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A LINEAR PUMP FOR CONDUCTANCE LIMITED VACUUM SYSTEMS

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Abstract: In order to best fulfil the requirements of conductance limited vacuum systems such as those of particle accelerators, linearly distributed pumping is desirable. A linear pump has been developed making use of a commercially available gettering ribbon and providing a few hundred litres of pumping speed per second and metre for the most common active gases. This pump does not show limitations down to the 10^{-11} Pa range and maintains its full pumping speed during bakeout.

INTRODUCTION

A common feature of electron and proton storage rings is the pressure rise as a consequence of the release of gas from the surfaces of the vacuum chamber under radiation or ion bombardment. Extremely clean surfaces and/or high pumping speeds are required to keep the pressure acceptable for the operation of these machines /1/. The pumping speed requirement is often difficult to meet because of the low conductance of the vacuum chambers. Particularly in high energy machines equipped with superconducting magnets, small chamber apertures are desirable. For electron storage rings this problem has so far been successfully solved by using linearly distributed sputter-ion pumps (LSP) providing a constant pumping speed in the order of a hundred ℓs^{-1} per metre along all parts of these machines where magnets are installed. More generally, it appears that linear pumping speeds of about 100 ℓs^{-1} m^{-1} fulfil the vacuum requirements of all the electron or proton storage rings so far envisaged or built.

However, the existing designs of LSP, which have proved to be a valid solution for electron machines, cannot be applied directly to proton storage rings without risk because of the lower operating pressure required (about 10^{-9} Pa). These pressures are not normally achieved by sputter-ion pumps without the assistance of some pumping of a different nature. Furthermore, for future proton storage schemes with superconducting magnets, no experience is available on the LSP's behaviour in the presence of magnetic fields in the range of 40 Tesla. At the other extreme, experience is also missing on operation of LSP's in the presence of weak magnetic fields as they are foreseen in some of the latest designs for large electron storage rings.

Even if these problems can be solved by developing adequate LSP's, some inconvenience deriving from the rigid link between the pumps and the magnets will still be present. Obviously, the LSP cannot be used where magnets are not installed. Care must be taken to place the pump properly in the magnetic field and this need can result in different mechanical solutions for the dipole and quadrupole chambers. The magnets must be powered during the baking of the vacuum chamber in order to condition the pumps so as to avoid the large gas release and subsequent wall contamination which are possible if started cold. In this respect, proton storage rings are much more demanding than electron machines (which can be "cleaned" by the electron scrubbing produced by synchrotron radiation) because the rate of surface ion bombardment is too low in the former to help clean the surface. Any surface contamination after baking might therefore have catastrophic effects.

For all these reasons we have studied the behaviour of a non-evaporable getter to provide a linear pumping, alternative to the LSP, which is both independent of the magnetic field and capable of maintaining adequate pumping speeds in the 10^{-9} Pa range of pressure.

NON-EVAPORABLE GETTER

Any material which can provide a pumping action when introduced in bulk into a vacuum system is called a non-evaporable getter (NEG), as distinct from materials which only provide pumping when sublimated /2/. The NEG's form thermally stable chemical compounds with the majority of the active gases (O_2, CO, N_2, CO_2, H_2O etc.), while the sorption of H_2 is thermally reversible. When exposed to air, the gettering surface is saturated and loses its pumping activity. An essential operation is, therefore, the activation of the pumping surface. This consists in producing by heating the diffusion of the saturated surface layer into the bulk of the material. The heating also reduces the H_2 content in the getter whenever the H_2 dissociation pressure of the getter exceeds the H_2 pressure in the vacuum system. After regeneration, the gettering action depends on the amounts and molecular species of the gases which are pumped. If large quantities of gases producing stable compounds are to be pumped, the getter operating temperature must be high enough to keep the rate of diffusion of the compounds into the bulk sufficiently high to prevent surface saturation. The diffusion rate of H_2 is much higher, and consequently much lower temperatures are required for continuous H_2 pumping. All these temperatures depend, of course, on the particular getter, and we will therefore limit ourselves henceforth to what appears to be the most promising NEG at present existing on the market. This is a Zr-16% Al alloy bonded in a powder form on an iron or konstantan (non-magnetic) ribbon. This alloy is known by the trademark ST 101 and is produced by SAES Getters (Milano, Italy) /3,4/. The ST 101 has already been studied extensively and its relevant characteristics as obtained from the published literature are reported below. Full activation requires heating at 750°C for a few minutes or at lower temperatures for longer times (600°C for a day for example). Heating can be achieved by Joule effect in the metallic ribbon. After activation, pumping speeds of the order of 1 ℓs^{-1} cm^{-2} have been measured both for H_2 and CO (in the temperature range from 20°C to 400°C)/5/. Total capacity for heavy gases is about 8×10^{-2} Pa m^3 (≈ 0.6 torr ℓ) per cm^2 of ribbon. For H_2 the absorption of larger quantities produces embrittlement. Below this limit H_2 can always be redesorbed by heating /6/. The optimum operating temperature of the getter is 400°C if heavy gases must be pumped at pressures above 10^{-5} Pa. Lower temperatures are sufficient at lower pressures and H_2 can be easily pumped at room temperature at pressures below 10^{-6} Pa. The getter is available in ribbons of various width; in all our tests we used a ribbon 30 mm wide and coated on both sides.

