MECHANICAL PUMPS

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Abstract
Various types of mechanical pumps are presented together with their pumping mechanisms and main characteristics. The combination of these elements to construct a roughing station is discussed in terms of reliability and efficiency. Various situations corresponding to real accelerators are considered to give guidelines for the design of roughing stations.

1. INTRODUCTION

The development of mechanical pumps was intimately linked with the progress of vacuum science up to the middle of this century when the introduction of both the sputter ion pump and the sublimation pump provided an alternate method for the production of low pressure. Nevertheless, the mechanical pumps are, with the exception of the sorbtion pumps, the unavoidable initial stage before any attempt can be made to activate capture pumps and to reach the ultra-high vacuum domain. This is due to their ability to evacuate efficiently from the vacuum vessel the large number of molecules present at atmospheric pressure. However the limited compression ratio of the pumps limits the achievable ultimate pressure. In this presentation an overview of the operating principles and of the characteristics of these pumps will be given. The rules for combining several mechanical pumps to build a roughing station will then be reviewed together with considerations on the control system and the operation of these types of pumps in accelerator vacuum systems.

2. MECHANICAL PUMPS

In mechanical pumps, the gas present in a vacuum system is transferred from a low pressure to a higher pressure region. In order to be efficient, the pump has to provide simultaneously a finite pumping speed and compression. To carry out this double task two main mechanisms have been used up to now:

- Isolation and subsequent compression of a gas volume defining a first category often named “Positive-displacement pumps”.
- Transfer to the gas molecules of a preferential velocity direction introducing a mean drift of the gas towards the high pressure region. This category is known as: “Momentum transfer pumps”.

2.1 Displacement pumps

2.1.1 Principle

The principle of these pumps is shown in the Fig. 1. During a cycle, a given volume of gas at low pressure is trapped mechanically and subsequently compressed to the exhaust pressure. During this cyclic process two difficulties arise:

- The swept volume has to be sealed in order to ensure a good compression ratio hence an efficient dynamic seal has to be provided.
- The compression of the gas during the pumping cycle creates heat, which must be evacuated.

These two difficulties can be efficiently mastered by the use of a fluid, which produces a sealing film between the moving and fixed parts of the volume while efficiently evacuating the heat liberated during the gas compression. This role was played by water or mercury in the first mechanical pumps but oil now replaces it in a very efficient way.

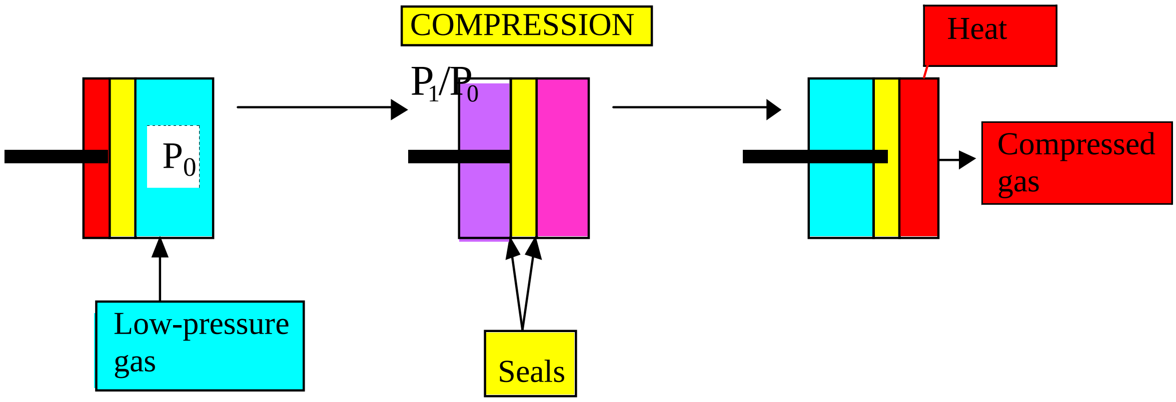

Fig. 1 Principle of the displacement pump

In order to avoid the presence of oil and the related maintenance and backstreaming problems, dry pumps have been developed. Here the absence of an efficient dynamic seal reduces the compression per stage of the pumps and the necessity to evacuate the heat implies the use of an external water cooling circuit. Several successive elementary stages are often combined in dry pumps to improve their compression ratio and to allow gas exhaust at atmospheric pressure.

2.1.2 Oil-sealed pumps

In all these pumps, the compression is produced between one fixed cylinder and a second one rotating off-centred inside the fixed cylinder. The two main types are the piston pump and the rotary-vane pump. Both are able to exhaust gas at atmospheric pressure and their typical main characteristics are presented in Table 1.

