and ultra-high vacuum (table 2). The high and very high vacuum range is limited to use materials having corresponding low vapor pressures at room temperature. This is the range of elastomer gasket seals. The ultra-high vacuum requires baking. This practically restricts the list of materials to a few metals, glasses and ceramics, and the gaskets to metallic ones.

Table 1.2. Vacuum ranges

Pressure (torr)	Mean free path	Vacuum range		Pumps	Gauges	Materials	Seals*
760	0.06μ	Rough	Low	Piston Rotary	Diaphragm Liquid Level	Any	
25	2μ	Fine	Medium	Rotary	McLeod Tesla coil Pirani gauge Alphatron	Waxes, glasses, ceramics metals and elastomers Porous and high vapor pressure materials excluded	Any elastomer seals, waxes seals, soldered seals, greased ground seals, liquid seals.
1	50μ						
Pressure (torr)	Mean free path	Vacuum range		Pumps	Gauges	Materials	Seals*
10^{-3}	5 cm	High		Molecular Diffusion	McLeod Penning Ionization	Only glass, metal, ceramics and low vapor pressure elastomers	
10^{-6}	50 m						
10^{-9}	50 km	Very high		Molecular Diffusion Ion Pump	Ionization Bayard-Alpert	Preferably clean bakeable materials (glass, copper, stainless steel, ceramics, Viton)	Elastomer, greaseless ground, glass-glass, glass-metal, guard vacuum, ethoxyline, silver chloride
		Ultra-high		Ion Pump Cryopump	Bayard-Alpert Magnetron	Only bakeable materials and with low permeability for glasses	Welded and brazed glass-metal, glass-ceramic and ceramic metal, metal gasket

2. AIM AND TASKS OF COURSE

The practical course is aimed at providing basic knowledge on vacuum technique essentials, vacuum measurements, pumping speed, as well as skills for application of vacuum components. This course will cover the basics of preparation and assembly of vacuum components, as well as basic measurements and calculations. During the course, the vacuum level will be measured at different stages of pumping (from coarse to ultra-high vacuum) using different measuring sensors (Thermal resistance vacuum gauge, Bayard-Alpert Pirani vacuum gauge, Invert magnetron

vacuum gauge). Based on the curves of change of degree of vacuum determine the pumping speed for each vacuum level and the type of pump (scroll backing pump, turbo-molecular pump, ion pump) used.

The second part of the experimental work is measurement of the vacuum conductance of apertures. In this experiment, the connection of the pump to the vacuum chamber is made through apertures of different diameters. apertures with 100% of nominal (corresponding to the inlet of the pump), 50% of nominal, and 10% of nominal are used. For each aperture size is made by pumping the vacuum chamber to obtain a maximum level of vacuum in the chamber, which corresponds to the capabilities of the pump. Vacuum level measurements are made for each aperture throughout the pumping process. Based on the curves of change of degree of vacuum determine the pumping speed for each aperture. According to the results of calculations, it is necessary to obtain an analytical dependence of the pumping speed ($V_{pumping} = f(d)$) on the aperture diameter.

3. EQUIPMENT AND MATERIALS

As materials and equipment in practical course will be used respective components and equipment of Vacuum Technology laboratory of CANDLE Synchrotron research institute. Among its are vacuum pumps, vacuum gauges, vacuum components, controllers and adapters.

3.1 Vacuum pumps

The vacuums pumps used throughout the course are: dry scroll pump, turbomolecular pump, ion pump. Their technical characteristics and working principles are listed below.

Dry scroll pump (Agilent IDP-3)

High performance in a compact package – the Agilent IDP Series Dry Scroll Pumps provide affordable oil-free vacuum with easy system on and they are suitable for a wide variety of applications. The IDP Series employs an innovative hermetic design in which the motor and bearings are outside the vacuum space allowing full isolation of all pumped gases.

IDP Pumps create vacuum using a simple dual scroll mechanism (Figure 3.1) in which one of the nested scrolls orbits about the other, creating moving zones of captured gas. Gas enters the scroll set at the perimeter and is displaced and

compressed toward the center hub where it is exhausted. The uncomplicated dual scroll design offers many benefits including lower noise and vibration levels, simple and infrequent maintenance requirements, plus the elimination of catastrophic failure modes.

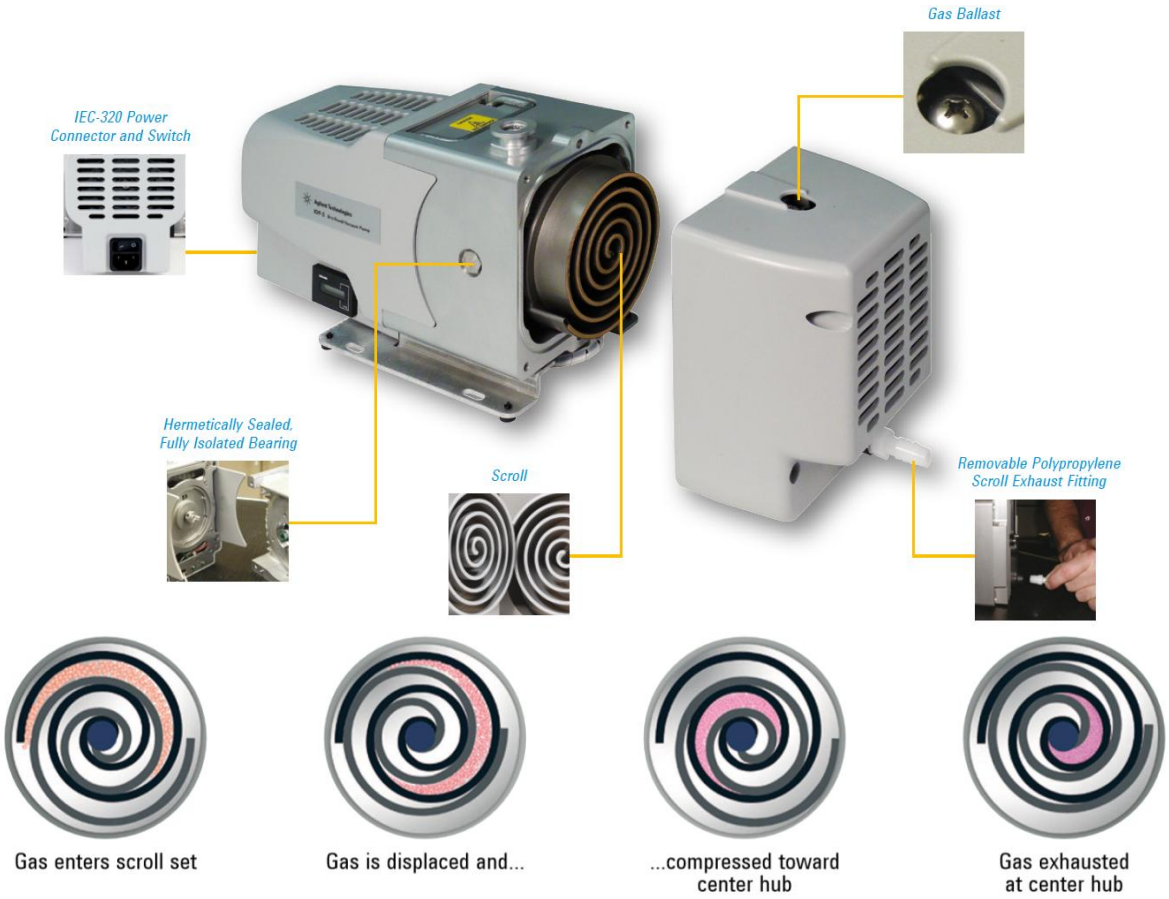


Figure 3.1 Principal of scroll technology

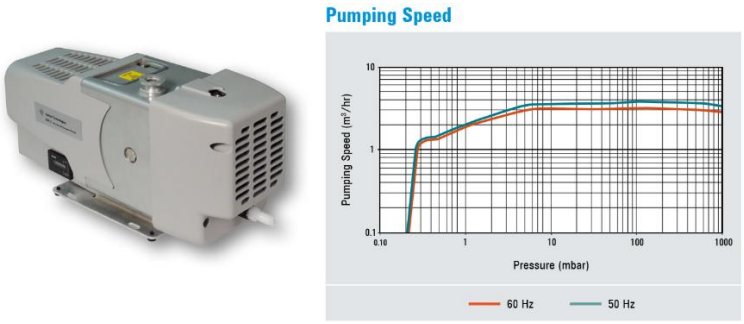
Advantages of scroll pump

- Oil-free technology of IDP Pumps eliminate the possibility of oil contamination in the vacuum system or of oil spills or leaks into the work environment.
- Maintenance of the IDP Pumps require only a simple, infrequent tip seal change as compared to oil checks, changes, and disposal.
- The IDP Pumps do not depend on the presence of sufficient oil to prevent seizing.
- IDP Pumps are compact at 358 x 181 x 140 mm, yet provide base pressure of less than 250 mTorr, almost 4 times lower than equivalently sized membrane/diaphragm pump.