APPARATUS AND RESULTS

Our experiments were not aimed directly at checking the above-mentioned characteristics but rather aimed at investigating the performance of the NEG in the range of pressure below 10^{-8} Pa. In fact, very little has been done at these pressures and the capability of the getter to pump H_2 in the 10^{-9} range had even been questioned /7/. A second point of interest was the optimisation of the baking cycle.

Experiments have been carried out on two different vacuum systems. The first, a standard ISR "long-magnet" chamber and the second a circular tube of 60 mm diameter. In both cases the NEG was inserted along the entire length of the chamber and electrically insulated from it by small ceramic spacers. The two systems are shown in Fig. 1

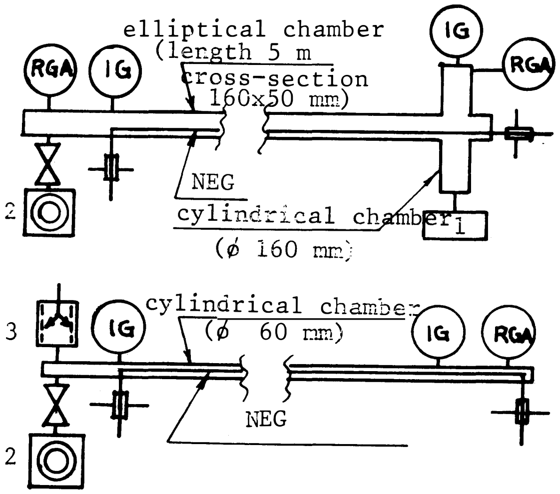

Fig. 1. The two vacuum systems which have been used for the tests. In the upper system, 1 represents the main pumping station, of which the components have varied as described in table 1. The turbomolecular pump located at 2 has a pumping speed of 120 ℓs^{-1}, and the sputter-ion pump (3) of 30 ℓs^{-1}. On each system total pressure measurements are carried out with a gauge of the Helmer type /8/ and standard ISR gauges /9/ of the Bayard-Alpert type. The RGA's are of the quadrupole type.

The average degassing rate of the elliptical vacuum chamber, as obtained from the pressure gradient between its two extremities, is 5×10^{-10} Pa m s^{-1} (4×10^{-13} torr ℓs^{-1} cm^{-2}), i.e. about twice the rate of the standard ISR steel. This seems reasonable when considering the presence of many gauges, gaskets, flanges and feedthroughs. The speeds of the various pumping systems used were obtained at high pressure (10^{-8} and 10^{-7} Pa) by injecting gas at one end and measuring the pressures at both ends. The pumping speeds and the degassing rates so obtained were then used to estimate the ultimate pressures of the system in the various experimental situations and at the level of the gauge located on the cylindrical chamber. These estimations are compared with the measured ultimate pressures in Table 1 (both estimations and measurements are N_2 equivalent). Their good agreement is relevant here because it guarantees that both pressure measurements in the low 10^{-10} Pa range and the measured degassing rates are correct. It also shows that the titanium sublimation pumps keep their full pumping speed even at these extreme vacua.