Table 1
Main characteristics of oil-sealed pumps

TYPE	ULTIMATE VACUUM (Total pressure) (Pa)	PUMPING SPEED (m^3/h)
Rotary-piston pump	1	30–>1500
Rotary-vane pump (single stage)	1	1–>300
Rotary-vane pump (double stage)	2×10^{-2}	1–>300

The rotary-vane pump is mainly used for small to medium pumping speed, and is the most commonly used forevacuum pump in accelerators. The rotary-piston pump is often reserved for applications where high throughput is needed, in which case water cooling is necessary.

The compression ratio of double-stage rotary-vane pumps can be very high (10^8 for air) [1] and their ultimate pressure correspondingly low provided special care is taken [2]. When these pumps operate close to their ultimate pressure, i.e. in the molecular flow regime, the risk of oil-vapor back-streaming is important. Various trapping methods have been investigated [3, 4] and have shown the efficiency of zeolite traps, when they are properly reconditioned, to prevent the oil backstreaming.

2.1.3 Gas ballast

The role of the oil is very important in these pumps and determines greatly their performance. The pumping of aggressive gases (seldom in the case of accelerators) or the condensation of gases such as water might perturb their performance. This condensation takes place usually in the high-pressure stage of the rotary-vane pump when pumping humid gases. It occurs when the saturation vapor pressure of water is reached in the compressed mixture. In this case, the formation of an oil/water emulsion reduces the lubricating properties of the oil. Furthermore, the circulation of liquid water transported with the oil from the outlet stage to the inlet stage fixes the ultimate pressure of the pump at the corresponding water vapor pressure. To remedy this detrimental effect gas ballasting was proposed in 1935 by Gaede [5].

The aim of the gas ballast is to introduce in the pump, at the end of the compression cycle where condensation might occur, a certain volume of unsaturated vapor to lower the partial pressure of the condensable gas. This injection results also in a higher pressure in the compressed volume and hence causes the discharge valve to open at an earlier stage of the compression. The amount of gas to be injected during the ballasting process can be calculated in the following way:

If P_e is the exhaust pressure of the pump and P_I the inlet pressure then the compression C can be written as:

$$C = \frac{P_e}{P_i} = \frac{P_e}{P_G + P_W}$$

$$P_s > C \times P_W$$

where P_G is the uncondensable and P_W the condensable gas pressure. In order to avoid condensation the partial pressure of condensable gas at the exhaust must be lower than the saturation pressure P_s of the condensable gas. Hence:

$$P_W < \frac{P_G \times P_S}{P_E - P_S}$$

gives the highest condensable pressure in the pumped gas to avoid condensation in the pump without gas ballast.

If a gas ballast (pressure P_B, speed S_B) is introduced then P_G becomes:

$$P_G \to P_G + P_B \times \frac{S_B}{S}$$

and the pressure P_W is increased to:

$$P_W > \frac{\left(P_G + P_b \times \frac{S_b}{S}\right) \times P_S}{P_E - P_S}$$

From this equation it can be concluded that raising the ballast flow (P_B*S_B) avoids condensation. It also shows the great importance of the pump temperature during the evacuation of condensable gases. Raising the pump temperature very quickly increases the vapor pressure of the condensable gas. Part of the action of the gas ballast results from an increase of the operating temperature of the pump because of the enhanced gas flow.

In practice it is important before starting to evacuate a vessel in which a large quantity of condensable gas is present, to start the pump with the gas ballast open before the beginning of the roughing procedure. This has two beneficial effects: the oil is purged from possible traces of condensation and the pump reaches a higher temperature. This is not necessary if the pump is expected to run, during the roughing of the vessel, at high pressure for a long period and hence is expected to reach a sufficiently high temperature before attaining the pressure at which condensation can occur.

2.1.4 Dry pumps

Despite the very important role played by the oil in the operation of displacement pumps, its presence has two major inconveniences:

- Interaction of the pumped gases, often aggressive in the case of the semiconductor industry, degrades the oil and necessitates frequent oil changes even in the case of the expensive fluorinated oils. This results in excessively high maintenance costs for oil pumps exposed to aggressive chemicals.
- Oil vapor present in the foreline pipe when the pump operates close to its ultimate pressure can contaminate sensitive equipment to which the pump is connected. Even worse, if the pump stops under uncontrolled conditions this can lead, if the internal safety valves of the pump do not operate, to an important oil migration towards the vacuum system.

For these two reasons the leading market for vacuum technology, the semiconductor industry, has forced the vacuum manufacturers to develop oil-free pumps.