- In turbo pump applications, the pumps' lower base pressure reduces power consumption and bearing temperature and increases the reliability of the system.
- IDP Pumps avoid catastrophic failure mechanisms. A diaphragm pumped system may suffer sudden, rapid loss of pressure when a membrane ruptures.
- IDP Pumps produce lower noise and vibration levels than diaphragm pumps, creating a quiet, pleasant work environment, and much lower contribution to system noise and vibration.

Technical Specifications

Peak pumping speed	60 Hz: 50 Hz:	60 l/m, 3.6 m3/hr 50 l/m, 3.0 m3/hr
Ultimate pressure		2.5 x 10-1 torr (3.3 x 10-1 mbar, 33 Pa)
Maximum inlet pressure		1 atmosphere (1.0 bar, 101 kPa)
Maximum outlet pressure		1.4 atmospheres (1.4 bar, 142 kPa)
Inlet connection		NW16 KF flange
Exhaust connection		Female 1/4 in. NPT (10 mm bellow barb provided)
Gas ballast connection		Female 1/8 in. NPT
Ambient operating temperature		5 to 40°C (41 to 108°F)
Motor rating		0.16 horsepower (0.12 kW)
Supply power		1Ø - 100 VAC, 50-60 Hz : 115 VAC, 60 Hz : 220-240 VAC, 50-60 Hz
Motor thermal protection		Automatic
Rotation speed	60 Hz: 50 Hz:	3200 RPM 2600 RPM
Cooling		Air-cooled
Leak rate		<1 x 10−6 std-cc/sec helium
Noise level (per ISO 11201)		55 dB(A)
Vibration level at inlet (per ISO 10816-1)		1.5 mm/second
Compliance		Conforms with CE, CSA, CSA/CUS, Semi S2-703, and RoHS



Turbo molecular pump. (**Agilent TPS-compact**)

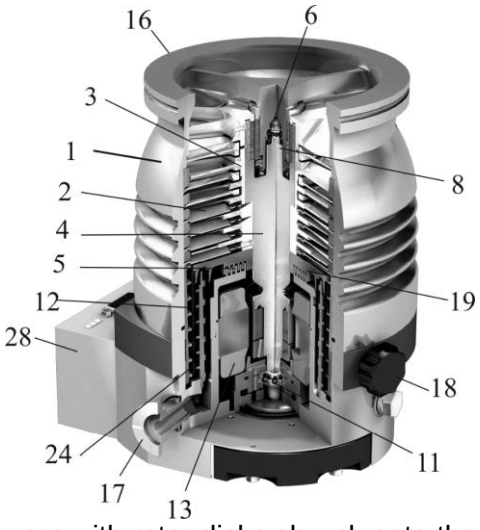


Figure 3.2 Turbomolecular pump with rotor disks shrunk onto the shaft. Bearings at both ends (UHV compatible permanent-magnet bearing on the inlet side and oil-lubricated bearing on the fore-vacuum side) provide favorable dynamic behavior of the rotor. 1: housing; 2: stator; 3: rotor; 4: rotor shaft; 5: labyrinth seal; 6: safety bearing; 8: radial magnetic bearing; 11: lower ball bearing; 12: Holweck stators; 13: motor; 16: suction flange; 17: fore-vacuum port; 18: vent valve; 19: Holweck hub; 24: Holweck sleeves; 28: electronic drive unit.

The gas enters the pump through the suction flange (16), is compressed by several turbomolecular stages, and is fed to the backing pump via the fore-vacuum port (17). Genuine turbomolecular pumps produce fore-vacuum pressures of approximately 50 Pa under high gas loads.

In compound pumps, the gas compressed by the turbomolecular stages is transported to the Holweck stages with lower pumping speed where it is compressed to a fore-vacuum pressure of 100–1500 Pa. After pumping is com-pleted, the pump can be vented via the vent valve (18). Nowadays the two rotor designs are common. The first design is shown in Figure 5.13 and consists of a rotor with disks shrunk onto the shaft. Hence, these are frequently also referred to as “disk rotors”. The shaft is mounted at its two ends: A permanent magnet bearing suited for ultrahigh vacuum (UHV) is found on the suction side and a ball bearing is provided on the fore-vacuum side. The second design is generally referred to as a “bell-shaped rotor”. With this,

the blades are milled from the external circumference of a cylindrical base metal. In the center of the base metal, a hollow cavity is created that contains a central shaft and houses the motor and bearing.

In both designs, a part of the fore-vacuum-side turbomolecular pump disks can be replaced by one or more concentric Holweck stages (12) in order to produce higher exhaust pressures, whereby diaphragm pumps can be used as backing pumps.

Disk rotors offer the advantage of being connected in parallel in order to obtain high gas throughput and fore-vacuum pressures of approximately 100 Pa. For this, openings are arranged in the Holweck hub (14) between the two Holweck cylinders, and the thread grooves in the stator are designed accord-ingly. A part of the Holweck hub can be used to dynamically seal the bearing range and motor range from the pumping space by means of a labyrinth seal (5).

Rotor disks and shafts (Figure 3.2) are made from high-strength aluminum alloys. They comply with special criteria in terms of purity and homogeneity of materials.

Carbon fiber sleeves are used for Holweck rotors. Their low expansion due to thermal load and centrifugal forces guarantees nearly constant inside and outside gap widths in Holweck stages under any permitted operating condition. These rotors reach circumferential speeds of up to 500 m s^{-1} without exceeding tolerable material stresses. In bell-shaped rotors, the blades are milled from solid bulk material. The large inside diameter with space for motor and bearings leads to high tangential stresses in the bell. Therefore, the rotational speed is limited. Optimum machining and shaping permits circumferential speeds of 400 m s^{-1}.

Technical Specifications

Pumping speed	N_2: 180 L/s (with inlet screen)*
Base pressure**	$1x10^{-8}$ mbar [ISO flanges]
Pumpdown time (15 L volume)	80 sec (16 mbar); 110 sec (3 mbar); 155 sec (6×10^{-5}); 200 sec (1×10^{-5})
Turbo pump rotational speed	60,000 RPM
Start-up time	150 sec.
Operating ambient temperature	5 °C to 35 °C
Input voltage and frequency	115 Vac 60 Hz or 220-240 Vac 50/60 Hz or 100 Vac 50/60 Hz
Maximum input power	310 VA
Bakeout temperature	80 °C at inlet [ISO flanges]
Communications	RS-232 - Analogical I/O
Weight kg (lbs.)	20.1 kg

Ion Pump (Gamma vacuum 75S)

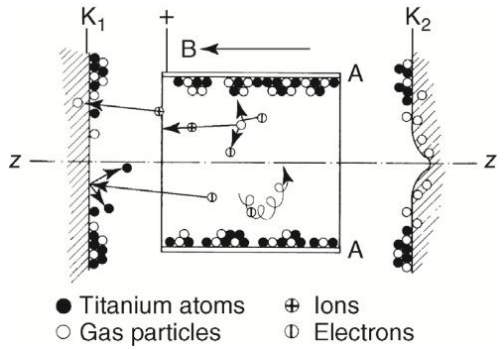


Figure 3.3 Diagram of the pumping action in a Penning cell (diode). K_1, K_2 cathode plates made of getter material (titanium), A anode cylinder with the z-axis, B magnetic field. The getter film with buried gas particles is visible on A and toward the ends of K1 and K2. Implanted gas particles in the center of K_2 (and K_1 as well, not drawn).

Sorption in ion getter pumps relies on (cathodic) sputtering of a getter material inside a gas discharge, and additionally, on bombardment (implantation) of ions from the gas discharge. Utilization of these effects for development and design of vacuum pumps was encouraged by investigations aimed at preventing such processes (gas depletion and erroneous pressure measurement) in ionization vacuum gauges.

Gas discharge in an ion getter pump is of the Penning type. Figure 3.3 illustrates an electrode arrangement, two parallel cathode plates K_1 and K_2, and an anode cylinder A with the z-axis arranged perpendicularly to the cathode planes. A magnetic field of flux density $B \approx 0.1 - 0.2\ T$ is applied in the z-direction.