The insertion of the NEG in presence only of a sputter-ion pump of 350 or 30 ℓs^{-1} has repeatedly produced pressures of 2×10^{-10} Pa in the centre of the magnet chamber and between 4 and 5×10^{-10} Pa at both ends. The higher pressure at the ends is due to a higher ratio of wall surface to getter surface area. This ratio is practically constant along the central part of the chamber, and therefore from the degassing rate of the latter and the pressure measured in the centre, the pumping speed per metre of NEG at the ultimate pressure of the system can be obtained. The result, about 500 ℓs^{-1} m^{-1} or 1 ℓs^{-1} cm^{-2} agrees very well with the values quoted for higher pressure operation indicating that the NEG maintains its pumping speed independent of pressure. These pressures were achieved after a normal ISR bakeout cycle, i.e. pumping with the turbomolecular pump with the chamber at 300°C for 24 h, followed by a temperature reduction to 200°C, when the turbopump is valved off and the SP switched on; the final cooling to room temperature is within 36 h from the beginning of the bakeout cycle. The NEG is activated by heating to about 700°C for 30 minutes, at the end of the period at 300°C and then left alone. The same ultimate pressures are also achieved without heating the NEG when baking at normal temperatures and times but starting from the ultimate pressure of the system and keeping the turbopump valved off. During this modified cycle pressures in the low 10^{-7} Pa have been measured at 300°C; all gases except H_2 were in the 10^{-9} Pa range. After exposure to air we have also tried to apply a shorter bakeout cycle carried out within the eight hours of a normal working day, using the same procedure as outlined above but remaining at 300°C for only 2 hours instead of the usual 24. After 8 h from the beginning of baking the pressure in the central point of the ISR chamber was already about 6×10^{-9} Pa, and after two days the same as obtained after the standard bakeout.

Considerably less effort has been so far devoted to the second system (circular

Pumping Station	ultimate pressure Pa (N_2 equivalent)	
	estimated	measured (average of 3 measurements
Sputter-ion pump (SP)	2×10^{-9}	6.6×10^{-9}
SP + titanium sublimation pump	6×10^{-10}	6.1×10^{-10}
SP + cryopump	4.3×10^{-10}	4.6×10^{-10}

Table 1. Comparison of the ultimate pressures estimated or measured on the cylindrical arm of the ISR long-magnet chamber (see Fig. 1). The nominal pumping speed of the SP is 350 ℓs^{-1}.

vacuum chamber with 60 mm diameter and 5 m length (see Fig. 1). The chamber had been degassed in a vacuum furnace at 950°C and 10^{-4} Pa, a treatment which normally leads to a degassing rate at ambient temperature of 5×10^{-11} Pa m s^{-1} (4×10^{-14} torr ℓs^{-1} cm^{-2}). According to this degassing rate and to the lower ratio of the chamber to the NEG surface area, an ultimate pressure of about 2×10^{-11} Pa was expected. The pressure measured after a standard ISR 24 h bakeout cycle agrees with this estimation to within our measuring accuracy. In other words, even at these extreme vacua the NEG does not lose any measurable fraction of its pumping speed.

In all tests on both systems the ultimate partial pressure of any gas other than H_2 never exceeded a few 10^{-11} Pa.

Although the NEG can be exposed to air and reactivated more than 30 times before its pumping speed virtually ceases, each exposure to air reduces its residual pumping capacity. This inconvenience can be minimised by bringing the vacuum systems to atmospheric pressure with argon gas. After baking the ultimate pressure of the system can be recovered even without activating the NEG. This shows that such interventions do not reduce the capacity of the getter much.

CONCLUSIONS

Pressures two orders of magnitude lower than the lowest pressures required for proton rings have been achieved by means of distributed linear pumping using a non-evaporable getter. Pumping speeds of 500 ℓs^{-1} m^{-1} are thus available at pressures as low as 10^{-11} Pa. These speeds are 5 to 10 times higher than the highest so far specified as required for any machine built or studied. The excess of pumping speed could result in higher circulating currents or higher safety margins or decreased effort in cleaning the vacuum chamber prior to installation, or, finally in less stringent bakeout cycles. Although some lumped SP pumps would be required to pump inert gases and methane, the NEG could supply more than 99% of the main pumping speed very cheaply. It could also be used as a built-in heating element with possible savings on heating equipment and dimensions of the magnet bore. Finally, the pumping would be completely independent of the magnetic field, a feature which is often desirable and in certain cases essential. However, there is one inconvenience and that is the temperature of 750°C needed for activation of the NEG. This is particularly aggravated when the NEG is inserted in the bore of a superconducting magnet. In this case the vacuum chamber is well insulated so its temperature, at thermal equilibrium, will approach that of the NEG. If the vacuum chamber is stainless steel surrounded by vacuum on both sides, it would easily withstand this temperature. However, the usual superinsulating materials cannot be heated to such high temperatures. It is therefore important that future development be aimed at reducing the activation temperature and/or time to avoid this inconvenience. For electron machines the problems are different and maybe even better suited to the NEG. In such machines because of the synchrotron radiation load, cooling systems are generally foreseen which can easily handle more than 1 kW m^{-1} of heat dissipation. Thus similar amounts of heat can be handled during the activation of the NEG. However, the activation cycle in this case is not as well defined as for proton machines but will strongly depend upon the vacuum chamber "conditioning" procedure adopted.

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