The elimination of oil in the displacement pumps introduces major constraints on the design of the pump: the sealing and the lubrication effects of the oil are eliminated and heat transfer from the mobile parts is much reduced. This results in a reduced compression-per-stage of the pumps and the need for external cooling. In consequence, most of the dry pumps available on the market need water cooling and have more stages (about double) than an equivalent oil-sealed pump.

The various types of commercially available dry pumps are summarised in Table 2.

Table 2
Various types of dry pumps

Type of pump	**Compression per stage**	**Speed (m^3/h)**	**Ultimate pressure**
Piston	15-20	12	3-4 Stages, atm –> 4 Pa
Diaphragm	200	0.8 –>5	atm –>200 Pa
Scroll	10^5	15 –>600	atm –>1 Pa
Roots	30	25 –>1000	4 Stages, atm –> 0.1 Pa
Screw	30-100	25 –>2500	atm –>1 Pa
Claw	20-50	25 –>500	3 Stages, atm –> 10 Pa
Tongue/groove	10-20	50	4 Stages, atm –> 5 Pa

Different types of pumps are often combined into a single system, e.g. a Roots pump is used to provide high pumping speed at the entrance stage after which claw stages are used to increase the compression at the high-pressure stages where the volume throughput is reduced. Two types of pump have neither oil nor joints between vacuum and oil: these are the scroll pumps and the diaphragm pumps.

The advantage of oil-free pumping is certainly more important for applications where the cost of maintenance is high. In the case of accelerators, the pumping of radioactive zones, where the disposal of contaminated oil and the maintenance of activated pumps is a concern, dry pumps offer an interesting alternative to the oil-sealed type.

3. SORBTION PUMPS

Although the sorbtion pump belongs to the family of cryopumps, it is also used for the roughing of vacuum systems and is perhaps the only absolutely dry pump. In this pump zeolites are used because of their porous crystal structure which is able to pump a large amount of gas when activated. This unique property is due to the size of the pores, comparable to the size of molecules, providing a high binding energy (low equilibrium pressure) and a large specific area (large pumping capacity). This geometrical effect is enhanced by lowering the surface temperature of the zeolite to liquid-nitrogen temperature in order to lower the equilibrium pressure for a given gas quantity. The interaction of the molecules with the adsorbent depends on the nature of the pumped molecule and is of course much greater for nitrogen and water than for noble gases. When adsorbed, these latter gases will be very quickly displaced by other air molecules and will finally be desorbed when the pump is saturated. For this reason several pumps (two or three cartridges) are used to evacuate a volume from atmospheric pressure down to 1 Pa. The first pump reduces the pressure from atmospheric to some 10^4 Pa. A second pump brings the pressure down to some tens of Pa, the third pump providing a final pressure in the 0.1 Pa region, mainly limited by noble gases. The size of the pumps depends directly on the volume of the vacuum vessel: 1 kg of molecular sieve is needed to evacuate 8×10^3 Pa.m^3 of nitrogen.

Sorption pumps are very simple and robust and consist of a metallic can containing the sieves and providing a good thermal contact between the sieve and the liquid nitrogen surrounding the pump. Between two pumping cycles, the pump has to be regenerated by allowing the sieve to warm to room temperature. During this regeneration, the pump has to be properly vented to let the pumped gas escape and avoid dangerous pressure build up. Water has a great affinity for the sieve so, after several pumping cycles, the pump has to be reactivated by baking to 300 ºC under vacuum. The main limitation of these pumps is their limited capacity, which restricts their use to small unbaked systems. They are nevertheless very interesting for their simplicity, reliability and absolute cleanliness.

4. MOMENTUM TRANSFER PUMPS

4.1 Principle

In displacement pumps, a volume of gas is isolated in a moving volume in order to transmit a preferential direction to the molecules despite the viscous type of flow corresponding to the pressure in this volume during most of the compression cycle. In molecular flow, it is possible to alter their uniform velocity distribution by repeatedly giving to the molecules a preferential velocity direction. This can be achieved when molecules hit a fast-moving surface. To be efficient the velocity transmitted to the molecules must be comparable to their thermal velocity (460 m/s for nitrogen at room temperature); hence the pumping effect requires fast-moving surfaces. Furthermore, this pumping mechanism is only efficient in the molecular flow regime and hence this type of pump cannot pump gas against atmospheric pressure.

To illustrate the effect, the following simplified calculation shows the pumping performance obtained in a thin rectangular duct with one moving surface [6]. The geometry of the system is shown in Fig. 2 .