Operating voltage U between anode and cathodes is approximately 6 kV

In detail, the pumping effects are as follows: Ion implantation. The applied electrical potential (6 kV) accelerates the ions produced in the discharge to several kV, depending on their point of origin. Acceleration occurs nearly along a straight path toward the cathode because the ions, due to their large mass compared to electrons, are hardly influenced by the magnetic field. The ions penetrate the crystal structure of the cathode by approximately 10 atomic layers (ion implantation). This corresponds to a gas depletion that affects any species of gas ion including atomic and molec-ular ions of noble gases and other gas species. However, very large molecular ions, such as hydrocarbons, do not penetrate the lattice structure. Of these ions, only the fraction disintegrating during surface impingement is pumped. The penetration depth of such fragments, however, is lower because their kinetic energy is low.

a) Cathode sputtering. The ions hitting the cathode are implanted in part and sputter individual or larger numbers of lattice atoms. These atoms are released and deposit on surrounding surfaces where they form the getter film when the cathode is made from getter material (e.g., titanium). The mass of

the sputtered material is roughly proportional to the pressure in the pump so that the pumping speed adjusts to this pressure. Pumping action, as any getter effect, is strongly influenced by the gas species. Depending on the field configuration caused by the electrons and the volume charge in the discharge, the ions accelerated toward the cathode can become focused to the z-coordinate. This produces a sputter crater in the center of the cathode (Figure 3.3, cathode K_2). In any case, getter action takes place mainly at the edges of the cathodes and at the anode; implantation occurs mostly in the center of the crater because the getter film here is resputtered.

b) Neutral particle implantation. When ions, particularly noble-gas ions, impinge the surface, they can be reflected if they become neutralized in the metal. Indeed, this occurs often in an ion getter pump. Neutralized gas parti-cles then become implanted at other spots because they still carry high kinetic energy.

Technical specification

Pumping speed (max.)	75 l/s
Weight:	22 (48) kg
Shipping Weight:	25 (55) kg
Ultimate Pressure:	less than 10^{-11} mbar
Starting Pressure:	1 x 10^{-3} mbar
Lifetime:	50,000 hours @ e^{-6} mbar
Operating Bake Temp:	250 Deg C
Maximum Bake Temp:	450 without magnets Deg C
Dimensions:	277 x 242 x 130 mm, l×w×d

3.2 Vacuum gauges

Vacuum technology measures pressure *p* either directly according to its defining equation, by measuring the force $F = pA$ exerted to an area ***A*** or indirectly by

measuring a physical quantity proportional to the pressure, for example, particle number density n, particle impingement rate nc, and thermal conductivity, among others.

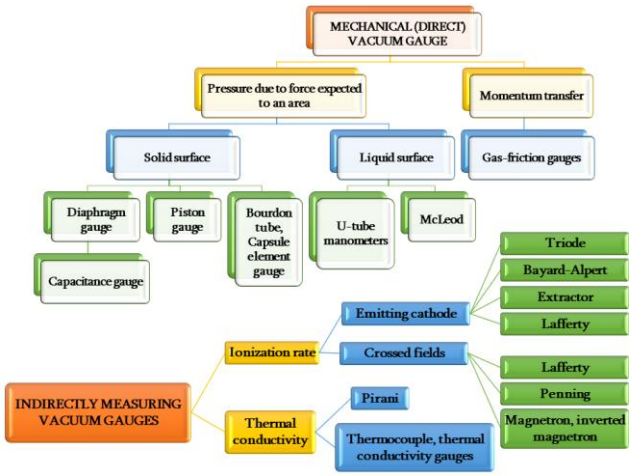


Figure 3.4 Classification of common vacuum gauges according to their physical principles. Crossed fields mean crossed electric and magnetic fields.

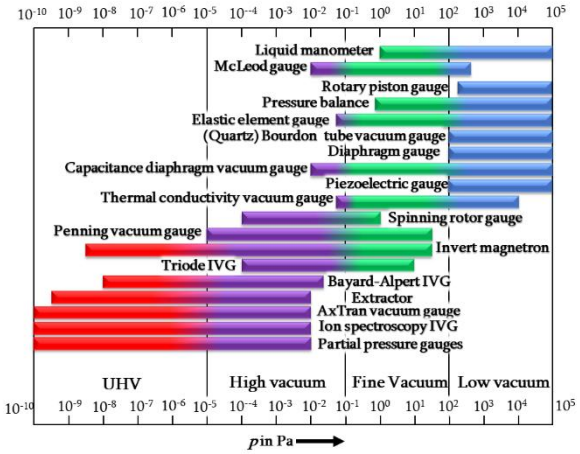


Figure 3.5 Overview of the gauges common to individual pressure ranges.

Measuring pressure directly by assessing the effect of a force is limited to pres-sures greater than approximately 1 mPa. At this pressure, the force exerted to 1cm^2 amounts to only about 10^{-7} N. Measuring such low forces requires an electrically amplified signal.

The pressure range measured in vacuum technology spans across 15 orders of magnitude. No single gauge type covers the whole range. Figure 3.4 classifies common vacuum gauges according to their physical measuring principles. Figure 3.5 provides an overview of the gauges common to individual pressure ranges. See support material for details on working principle of the various sensors.

Agilent Varian FRG-720

The FRG-720 combine Agilent's Pirani and Bayard-Alpert sensor into a single compact design that provides measuring capability from 5 x 10-10 mbar to atmosphere (3.8 x 10-10 Torr to atmosphere). Combining these two technologies into a single unit reduces complexity and integration challenges while protecting the Bayard-Alpert sensor from premature burnout.

IMG-100 Inverted Magnetron Gauge

The Agilent IMG-100 Inverted-Magnetron Gauge Tubes produce accurate, repeatable pressure readings and may be used in dirty or corrosive applications.

Their measurement performance is similar to that of Bayard-Alpert gauges, but like cold-cathode gauges they are easy to clean and repair, without the limitations that most cold-cathode gauges have. These features make them perfect for use in vacuum furnaces and other industrial systems, where ruggedness is of prime importance. The Agilent IMG-100 can measure pressures in a range comparable to that of most glass hot-filament gauges (from $1x10^{-3}$ mbar up to $5x10^{-9}$ mbar).

The ionization gauge transducer

The hot cathode ionization gauge is useful in measuring the total pressure of all the gases present in the system. The biggest advantage of this device is its very small response time. This is because of the devices small inertia. The device is used for pressure measurement between the ranges of 10^{-8} to 10^{-3} Torr with an output current varying between 10^{-9} to 10^{-4} A. But this range depends on the gas, other things remaining constant.

Agilent Varian FRG-720

IMG-100 Inverted Magnetron Gauge

The ionization gauge transducer

3.3 Vacuum components

Fittings.

6-Way Cross

CF crosses and cubes is for UHV systems from 304L stainless steel tubing and knife-edge (ConFlat) flanges. The CF flange is the most widely used for high vacuum and UHV applications. Many gauges, instruments, accessories and feedthroughs are available on this flange system.

CF Crosses & Cubes Feature:

- One rotatable flange on each axis (crosses only)
- Through-hole bolt hole flanges (crosses only)
- Tapped sides (cubes only)

Flanges.

In practical course we will use standard Conflat flanges (CF 35) and ISO KF as well.

Gaskets

Copper. Gaskets for sealing UHV flanges are often made from high purity oxygen-free copper. In a standard, so called conflat flange, the sealing is achieved by the flange knife edges cutting into the soft copper. The picture below shows a new (left) and used (right) [7].

Figure 3.6. Copper gaskets.

Given the high price of copper gaskets, one may want to re-use them. In principle this is possible if the knife edges have not cut in too far into the copper, i.e. if you can still drive them further in the second time you use the gasket. Re-using gaskets is certainly not the recommended procedure unless you are experienced with this because the risk of leaks is quite high.

Sometimes it can be difficult to get used gaskets out of the flange because they are squeezed in so tightly. When trying to remove them anyway, it is advisable to use a

special gasket removal tool rather than a screwdriver or something similar because of the risk of damaging the knife edge of the flange.

For some very big flanges, the sealing is often just achieved by placing a copper wire loop between two polished, flat areas of the mating flanges. It can be tricky to place the wire such that it does not overlap with the screw holes and that it stays in place when the flanges are brought together. One can hold the copper loop in place by very thin gold wire which is then fixed to the outside of the flange by scotch tape. When the two sides come together, the soft gold is pressed in the copper and does not affect the sealing properties.

Viton gaskets can be used instead of copper gaskets for temporary sealing. Their advantage is that they can be re-used. Their disadvantage is not necessarily that they are leaky (even though He gas diffuses through viton) but that they cannot be baked. Indeed, if you put viton gaskets in your system and keep them there for some time, it can easily happen that you bake them because you have forgotten. A good way to remember is therefore to close the flanges with fewer screws. Actually, you will not need as many screws as with the copper gaskets anyway because the viton gaskets will be compressed already when just pumping on the system with the roughing pump.

Valves and gates.

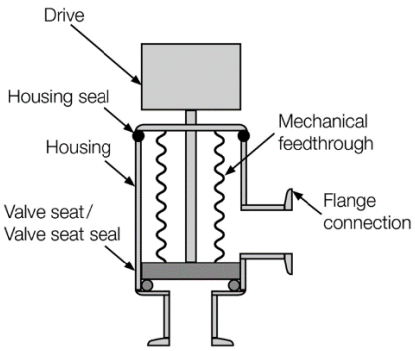


Figure 3.7 Schematic presentation of a right-angle valve.

