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PRESSURE LIMITS IN ACCELERATOR VACUUM SYSTEM

H. J. Halama

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Collider Accelerator Department

Brookhaven National Laboratory

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Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York 11973

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H.J. Halama and H.C. Hseuh

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Summary

The potential sources of gas load in the vacuum system of proton accelerators are identified and compared with operational experience. Methods of eliminating or minimizing these gas loads are described.

Introduction

The fundamental quantity in a real vacuum system is the total gas load Q, which a pumping system has to remove continuously after an initial pump down. In accelerator vacuum systems, Q is given by

$$Q(t) = \left[Q_B + Q_S(t)\right] A + Q_L + Q_{SE}(t) + Q_{ID}$$

where Q_B is the outgassing rate due to the gas dissolved in the bulk of vacuum system materials with surface area A; in particular, the wall of vacuum chambers. Q_S is the time dependent outgassing of adsorbed surface molecules of various bonding energies. Q_L represents the total leak rate. Q_{SE} is the gas load generated by special equipment such as pick-up electrodes, kicker and septum magnets, which are necessary for the proper operation of accelerators. Q_{ID} is the gas load generated by ion induced desorption of surface molecules.

Once Q has been determined, an appropriate pressure, P, can be achieved by selecting an appropriate pumping system with pumping speed S; such that $P = Q/S$.

Sources of Gas Load

Q_B

In all metal systems, hydrogen is the dominant (> 99%) of the gas species diffusing from the bulk into the vacuum system. The amount of dissolved hydrogen as well as Q_B can be drastically decreased by proper high temperuater vacuum firing before the construction of the vacuum system. The estimated Q_B or Q of vacuum chambers in various accelerators are listed below.

CBA, ISR	SS with vacuum firing	1×10^{-13} Torr. $\ell . s^{-1} cm^{-2}$
AGS	Inconel	$< 1 \times 10^{-10}$
PS	SS	$> 5 \times 10^{-11}$
SPS	SS	1×10^{-12}

Q_S

Q_S will depend on the roughness of the surface, as well as the bonding strength of adsorbed molecules, which are replenished after every exposure of a few hours to the atmosphere. Q_S will decrease with time. For an unbaked reasonably smooth surface, the upper limit of Q_S[1] is

$$Q_S \text{ max} \approx 1.7 \times 10^{-5}/t \text{ (Torr.} \ell . s^{-1} cm^{-2})$$

with t being time in seconds. Over a period of several weeks Q_S (with water vapor as the major outgassing) remains the dominant part of Q; if the vacuum system is not opened to the atmosphere, a low equilibrium pressure will be reached in about a month of pumping with Q_B and Q_L becoming more important (i.e., SPS reaches 5×10^{-10} Torr in about six

weeks[2]). The surface roughness of the vacuum chamber can be reduced either by selecting the right material (i.e., SS over Al) or by chemically and/or mechanically polishing the surface. If an even lower Q_S is required, an insitu bakeout will have to be implemented. An additional advantage of a bakeout is the attainment of low pressure shortly after the end of the bake cycle since the desorption of loosely adsorbed molecules depends exponentially on temperature.

Q_L

The total leak rate constitutes real leaks and virtual leaks. Virtual leaks can be kept low by using an all metal system, metal gaskets and good vacuum practices. Organic materials/gaskets have one to two orders of magnitude higher surface roughness and are also susceptible to atmosphere permeation. With the present day leak detectors of sensitivity down to 1×10^{-10} Torr ℓ/s, real leaks can be minimized by careful leak checking. To enhance the sensitivity of leak detection,[3] turbo-molecular pumps should be used for roughing down and during leak checking.

Q_{SE}

The outgassing due to special equipment such as septum magnets and kicker magnets is the major source of pressure in both the AGS and the PS[5] with water vapor and CO being the dominant gas. By specail treatment and proper selection of materials, Q_{SE} can be kept low enough to permit operation even below 1×10^{-9} Torr as in the case of the SPS.[2] The septum magnet laminations having large surface areas have been oxidized rather than phosphated is the SPS[6] and in SATURNE.[7] This improved the outgassing by more than an order of magnitude. A mild insitu bakeout of septum magnets using infrared rod heaters mounted above the laminations inside the vacuum boxes was also required to achieve 1×10^{-9} Torr.

The average pressures in various proton machines are given below.

AGS	3×10^{-7}	Unbaked
PS[5]	$1\text{-}2 \times 10^{-8}$	"
Saturne[6]	5×10^{-8}	"
SPS	5×10^{-10}	"
ISR	10^{-12}	Baked
CBA (50 m long section)	10^{-12}	"
LEAR	10^{-12}	"

In the AGS, more than one-third of gas load is caused by special equipment, while they only occupy less than 5% of the circumference.

Q_{ID}

When a high intensity beam is introduced into the machines, the ionized residual gas molecules which are accelerated by beam-wall potential toward the vacuum chamber wall will desorb gases from the surface. Q_{ID} is important only if the beam current is high enough to produce a potential[4] of several hundred volts (above desorption threshold) according to

$$V = \frac{I}{2\pi \varepsilon_o c} \ln \frac{r_1}{r_o}$$

where r_1 and r_o are the beam and the vacuum chamber radii, and I is the circulating beam current in A. Appropriate modifications to this equation have to be made if the beams are bunched. The desorption yield η (number of desorbed molecules per incident ion) can be reduced by glow discharge cleaning and/or insitu bakeout. η is one order of magnitude higher for an unbaked chamber.

Additional outgassing, which may be very important as the current in proton synchrotrons increases, is due to the beam hitting/heating the vacuum chamber or other components.

Conclusions

Based on the operational experience of various proton machines, we can draw the following conclusions:

a. Pressure of 1×10^{-9} Torr can be achieved in unbaked vacuum systems if designs, assembly and processing follow UHV practices and if frequent interventon can be avoided. This is seemingly the situation in the SPS.

b. In storage rings with high circulating current, the insitu bakeout is needed to reduce the desorption from the walls under the bombardment of residual gas ions. For smaller currents (i.e., SPS $p\bar{p}$ operation), the beam lifetime due to beam-gas nuclear scattering is approximately 500 hours at an average pressure of 1×10^{-9} Torr.

c. For the proposed AGS accumulator/booster with heavy ion option, a pressure of 10^{-11} Torr may be required to minimize beam loss due to (1) high charge exchange cross section between partially stripped beam and residual gas; and (2) pressure bump caused by ion induced desorption, due to high ionizing cross section of residual gas, which is proportional to Q^2.

d. For the improvement of AGS vacuum for heavy ion operation, a pressure of $< 1 \times 10^{-8}$ Torr inside a regular vacuum chamber is possible with thorough cleaning and additional pumping. Major modification of a vacuum chamber and insitu bakeout may not be required.

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