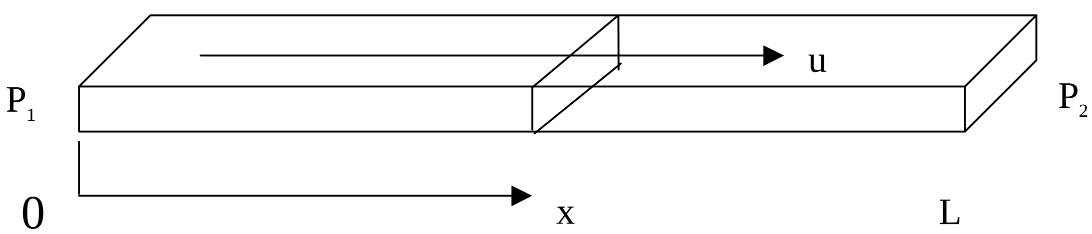

Fig. 2 Geometry of momentum-transfer pump

The molecular conductance c of a rectangular ($W*h$) duct, with the perimeter:

$$H = 2(w + h)$$

and the section A is given by:

$$c = \frac{4\bar{v}}{3\int_0^x \frac{H}{A^2} dl} = \frac{2}{3}\bar{v}\frac{h^2 w^2}{x(h+w)} \ .$$

In molecular flow the relation between pressure gradient and flow is:

$$\frac{dP}{dx} = \frac{Q}{c}$$

Assuming that one surface is moving with the speed *u*, the gas flow, which traverses a given cross section, corresponds to:

$$\frac{dP}{dx} = \frac{u}{2c} AP \ .$$

Thus

$$\int_{P_1}^{P_2} \frac{dP}{P} = \frac{u}{2c} A \int_0^L dx \ .$$

Integrating over the length of the duct one obtains:

$$K = \frac{P_2}{P_1} = e^{\frac{u}{2c}AL} \ .$$

These calculations show the exponential dependence of the compression on the velocity of the moving surface, and through *c*, its inverse exponential dependence on the square root of the mass of the gas. Accurate calculations can be found in Refs. [7–9] and again demonstrate the drastic influence of the surface speed on the performance of the pumps. This speed and the narrowness of the gap between the surfaces needed to ensure an efficient pumping has restricted the use of this type of pump until recently.

4.2 Molecular and turbomolecular pumps

The first molecular pump was proposed by Gaede [10] and later types by Holweck [11] and Siegbahn [12]. Up to the late 1970's this type of pump was not used because of its poor reliability and low pumping speed. Recently with the advent of dry pumping, these pumps were revised and integrated as the first stage of turbomolecular pumps in order to improve their compression and hence make them compatible with the high backing pressure of dry roughing pumps.

In 1957, Becker [13] proposed the first turbomolecular pump. A development using rapidly rotating blades was initially made to reduce the backstreaming from diffusion pumps. This type of pump with its high compression for hydrocarbons replaced the diffusion pump as the workhorse in laboratories. The success of the turbomolecular pump is based on its high compression (between 300 and 3×10^4 for hydrogen, 10^8 to 10^{12} for nitrogen) and its high pumping speed (50 to 5000 l/s). In modern turbomolecular pumps, the rotation speed of the blades (up to 1500 Hz) is such that the linear speed is close to 500 m/s.

The geometry of the blades influences the pumping and the compression performance of the pump. Usually the blades are more open on the low pressure side providing a higher pumping speed. On the high pressure side, the volume flow being smaller, the blades can be more closely spaced (lower pumping speed) to provide more compression. The tips of the blades are submitted to very high mechanical stresses which limit the rotational speed of the turbine and hence the performance of the pumps. Because the pumping effect requires a molecular flow between rotor and stator, these pumps reach their full performance for compression and pumping speed below 1 Pa exhaust pressure. In the 1980's the demand for oil-free pumps able to evacuate vacuum systems in the pressure range used for coating processes led to the introduction of combined molecular-drag pumps providing a higher compression and a possible backing pressure between 10^2 and 10^3 Pa. To suppress completely the presence of hydrocarbons in the pumping systems, magnetically suspended pumps have been developed.

Turbomolecular pumps operating in a metallic and baked environment can reach a very low pressure (10^{-9} Pa) [14]. They are especially interesting for vacuum measurements as they have no memory effect nor selectivity compared to ion pumps or sublimation pumps, and a stable pumping speed across a large pressure range (10^{-1}–10^{-7} Pa). Because of these features these pumps are widely used in accelerators for the initial pumping and during bakeout.

5. PUMP CHARACTERISTICS

It is often useful to check the performance of commercially available pumps in order to detect possible deviations from the expected values. Apart from the pumping speed, the main characteristics of mechanical pumps are the ultimate pressure and the compression. The methods and procedures used to measure these quantities are defined by, for example, the International Standards Organisation (ISO), the American Vacuum Society and the Pneurop Association.