Valves are feedthroughs for gases that, according to demand, can admit, regulate, throttle, or interrupt the gas flow between two volumes. They are placed between two or more systems with different pressures. Conductance, leak rate, number of the guaranteed load cycles, and media-exposed materials characterize the valves in vacuum technology. A valve consists of a valve case, valve seal, mechanical movement feedthrough, and an external drive (mechanically, electrically, or pneumatically). The basic construction of a valve is shown in Figure 3.7

Vacuum gate valves are devices that regulate the flow of gases, fluids or materials through a structure or aperture by opening, closing or obstructing a port or passageway. Gate valve assemblies consist of three key components: an actuator, a carriage/gate and a valve body. The actuator provides the power to position or

transport the valve's carriage/gate. The actuator is attached to the valve's body via a rectangular bonnet flange. The gate closes or opens one of the valve's body ports. The valve body is a vacuum tight chamber that is screwed, flanged or welded into a larger vacuum vessel or system.

Electronic equipment

As an electronic equipment will used the respective equipment (controllers, power supplies, connectors etc.) for all vacuum devices.

4. GOALS OF THE PRACTICAL COURSE

The practical course is aimed at providing basic knowledge on vacuum technique essentials, as well as skills for application of vacuum components.

As a result of the course participants should have acquired the following knowledge and practical skills:

Knowledge

- -Vacuum characteristics and its definition;
- -the main units for vacuum measurement;
- -materials used in vacuum technique;
- -sealing techniques in vacuum systems;
- -technology of preparing vacuum components for installation;
- -the basic measurement devices;
- -sources of gas load in vacuum chambers.

Skills

- -Assembly of vacuum systems;
- -preparation and cleaning of components;
- -camera cleaning the via bake out process;
- -installation and connection of measuring equipment;
- -installation and connection of pumping equipment.

5. THE PROCEDURE OF THE COURSE

Practice course will be held in the Vacuum technology laboratory of CANDLE synchrotron research institute. The practice course has 2 main tasks:

1. Determination the pumping speed in the end volume for different pumps and gauges.
2. Measurement of the vacuum conductance of aperture.

5.1 TASK 1

The first task of the practical course consists of the following stages:

- Preparation of vacuum components

for the Assembly of the vacuum chamber, including a vacuum chamber, measuring sensors (full pressure sensor, inverted magnetron sensor, ionization sensor), gate elements (valves and valves), vacuum pumps, adapters for vacuum pumps, sealing elements, controllers and power supplies.

Preparation of vacuum components is a special cleaning procedure to remove dirt from the internal surfaces formed as a result of being in the open state, storage, etc. All the main elements of the vacuum chamber and adapters are made of 304 stainless steel. Thus, the cleaning procedure of the components should be carried out according to the technology given below.

The procedure described below for cleaning stainless steel is a very high specification process for the very demanding requirements of an electron storage ring where cleanliness is of paramount importance. For less demanding applications, the procedure could stop at the appropriate point in the procedure where requirements had been met.

1. Remove all debris such as swarf by physical means such as blowing out with a high pressure air line, observing normal safety precautions. Remove gross contamination by washing out, swabbing or rinsing with any general purpose solvent. Scrubbing, wire brushing, grinding, filing or other mechanically abrasive methods may not be used.

2. Wash in a high pressure hot water (approx. 80^{o}C) jet, using a simple mild alkaline detergent. Switch off detergent and continue to rinse thoroughly with water until all visible traces of detergent have been eliminated.
3. If necessary, remove any scaling or deposited surface films by stripping with alumina or glass beads in a water jet in a slurry blaster.
4. Wash down with a high pressure hot (approx. 80^{o}C) water jet, with no detergent, ensuring that any residual beads are washed away. Pay particular attention to any trapped areas or crevices.
5. Dry using an air blower with clean dry air, hot if possible.
6. Immerse completely in an ultrasonically agitated bath of clean hot stabilised trichloroethylene for at least 15 minutes, or until the item has reached the temperature of the bath, whichever is longer.
7. Vapour wash in trichloroethylene vapour for at least 15 minutes, or until the item has reached the temperature of the hot vapour, whichever is longer.
8. Ensure that all solvent residues have been drained off, paying particular attention to any trapped areas, blind holes etc.
9. Wash down with a high pressure hot (approx. 80^{o}C) water jet, using clean demineralised water. Detergent must not be used at this stage.
10. Immerse in a bath of hot (60^{o}C) alkaline degreaser (P3 Almeco P36) with ultrasonic agitation for 5 min. After removal from the bath carry out the next step of the procedure immediately.
11. Wash down with a high pressure hot (approx. 80^{o}C) water jet, using clean demineralized water. Detergent must not be used at this stage. Ensure that any particulate deposits from the alkaline bath are washed away.
12. Dry using an air blower with clean dry air, hot if possible.
13. Allow to cool in a dry, dust free area. Inspect the item for signs of contamination, faulty cleaning or damage.
14. Vacuum bake to 250^{o}C for 24 hours using an oil free pumping system.
15. Reduce the temperature to 200^{o}C and carry out an internal glow discharge using a helium 10% oxygen gas mix.
16. Raise the temperature to 250^{o}C for a further 24 hours then cool to room temperature.

For other components, the cleaning procedure is carried out according to the requirements of the technical documentation from the manufacturer. It should be noted for vacuum pumps cleaning procedure is not carried out due to the peculiarities of their operation and storage. In the practical course, the complete cleaning procedure of the vacuum components will be carried out in advance by the laboratory staff and pre-Assembly of the components to the vacuum chamber will be carried out. Participation in the procedure of cleaning components before installation is provided in the second task of the practical course.

After pre-installation of vacuum components, measuring equipment and vacuum pumps, the vacuum system is sealed and can be left in the open air without additional insulation procedures.

- Pre-installation of the vacuum system.

Installation of the vacuum system is carried out according to the scheme shown in Figure 5.1.

Installation of the vacuum system is carried out in the following sequence:

- Mounting the blank flange to the vacuum chamber.
- Installation of measuring equipment to the vacuum chamber.
- Mounting the shutter 8 to the vacuum chamber
- Mounting the gate 9 to the vacuum chamber.
- Closing gates 8 and 9.
- Installation of flexible connection 10 to the chamber and turbomolecular pump.
- Installation of the ion pump.

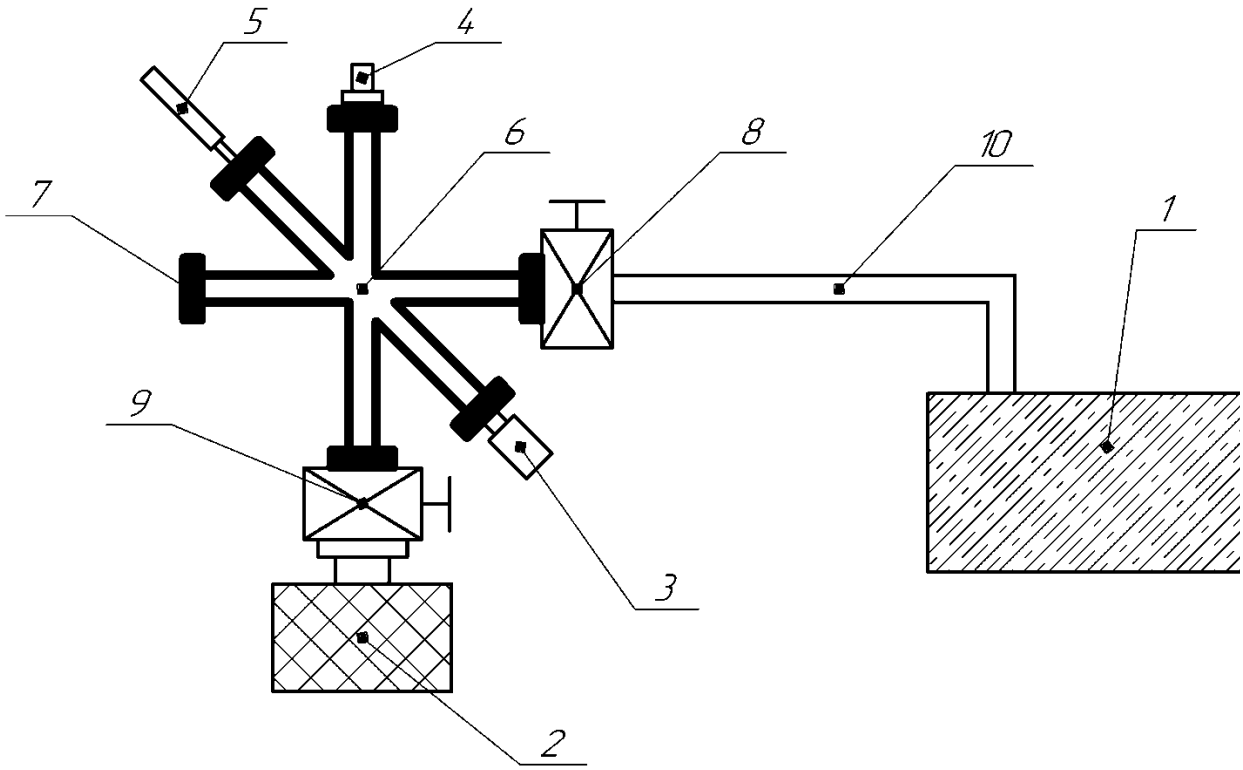


Figure 5.1 – Principal scheme of vacuum system. 1 – TPS-compact Turbo vacuum pump, 2 – Ion Pump, 3 – Pirani, Bayard-Alpert gauge, 4 – IMG 100 gauge, 5 - Ionization gauge transducer, 6 – vacuum chamber, 7 – Blank flange CF35, 8 – Turbo pump valve, 9 – Ion pump gate valve, 10 – Flexible connecting bellow.

