

# PRESSURE LIMITS IN ACCELERATOR VACUUM SYSTEM

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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

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

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 temperature 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	$1 \times 10^{-13}$ Torr. $\ell.s^{-1}cm^{-2}$
AGS	Inconel	$< 1 \times 10^{-10}$
PS	SS	$> 5 \times 10^{-11}$
SPS	SS	$1 \times 10^{-12}$

$Q_S$

$Q_S$  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  $Q_S$  is

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

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  $5 \times 10^{-10}$  Torr in about six

weeks<sup>2</sup>). 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  $1 \times 10^{-10}$  Torr  $\ell/s$ , real leaks can be minimized by careful leak checking. To enhance the sensitivity of leak detection,<sup>3</sup> 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<sup>5</sup> with water vapor and CO being the dominant gas. By special treatment and proper selection of materials,  $Q_{SE}$  can be kept low enough to permit operation even below  $1 \times 10^{-9}$  Torr as in the case of the SPS.<sup>2</sup> The septum magnet laminations having large surface areas have been oxidized rather than phosphated in the SPS<sup>6</sup> and in SATURNE.<sup>7</sup> 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  $1 \times 10^{-9}$  Torr.

The average pressures in various proton machines are given below.

AGS	$3 \times 10^{-7}$	Unbaked
PS <sup>5</sup>	$1-2 \times 10^{-8}$	"
Saturne <sup>6</sup>	$5 \times 10^{-8}$	"
SPS	$5 \times 10^{-10}$	"
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<sub>ID</sub>

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<sup>4</sup> of several hundred volts (above desorption threshold) according to

$$V = \frac{I}{2\pi \epsilon_0 c} \ln \frac{r_1}{r_0}$$

where  $r_1$  and  $r_0$  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  $\eta$  (number of desorbed molecules per incident ion) can be reduced by glow discharge cleaning and/or insitu bakeout.  $\eta$  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  $1 \times 10^{-9}$  Torr can be achieved in unbaked vacuum systems if designs, assembly and processing follow UHV practices and if frequent intervention 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 pp operation), the beam lifetime due to beam-gas nuclear scattering is approximately 500 hours at an average pressure of  $1 \times 10^{-9}$  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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