5.1 Displacement pumps

The usual reception tests consist of measuring the ultimate pressure, the pumping speed and the water-vapor pumping capacity. In the case of pumps using oil, a distinction is made between condensable and non-condensable gases, depending on the type of gauge used to measure the pressure. For the measurement of the pumping speed S a fixed and known flow Q is injected in a dome where the resulting pressure P is measured. The pumping speed is given by the simple equation:

$$Q = P \times S \ .$$

Procedures also exist for the measurement of water-vapor pumping and are described in Refs. [15–17].

5.2 Turbomolecular pumps

The control of turbomolecular pump performance could be important especially for the compression ratio, which could be subject to variation. The other characteristics, which are usually measured, are: the ultimate pressure and the pumping speed. For turbomolecular pumps, these measurements are often made on a baked measuring bench. Procedures and methods are described in Ref. [18].

6. LAYOUT OF A ROUGHING STATION

The roughing stations are used in accelerators to lower the pressure from atmospheric to the pressure required either to switch on the sputter ion pumps, the most widely used holding pumps in such machines, or to start a bakeout. The design of these stations should provide safe and efficient pumping to reach these targets. It must be safe in order to avoid the contamination of the beam pipe, often exposed to the enhanced desorption induced by the bombardment of energetic particles or to protect the vacuum system against accidents (e.g. power cut or human errors) leading to uncontrolled venting. It must be efficient in fulfilling its role: the achievement of a given pressure and gas composition in a given time with a minimum investment.

To fulfil these constraints one should take into account some general rules for the construction and the operation of a safe and clean pumping station and adapt the size of the station's elements to the particular case envisaged. The following paragraphs will deal first with the construction and the operating procedure of a roughing station and then consider some particular aspects depending on the characteristics of the accelerator.

6.1 Layout of a roughing station

Apart from breakdowns, which, with modern pumps, are very rarely due to misuse of the station, the main accidents which can take place with a roughing station are undesired venting of the accelerator vacuum system through the roughing station, or contamination with oil vapors. Both these events can be avoided by using an appropriate layout of the station and proper operational procedures controlled by an automatic controller system.

Some of the common reasons for accidental venting of an accelerator vacuum system are: the connection of a leak detector without isolating the pumping station or, during a power cut, an uncontrolled opening of a venting valve. To avoid these incidents, normally-closed valves interlocked by an appropriate control system are used. The sequence used in this controller must take into account various characteristics ensuring a clean operation of turbomolecular pumps.

The question of oil contamination through roughing stations is only relevant during the periods when the turbomolecular pump is not running at full speed. At its nominal speed, the compression ratio is such that contamination by oil vapor is not visible and certainly irrelevant in a normal accelerator vacuum system. On the contrary, if a turbomolecular pump is left idle in contact with a vacuum system, an important contamination can occur. This is illustrated in Fig. 3 showing the evolution of the residual gas composition in a system in contact with an unpowered turbomolecular pump. Even after a pump restart the system remains permanently polluted with traces of heavy hydrocarbons. To avoid this, a valve must be positioned to isolate the pump from the system (system isolation valve, bakeable if the accelerator will be baked) when the rotational speed of the pump falls below 70% of its nominal value. The reason for this can be seen in Fig. 4, which shows the variation of the partial pressure of various gases as a function of the speed of a turbomolecular pump. Traces of light hydrocarbons become visible for a rotational speed lower than 60% of the nominal value. To avoid contamination of the pump itself, it is a well-established and sound practice to vent the pump before it is stopped. For this a venting valve must be connected to the orifice generally provided by the manufacturer in the high-pressure stages of the pump. A pump must never be vented through its foreline.