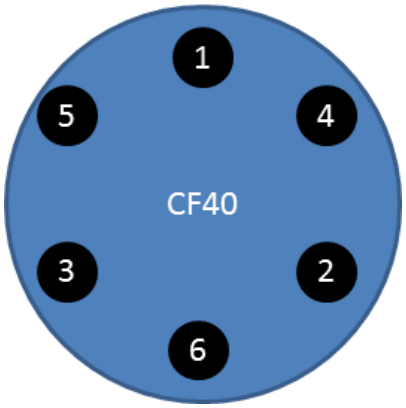


Figure 5.2 CF-40 flange nut tightening sequence

Installation of the ion pump is carried out in the last place to prevent long-term contact with open air. Most of the elements of the vacuum chamber is equipped with vacuum flanges CF 35, which is designed for use as a copper gasket seal (Fig. 3.6). Technology to tighten the flanges to obtain a uniform compression and a minimum clearance between the flanges is presented below [8].

The implied but unvoiced condition is to ensure that the Cu gasket is evenly clamped and creating a leak-free seal. In regard to the order to tighten the nuts the general rule is

“Do one miss one, until you land back where you started and when you do, do not do that one but instead the next one, then do one miss one in the opposite direction and try to ensure even loading by only increasing the tightness by ¼ a turn on each nut” Needless to say this is expressed more simply in a diagram, and pay attention to figure 5.2. Once you reach nut 6, restart again from nut 1 and continue until the copper of the gasket is just visible between the flanges (~1.5 mm) or if using a torque wrench set it to 20 Nm.

Once the vacuum system is installed, all flange connections are insulated with Teflon tape to prevent contamination from entering the gaps between the flanges through the leak check holes. Otherwise, accumulated contamination in the gaps between the flanges may enter the vacuum system during scheduled operations or equipment replacement.

- Bakeout

In order to obtain UHV, a system needs to be “baked”, i.e. heated to high temperatures (100 - 300 degrees °C or so). The reason is that rest gas (mostly water) is adsorbed to the chamber walls and the vapour pressure from the water is so high that the system does not go into the UHV range. This also means that the water slowly desorbs and is thus pumped away but this takes a very, very long time at room temperature [7].

The bakeout is performed in order to accelerate this process. Baking the system can take a long time because everything inside has to reach the high temperature at which the water (or other contamination) is desorbed. Especially for complicated chambers with a many thermally well-insulated components inside, getting everything to high temperatures (and down again) is necessarily slow.


Figure 5.3 View of the Bakeout setup.

There are different possibilities for heating the chamber, some are shown below. Electrical heating tapes can be used which are wrapped around the different parts of the chamber (shown in the picture below). Then everything is covered with aluminum foil for insulation and heat distribution. An easier solution is to put the whole chamber in an insulated box with some heaters inside. The drawback of this is the lack of flexibility. If you decide to attach something later to your chamber, the boxes might be too small. A good possibility is to use heating tents around the chamber, again with a heater (and sometimes a fan) in the tent.

Even if you use boxes or a tent, it is necessary to cover viewports and electrical feedthroughs with aluminum foil before bakeout to avoid thermal stress across these.

- The procedure of work

The procedure is presented in table 5.1.

Action	Description
1. Connection of power cables to vacuum pumps Connect the high voltage cable to the ion pump. Use the supplied cable or a cable with the appropriate mating connector for your feedthrough. Connect the high voltage cable to an Ion pump controller with the correct polarity. Connect the SAFECONN SMB connector, if included. Enable high voltage on the ion pump controller. The Ion pump should start immediately and follow the time, pressure, and current specifications recorded on the included certificate of conformance.	 +   + 
2. Connecting cables to vacuum sensors.	 ,  ,  + 
3. Connecting cables to control devices. As a controller will be used Agilent XGS 600 controller (top view) and VIT19I2T (bottom view).	   
4. Connecting cables for data collection with the monitoring instruments. For data collection we will use interfaces RS 485 an RS 232.	 
5. Check the valves: Valve 9 must be opened; Valve 8 must be open (see scheme, Figure 5.1).	
6. Switch on the FRG720 gauge Gauge must show the atmospheric pressure of approximately 760 Torr.	 

7. Switch on the turbomolecular TPS compact station. Start data registration from the FRG720 gauge. On first stage starts work the fore pump IDP 3. When the pressure on FRG 720 rich the level of $8x10^{-3}$ Torr switch on another two gauges – IMG 100 and ionization gauge transducer. Start registration data from all gauges. According to the technical parameters of backing pump to identify the time of starting the turbomolecular pump.	
8. Switch on the Ion pump. Starting time of Ion pump depends on the residual pressure in vacuum system. The highest pressure when pump can be started is $7x10^{-4}$ Torr. But, for increasing life time of pump and relief starting, the pressure in vacuum system better be as lowest as possible for respective condition before starting of pump. For existing vacuum system, starting of Ion pump can be possible after reaching of pressure in $5x10^{-5}$ Torr. Switch on the Ion Pump and keep turbomolecular pump switch on before High Voltage in Ion pump controller reach 6000 V. After that close the valve 8 and switch off the turbomolecular pump. Switching on of Ion pump procedure must be fix in the data collection. This will be transitional period.	2. Switch on the High voltage (press and hold 3 s)  1. Switch on the Power 
9. Pump down the system up to the 10^{-8} Torr.	
10. Close the gate valve 9, Switch off the Ion pump and collect data during pressure increasing up to 10^{-5} Torr. On the pressure curves it will be system outgassing process. In the data analysis process to give asses to gas load rate in the chamber.	
11 Switch off all gauges and finish data collection	

Procedure of data processing is listed in Section 6.

5.2 TASK 2

The main purpose of the second task of the practical course is to determine the conductance of the vacuum pipeline depending on the aperture relative to the initial value for the corresponding type of flange connection. In the course of the work, three similar vacuum pipeline structures with different aperture ratios will be used. The standard value of the channel for the CF35 flange is accepted as 100% in the experiment. This channel is a tube Ø38,1 mm and a wall thickness of 1,65 mm. and inner diameter $38{,}1 - 2 \cdot 1{,}65 = 34{,}8$ mm. In the course of the experiment it is supposed to use apertures of 50% and 10% of the initial to determine the effect of the vacuum channel reduction on its capacity.

Define the values of the pipe diameters for the specified space of the aperture. It should be noted that the aperture values will be considered relative to the inner diameter of the initial channel.

Thus, for 50% of the aperture, the diameter value is determined by the cross-sectional area:

$$F_{50\%} = 0.5 \cdot F_{100\%}$$

$$F_{100\%} = \frac{\pi D_{100\%}^2}{4} = \frac{3.14 \cdot 34.8^2}{4} = 950.67\ mm^2$$

$$F_{50\%} = 0.5 \cdot 950.67 = 475.335\ mm^2$$

The diameter value is determined on the basis of the conversion of the area value.

$$D_{50\%} = \sqrt{\frac{4F_{50\%}}{\pi}} = \sqrt{\frac{4 \cdot 475.335}{3.14}} = 24.6\ mm$$

Based on the standard sizes of pipes according to ASTM A312 for Stainless steel gauge pipes, the nearest value corresponds to the pipe size Ø25,4 and wall thickness 1,2 mm. The inner diameter of the pipe will be $25{,}4 - 2 \cdot 1{,}2 = 23$ mm, what makes 43,7%.

For 10% of the aperture value of the pipe size is determined by a similar method:

$$F_{10\%} = 0.1 \cdot F_{100\%} = 0.1 \cdot 950.67 = 95{,}067\ mm^2$$

$$D_{10\%} = \sqrt{\frac{4F_{10\%}}{\pi}} = \sqrt{\frac{4 \cdot 95{,}067}{3.14}} = 11\ mm$$

Similarly, the nearest standard pipe size for ASMT A312 correspond to the pipe Ø12,7 mm with a wall thickness of 1.0 mm. the internal diameter of the pipe will be $12{,}7 - 2 \cdot 1{,}0 = 10{,}7$ mm, what makes 9,45%.

The pipe length for all diameters is 200 mm and the relative dimensions and parameters of the vacuum elements to be used in the experiment are shown in Fig. 5.4.

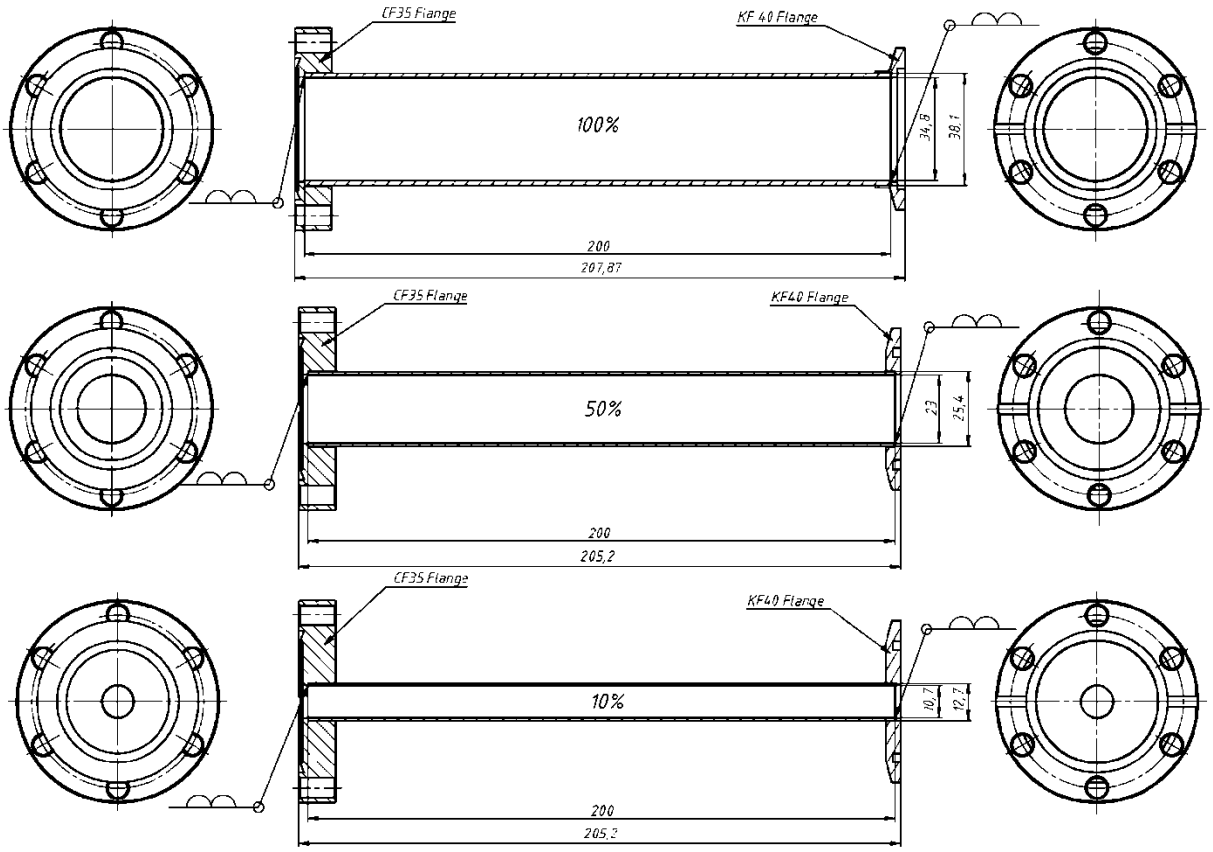


Figure 5.4 Vacuum components for experiment

- Preparation of elements.

All elements of the experiment on the capacity of the components of vacuum systems will be made at the Institute of synchrotron research CANDLE. After manufacturing, the elements will be subjected to cleaning procedures according to the procedure described above. Also, all elements will be pre-tested for vacuum density Packed and prepared for the experiment.

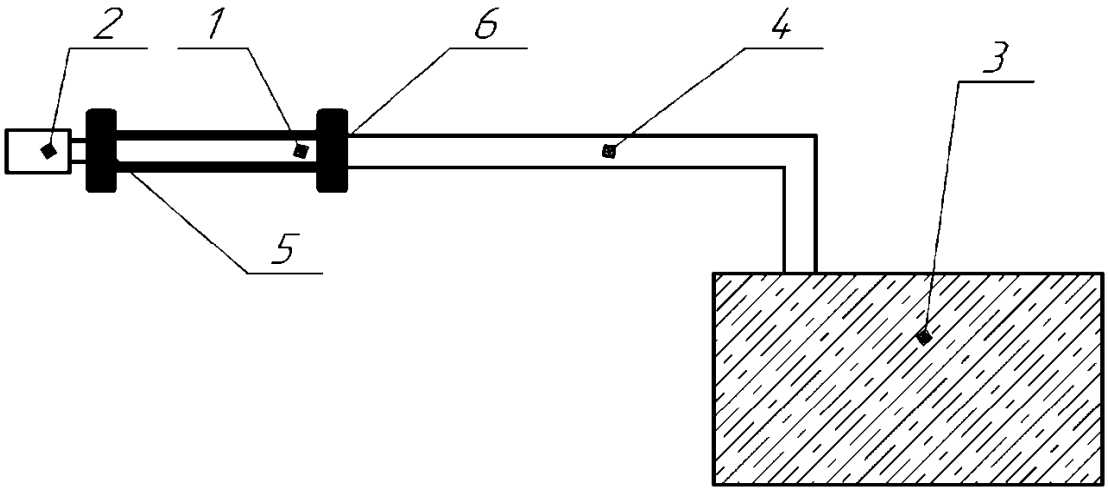


Figure 5.5 Principal scheme of conductivity test stand. 1 – test aperture, 2 – Pirani, Bayard-Alpert gauge, turbomolecular pump, 4 – flexible vacuum bellow, 5 – CF flanges connection, 6 – KF flanges connection.

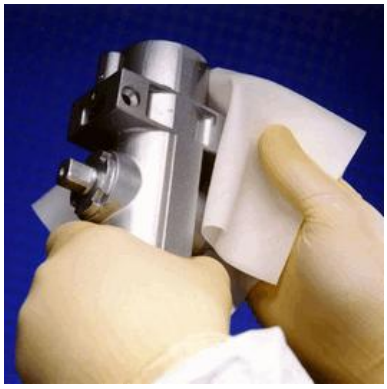
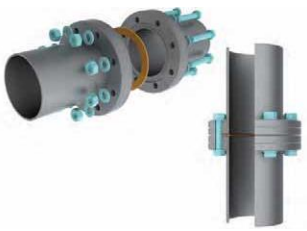
Each of the elements (Fig. 5.4) before installation must be subjected to final cleaning using alcohol and clean wipes. Wiping the elements before installation will allow you to partially familiarize yourself with the requirements and procedure for cleaning vacuum components.

- Installation of the vacuum system.

For each of the vacuum ducts, the vacuum system will be mounted separately by replacing element (1) in the common vacuum duct. The General scheme of the vacuum system for the experiment is shown in Fig. 5.5

- Procedure of work

The procedure is given in table 5.2

1.Final cleaning of vacuum components. Before cleaning the vacuum components (mounted pipe, rubber gasket, copper gasket, vacuum parts of the connecting flanges), you must wear clean gloves. Contact with non-hermetic vacuum elements should be carried out only in clean gloves corresponding to the class of clean rooms (not lower than ISO 7 by ISO-14644-1). Cleaning is carried out using pure alcohol and clean room wipes (not lower than ISO 7 by ISO-14644-1).	
2.Installation of vacuum components Mounting the vacuum sensor (2) Fig. 5.5 for test pipe (1) using copper Gazette for CF 35 flange. Mounting the test aperture to the KF connection flange (6) of the flexible bellow (4).	 (CF flanges)

Once the system is sealed, the protective gloves can be removed.	 (KF flanges)
3.Connection of power cables to vacuum pumps	 + 
Connecting cables to vacuum sensors.	
4.Connecting cables to control devices. As a controller will be used Agilent XGS 600 controller	 
5.Connecting cables for data collection with the monitoring instruments. For data collection we will use interfaces RS 485 an RS 232.	
6.Switch on the FRG720 gauge Gauge must show the atmospheric pressure of approximately 760 Torr.	 
7.Switch on the turbomolecular TPS compact station. Start data registration from the FRG720 gauge. On first stage starts work the fore pump IDP 3. Pump down the system before reaching saturation in pumping speed (approximately level $6x10^{-5}$ Torr). Saturation depends on conductivity of the aperture and will be different for each one.	
8.Finish the data collection	
9.Switch off the FRG 720 gauge	 

10.Switch off the turbomolecular pump After switching off turbomolecular pump, wait for stopping of the pump's main rotor.	
11.Vent the system For venting use the venting valve of the turbomolecular pump.	
12.Disconnect cable from the FRG720 vacuum gauge	
13.Disassembling the vacuum system Conduct procedure in the reverse order: 1. 1.Disassemble the KF flange connection (6) 2. 2.Dismount the FRG 720 from CF flange connection (5)	
14.Change the type of aperture and start from the paragraph 1 of this procedure.	
15.After finishing of all experiments last procedure will be paragraph 11.	