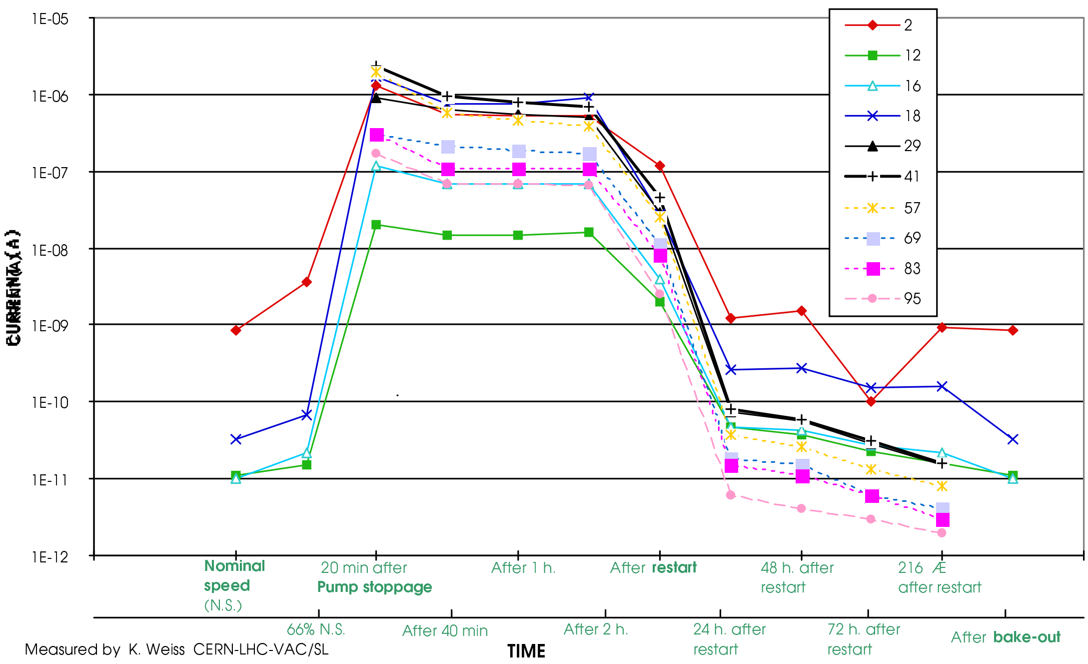

Fig. 3 Evolution of the residual gas composition after the stoppage of a turbomolecular pump

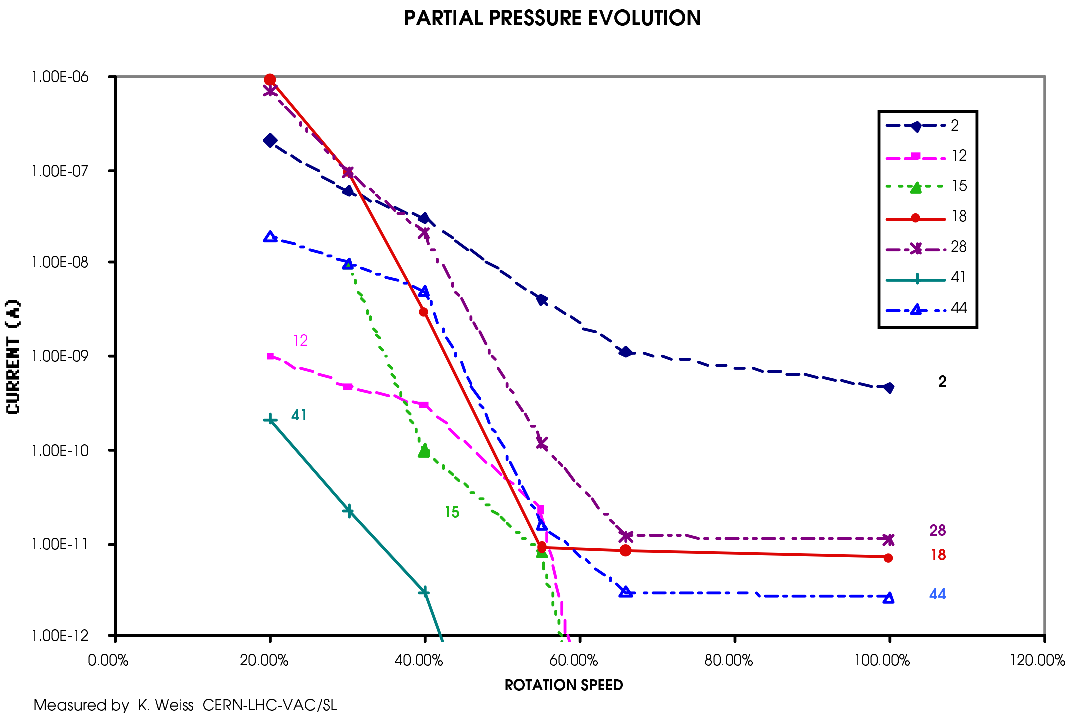

Fig. 4 Variation of the gas composition during the slowing down of a turbomolecular pump.

The contamination of a station or, worse, of the accelerator vacuum system through a massive flow of the rotary-pump oil is certainly the absolute nightmare against which the station must be perfectly immune. Although most of the modern roughing pumps are equipped with automatic valves closing in case of a rotary-pump stoppage, it is good practice, and also useful during leak detection, to have a valve isolating the two pumps (roughing pump isolation valve) when the group is stopped or in the case of some other anomaly. Lastly, to avoid contamination of the foreline with rotary-pump oil, this pump must also be automatically vented if the pump is stopped.