6. DATA PROCESSING ANG ANALYSIS

Vacuum pumps differ in physical principles, operational range, obtained ultimate pressure (or vacuum), pumping speeds, sizes, weights, and many other parameters that are used to select the most suitable pump for a vacuum system at a good price. Some fundamental parameters and terms used at pump characterizations are listed below:

1. Pumping speed is the volumetric gas flow passing via a considered pumping area or captured on a considered pumping area at a given pressure as a result of the pumping action. Then, in the SI unit systems, the unit of pumping speed is m^3/s. However, manufacturers of vacuum pumps usually give pumping speed in m^3/h for pumps operating in low vacuum ranges and in l/s for pumps operating in high and ultrahigh vacuum ranges. Producers of dry pumps for rough vacuum range also give pumping speed in "cubic feet per minute" (CFM).

2. Ideal pumping speed is the theoretical pumping speed at the inlet of a pump, with no effect working against the pumping action.
3. Intrinsic pumping speed is the actual pumping speed as measured at the direct connection of a pump to a large chamber.
4. Nominal pumping speed is the intrinsic speed at the inlet port of a pump and normally at pressure of a plateau or maximum of a pumping characteristic that is usually given by manufacturers.
5. Effective pumping speed is the pumping speed that includes effects of gas backstreaming, leaks, desorption, vaporization of materials, permeation, and influence of duct conductance. This is the actual pumping speed that is determined at an arbitrary place of the vacuum system. The effective pumping speed is smaller than the intrinsic and nominal pumping speeds.

6.1 TASK 1

The experimental data represent the total pressure inside the chamber as a function of the pumping time as illustrated in Fig. 6.1.

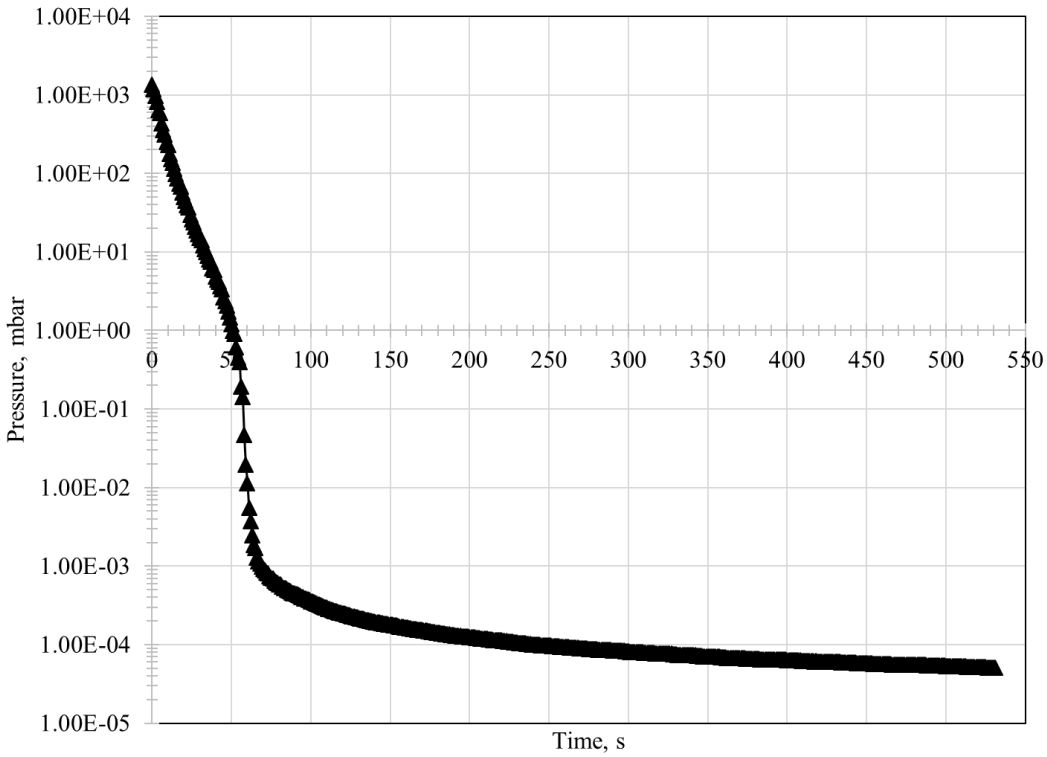


Figure 6.1 Dependence pressure of pumping time for existing pump.

For existing vacuum system pumping speed can be calculated as differential of volume change to differential of time.

$$S = \frac{dV_{sys}}{dt}$$

As you can see, the dependence includes the change in volume during pumping. To determine the volume change it is necessary to calculate the initial volume of the vacuum chamber and all its elements. The total volume of the camera will be:

$$V_{sys} = \sum_n V_n = V_{chamber} + \sum_k V_{k,adapters} + \sum_i V_{i,flanges} + V_{ion} + \sum_j V_{j,gauges}$$

were

$V_{chamber}$- volume of vacuum chamber,

$\sum_k V_{k,adapters}$ – total volume of all additional connection elements,

$\sum_i V_{i,flanges}$ total volume of gaps between flanges.

V_{ion} – volume of Ion pump,

$\sum_j V_{j,gauges}$ total volume of all gauges.

Note. For calculation of total volume in paragraph 8 the volumes of Ion pump and some adapters (flexible bellow, valve) must be deducted from total volume.

The volumes of standard elements are listed in table. 6.1

Table 6.1 Volume of vacuum elements.

Vacuum element	Volume, ml
6-way cross	395
gaps between flanges	8
ionization gauge	75
IMG 100	23
FRG 720	43
Flexible vacuum bellow	2100
Valve	181
Valve gate	34
Ion pump adapter	47.5

After calculation of the volume of vacuum chamber we can calculate the pumping speed for every moment of pumping time. The pumping speed is.

$$S = \frac{V_{sys}\frac{p_1}{p_2} - V_{sys}}{t}\ l/s$$

were

V_{sys}- total volume of the vacuum system [***l***],

t- current pumping time [**s**],

p_1 -total pressure at the start of current pumping time [***mbar***],

p_2 -total pressure at the end of current pumping time[***mbar***].

Pumping speed must be calculated for every moment of pumping time according to time (Fig.6.1) and for data from all gauges.

After processing all data, the result must be presented as a graph of pumping speed (Fig. 6.2) for all pumping time and independent graphs for every pump. It is necessary to separate the pumping process of the system for each pump according to the obtained characteristics of the pumping speed in comparison with the nominal technical characteristics of the pumps.

6.2 TASK 2

For the second task, the data processing procedure is similar to task 1. The resulting pumping rates for each aperture should be compared with the initial aperture value for 100% and conductivity calculated. The conductivity of each aperture is represented as the ratio to the initial value for 100%.

$$\mathrm{C}_i = \frac{S_{100\%}}{S_i}$$

were

C_i – current conductance of aperture.

$S_{100\%}$ - pumping for 100% aperture.

S_i – pumping speed for current aperture.

All the results of calculations of velocity of pumping should be presented in a graph and the total graph of the conductivity measurement of the size of the aperture.

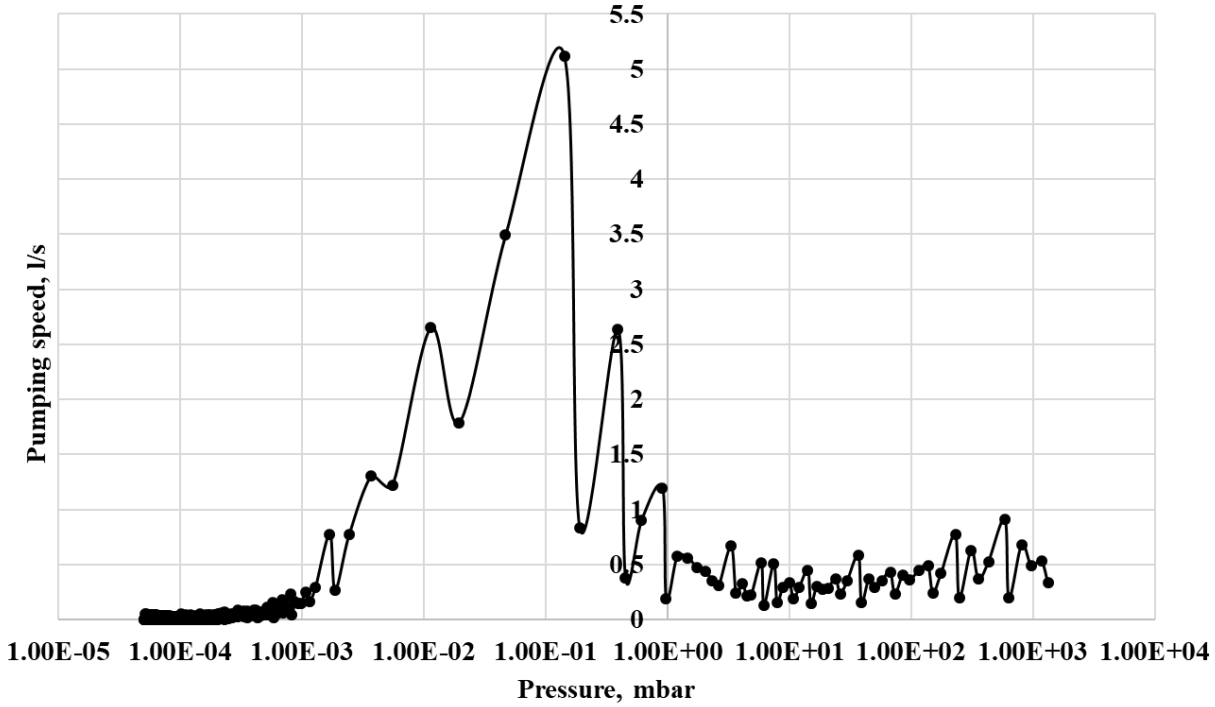


Figure 6.2 Total pumping speed for all pumps. (on graph show only turbomolecular and backing pumps)

7. SAFETY

Vacuum gauges.

This manual uses the following standard safety protocols:

WARNING 	Warnings indicate a particular procedure or practice, which if not followed correctly, could lead to serious injury.
CAUTION 	Cautions indicate a particular procedure or practice, which if not followed, could cause damage to the equipment.
NOTE 	Notes contain important information.

Be certain that the IMG-100 Inverted Magnetron Gauge Controller and vacuum system are separately grounded to a common ground.

WARNING 	• Do not place a ground wire between the vacuum chamber and the controller chassis; large continuous currents could flow through it. • Risk of death due to high voltages (160 to 900 V may be present in an improperly grounded system). • Make absolutely sure that the vacuum system is grounded. • Test the system ground to be sure that it is complete and capable of supporting at least 10 A.
CAUTION 	As with all ionization gauges, this device is not intrinsically safe. Exercise extreme care when using this vacuum gauge while pumping or backfilling a system or in any other system condition which contains combustible gases or mixtures. The filament, the end of a hot filament ion gauge and the high voltage discharge of a cold cathode gauge can be ignition sources. When such a gas or mixture is present, do not turn on any such vacuum gauge. Failure to follow this instruction could result in serious injury to personnel and damage to equipment.
NOTE 	When such a gas or mixture is present, do not turn on any such vacuum gauge. Failure to follow this instruction could result in serious injury to personnel and damage to equipment. Cleanliness is vital when servicing any vacuum equipment. Do not use silicone oil or silicone grease. Use powder-free butyl or polycarbonate gloves to prevent skin oils from getting on vacuum surfaces. Do not clean any aluminum parts with Alconox. AIconox is not compatible with aluminum and will cause damage. Normally, it is unnecessary to use vacuum grease. However, if it must be used, do not use silicone types, and use it sparingly. Apiezon L grease is recommended.

Turbomolecular pump

Turbomolecular pumps as described in the following operating manual contain a large amount of kinetic energy due to the high rotational speed in combination with the specific mass of their rotors.

In case of a malfunction of the system for example rotor/stator contact or even a rotor crash the rotational energy may be released.

To avoid damage to equipment and to prevent injuries to operating personnel the installation instructions as given in this manual should be strictly followed!

WARNING 	Never use the pumping system when the turboinlet flange is not connected to the vacuum chamber or is not blanked.
	Do not touch the turbopump or any of its accessories during the heating process. The high temperatures may cause burns.

	Avoid impacts or harsh movements of the pump when in operation. The bearings may become damaged and damages to the persons or the things could be taken place.
	When employing the pump for pumping toxic, flammable, or radioactive gases, please follow the required procedures for each gas disposal. Do not use the pumping system in presence of explosive gases

To switch on the TPS-compact it is sufficient to supply the mains and then move the external switch to ON position. The integrated controller automatically recognizes the mains presence and start up the pump.

At the first start up it is recommended to use the "Soft Start" mode by enabling it on the controller. For the following start ups it is recommended to disable the "Soft Start" mode. For the "Soft Start" mode activation procedure, see the paragraph "Signal Description" in the chapter "Technical Information".

The blue LED “STATUS” located on the TPS-compact base rear panel indicates with its flashing frequency the system operating conditions:

- with no flashing: the pump is normally rotating;
- slowly flashing (period of about 400 ms): the system is in ramp, or in braking, or in Stop, or in “Waiting for interlock” status;
- fast flashing (period of about 200 ms): error condition.

To switch off the TPS-compact it is sufficient to move the external switch to OFF position. The integrated controller immediately stops the pumping system.

To immediately stop the TPS-compact in an emergency condition it is necessary to remove the supply cable from the mains plug or moving the external switch to OFF position.

Ion Pump

Read the following recommendations before operating your ion pump:

- Ensure that the air and environment are free from contaminants.
- Hands should be gloved and free from oils. Use UHV practices when working with ion pumps.
- For better starting and pump down time, flush the system with dry nitrogen to decrease water vapor and noble gas quantities.
- Check to see that the ion pump controller is properly connected and that the system is tightly sealed.

- To increase ion pump life and shorten time to ultimate pressure, use the full extent of the roughing system and start the ion pump at the lowest possible pressure.

Pump Starting (Not Isolated)

This procedure is used when the ion pump is started after exposure to atmospheric pressure or any pressure above 2.5 x 10^{-2} torr.

1. Switch on the roughing pump and open the roughing valve.
2. On the ion pump controller, set the controller readout display to voltage. Set the ion pump controller switch to start, if so equipped.
3. Switch on the ion pump controller when system pressure has reached 1 x 10^{-4} torr (lower pressure is better).
4. The controller should read 300 to 500 volts and slowly increase to full voltage (normally 5000 to 7000 volts).
5. Close the roughing valve when the controller reads 2000 volts or greater.
6. When the controller reads 3500 volts, set the power unit switch to run, if so equipped. To determine ion pump pressure, set the controller readout display to a current range, and calculate pressure by means of the current to pressure equation.

WARNING:

	Gamma vacuum control units designed for ion-pump operation are capable of delivering 7000 vdc under open circuit or low pressure operating conditions. For safe operation, the control unit and ion pump should have a common chassis connector which is tied to the power system ground.
	High magnetic field. Can cause implanted heart pacemakes. And cardioverter defibrillators to cease operation. Maintain 30 cm safe distance from ion pump.
	Heavy object. To avoid muscle strain or back injury, use lifting aids and proper lifting techniques when removing or replacing.
	Burn hazard. All ion pump surfaces are hot during bake. Do not touch pump unless bake is off and pump has cooled.
	Heaters are configured for either 100-120 or 200-240 volts, 16 amps max. Verify appropriate connector and voltage prior to connection. Voltage or current can cause injury or death. Disconnect all power cords before servicing. 600°C wiring required at pump terminals.

Ongoing Operation

After the ion pump has started, it continues to reduce pressure in the system without further attention.

NOTE: The ion pump can be kept in permanent operation.

The ion pump controller should provide overload protection to turn off the ion pump if system pressure rises above ion pump operating pressure. Other desirable features of an ion pump controller are:

- ion pump over-current protection
- safety interlocks
- voltage, current, and pressure display
- analog outputs that correspond to ion pump voltage and current
- remote control on/off
- setpoints relays that can interlock equipment and processes, or control bakeout by ion pump current or calculated pressure
- computer interface for remote operation by computer

Venting Procedure

To enhance system performance:

- Minimize the time the ion pump is exposed to atmosphere.
- Use dry nitrogen gas when venting the ion pump to atmospheric pressure.

NOTE: If an isolation valve is included, close it (with ion pump in operation) before opening the system. When venting the system to atmosphere, ion pump current may rise. This is not a problem if pressure remains below 1×10^{-6} torr.

1. Switch off the ion pump controller.
2. Connect a source of clean dry nitrogen to the up-to-air valve.
3. Open the up-to-air valve slowly to prevent dry nitrogen from entering the system too quickly.
4. Open the roughing isolation valve, gradually.

CAUTION: When venting, do not pressurize the ion pump or vacuum system above atmospheric pressure.

Controllers.

This manual uses the following standard safety protocols:

WARNING 	The warning messages are for attracting the attention of the operator to a particular procedure or practice which, if not followed correctly, could lead to serious injury.
CAUTION 	The caution messages are displayed before procedures, which if not followed, could cause damage to the equipment.
VOLTAGE 	Alerts the user to the presence of uninsulated dangerous voltage within the product's enclosure that may be of sufficient magnitude to constitute a risk of electric shock to persons.

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