Most commonly, the roughing stations are also used during leak detection and a leak detection valve has to be installed on the high-pressure side of the turbomolecular pump. In order to vary the gas flow to the leak detector, this valve should be installed upstream from the roughing pump isolation valve.

Hence five valves as described above when properly activated can protect an accelerator vacuum system against contamination by oil backstreaming and ensure a flexible and reliable use of the station. A possible scheme of the roughing station corresponding to this description is given in Fig. 5. For these valves, electropneumatic types of DN16 or DN25 size are generally well suited with the exception of the system isolation valve which must be sized in relation to the turbomolecular pump. The use of normally-closed valves is a good protection against accidental venting in case of failure. Furthermore, a hard-wired safety system forbidding the actuation of venting valves when the system isolation valve is open has been found useful on some occasions. In the same way, protection can be installed on the leak-detection valve to forbid its opening when the system isolation valve is open and so avoid the roughing of the leak detector connecting line by the accelerator.

The control of the station must ensure the appropriate sequencing for the start up and the shutdown of the station and is a key element for obtaining clean pumping of the accelerator. The development of programmable controllers (PLC) gives cheap and versatile control systems fulfilling the most complicated requirements to be made.

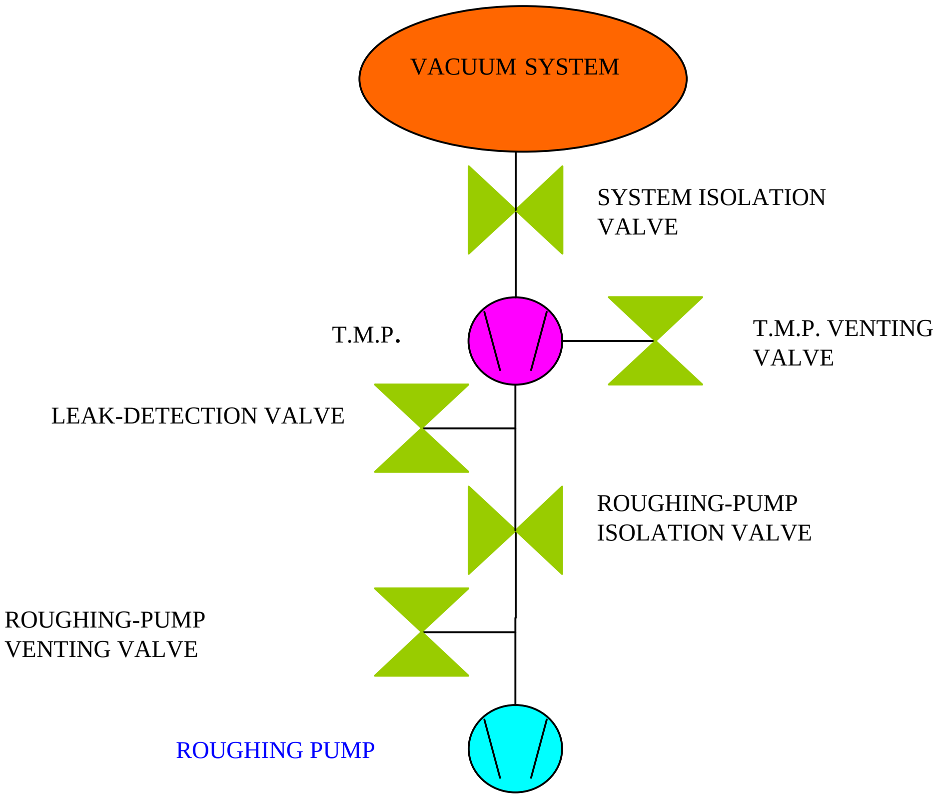

Fig. 5 Layout of a roughing station

6.2 Operational aspects

After these considerations on the layout of the roughing station, several other questions must be studied concerning their size, number and position. To address these points, the characteristics of the vacuum system must be considered i.e. the length and bakeability of the accelerator, the presence of radioactive or contaminated zones, of large tanks or of especially sensitive equipment (e.g. superconducting cavities). The vacuum system of accelerators is usually split in sectors. In large accelerators, the use of mobile stations reduces the investment, which could be quickly prohibitive since the spacing between stations should not exceed 100 m for conductance and leak detection reasons. Mobile stations are also useful in radioactive zones, as they are not exposed continuously to radiation that quickly damages their power supply. In fact, the trend in new turbomolecular pumps is to integrate the pump power supply with the pump. The use of fixed pumps in radioactive areas will hence require the purchase of specially built mechanical frequency converters at very high cost.

The timing of an intervention is completely different in baked and unbaked systems. In baked systems, interventions are usually long due to the time needed to heat and cool the chambers. On the contrary, in unbaked systems the time needed for the roughing of a sector is an important part of the down time of a machine in case of failure. So the constrains on the roughing station are quite different.

6.2.1 Baked vacuum systems

In this case the installation of a mobile roughing station does not change the intervention time. The function of the pumping groups is to evacuate the water vapor during the bakeout. The ultimate pressure after bakeout is not strongly dependent on the pumping speed during this operation. Furthermore accelerators have typically a specific conductance of about 100 l/s.m. For these reasons, small pumping stations equipped with pumps not exceeding 200 l/s, backed by primary pumps of about 15 m^3/h, are a good choice. The spacing between these stations is dictated by leak detection considerations and should not exceed 100 m for reasons of ease of localisation of leaks and of the time before leak detection can commence.

6.2.2 Unbaked vacuum systems

In such machines, the relevant target during an intervention is to reopen the sector valves as quickly as possible. The various steps required are the roughing of the sector and the leak detection followed by the ignition of the ion pumps. In a small non-radioactive machine, fixed groups are better suited for this application. If mobile groups are preferred, they should be connected as closely as possible to an ion pump in order to ease the start up of the pump. Large primary pumps or auxiliary pumps connected during the pre-evacuation phase through the leak detection valve will help to reduce the non-negligible time of this roughing phase. Larger turbomolecular pumps (not exceeding 400 l/s) can be of help for a quick start of the ion pumps if their pumping speed is not throttled by the connections to the vacuum system. Note that the price of the station increases drastically with the size of the turbomolecular pump especially since the price of the connecting valve and of the necessary connection scales accordingly. Lastly in the case of a radioactive area, the use of mobile stations is highly recommended for the reasons explained above. In that case special care must be taken to choose for the connection of the group a position of reduced radioactivity, easily accessible and equipped with a quick and reliable connection system. This will reduce the radiation dose received by the operators during the installation and the dismounting of the roughing stations.

6.2.3 Special devices

Some devices require special care for their evacuation. This is, for example, the case for superconducting cavities that are very sensitive to pollution and, in particular, to dust particles which might be transported during the venting or roughing of these cavities. For this reason special care has to be taken in order to avoid their transportation during pumping and it is often considered that laminar flow conditions must be maintained throughout the evacuation. The upper limit of the flow can be calculated from the diameter of the sensitive areas. The calculated flux can be maintained by keeping the corresponding pressure at the entrance of the primary pump by means of an automated valve. Of course the cleanliness of the roughing station is in that case of utmost importance. A preliminary baking of the station before an intervention on the cavity vacuum allows to remove all residual contamination and to test the cleanliness of the station which is otherwise masked by the predominance of the water vapor in the residual-gas composition.

6.2.4 Dry pumping

With the availability of more-and-more sophisticated dry pumping systems, the vacuum specialist is increasingly confronted with users asking for dry-pumping stations. The real need of these users is clean pumping, and dry pumping is certainly one way to achieve this. There is no indication that dry pumping is the only way to produce a clean roughing but it is certainly the most expensive way. This expense is certainly justified by the reduced maintenance in the case of the semi-conductor industry where the stations are exposed routinely to aggressive gases degrading the most stable and expensive oils. This is perhaps not the case in regular accelerators where the most aggressive gas pumped is water vapor. On the other hand, in some very sensitive places, e.g. photocathodes for the production of electrons, or windows and mirrors submitted to a high flux of synchrotron light, the doubt could subsist and justify the choice of a dry system with the implied extra cost.

Nevertheless one should not forget that oil is not the only source of hydrocarbon degassing and that many components of dry pumps (e.g. seals, electrical isolation for coils, …) in contact with the vacuum are also a possible source of hydrocarbons. Lastly, in most of the dry primary pumps, the “dry” property relies on the integrity of sliding gaskets which can also fail.

7. CONCLUSION

The vacuum expert has nowadays a wide variety of mechanical pumps covering the complete pressure scale from atmosphere to UHV. These pumps can satisfy the most stringent requirements in terms of ultimate pressure, cleanliness and resistance to aggressive media but, with the new trend towards active components, have the tendency to loose some of their resistance to radiation. This larger variety of pumps and their increasing price requires a careful analysis by the vacuum expert before choosing the type and the size of a pumping element. The design of a roughing station must take into account a great variety of parameters such as the volume of the vessel and its length but also the radiation level, the presence of radioactive contaminants, the accessibility and, of course, the budget available. The large number of components developed by the European vacuum industry allows adequate answers to the most difficult problems to be found in most cases.

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