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THE ULTRA HIGH VACUUM SYSTEM OF THE AGS BOOSTER*

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ABSTRACT

The AGS Booster currently under construction at Brookhaven is a synchrotron for the acceleration of both protons and heavy ions. The design pressure of 3x10⁻¹¹ Torr is required to minimize beam loss of the partially stripped heavy ions. This paper describes the design and processing of the ultra high vacuum system, and the performance of the prototype vacuum half cells.

INTRODUCTION

The AGS Booster[1], currently under construction at Brookhaven, is a small synchrotron of 200 m in circumference located between the existing 200 MeV linac, the Tandem Van de Graaff and the AGS. The major objectives of the Booster are:

(1) to increase the proton intensity in the AGS by a factor of 4 (to 6×10^{13} ppp)
(2) to increase the AGS polarized proton intensity by a factor of twenty (to 10^{12} ppp)
(3) to accelerate heavy ions up to gold in the Booster for the AGS and eventually for RHIC.

It is the third objective which puts the most stringent requirements on the vacuum system of the Booster ring. To avoid beam loss due to charge exchange between the heavy ions and the residual gas molecules, an ultra high vacuum of 10^{-11} Torr (3-4 orders of magnitude better than that for proton operation) is required.

VACUUM JUSTIFICATION

The vacuum requirement of accelerators, except for heavy ion machines, is relatively relaxed in comparison with that of the storage rings. In heavy ion accelerators, the cross sections for charge exchange (electron stripping and capture) between the partially stripped, low beta, high Z heavy ions and the residual gas molecules could be rather large.

The capture and stripping cross sections can be expressed as

$$\sigma_c \propto \beta^k \times q^m \times Z_t^n$$

$$\sigma_s \propto \beta^k \times q^m \times Z_t^n \times Z_p^r$$

with β equals to v/c
q the projectile charge state,
Z_p the atomic number of the projectile,
Z_t the atomic number of residual gas.

For capture, the values of k vary between -6 and -12; of $m \geq 2$; and of $n \leq 1$. For stripping, the values of k fall between -1 and -2; of m -3 to -4; of $n < 2$; and of r 2 to 2.5. The capture cross section is significant at low energy and drops off rapidly during acceleration cycles, while the loss cross sections decrease slowly with increasing β and become the dominant beam loss process at higher energy.

The charge exchange cross sections can be calculated by using the empirical formulae which give the best fit to the experimentally measured cross sections. Using the scaling rules proposed by A.S. Schlachter[2] for capture cross sections, and the modified Bohr-Lindhard formulae[3] for stripping, the total cross sections and beam loss during Booster acceleration cycles can be estimated. The results[4] for Au^{+33}, which will be the worst case for Booster, are summarized in Fig. 1. At the designed vacuum of 3×10^{-11} Torr with 90% hydrogen and the balance CO, CO_2 and methane, the integrated beam loss will be less than one percent.

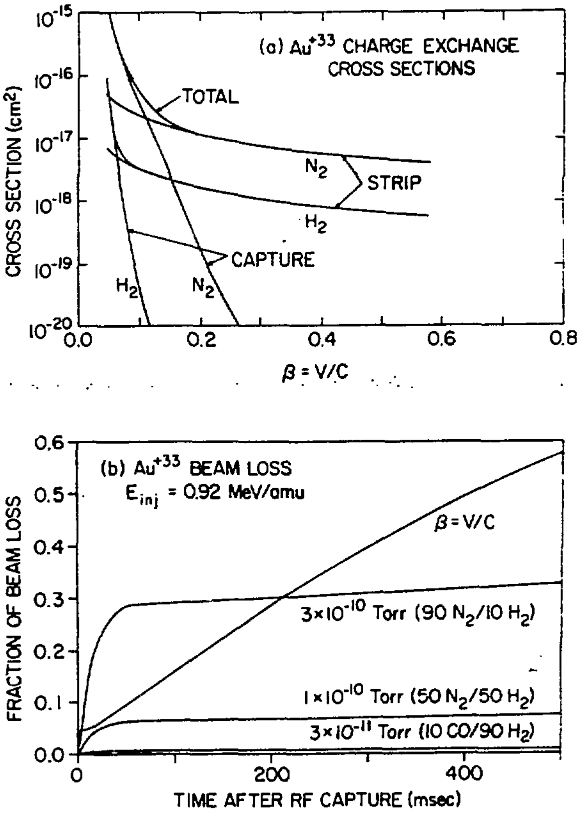

Fig. 1 (a) the charge exchange cross sections for for Au^{+33}; and
(b) the estimated beam loss for Au^{+33} during Booster acceleration cycles.

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VACUUM SYSTEMS

The designed vacuum levels for the ring and the injection/ extraction lines are $3x10^{-11}$ Torr and 10^{-10} - 10^{-9} Torr, respectively. The good vacuum for the beam transport lines will serve as pressure differentials between the 10^{-11} Torr ring vacuum in the existing 10^{-8} - 10^{-7} Torr vacuum of Linac and [illegible]

Ring Vacuum Chambers: The Booster ring is divided into 48 half cells. Thirty six standard half cells contain dipole, quadrupole and sextupole magnets. The twelve "missing dipoles" house the accelerating cavities, injection/extraction magnets and other beam components. It is logical to divide the vacuum chambers into 48 groups to coincide with these half cells. The halfcell chambers are grouped into 7 vacuum sectors isolatable by all metal gate valves. The standard halfcell chambers shown in Fig. 2 are ~ 2 m long and made mostly of Inconel 625. This material was selected for its good mechanical, electrical and vacuum properties. The dipole chambers have an elliptical cross section of 70mm x 105mm and are 2.8 m in length, curved with a bending radius of 13.75 m. Six pairs of correction coils will be mounted on the top and bottom of the dipole chambers to correct for the eddy current effect[5]. The remainder of the halfcell consists of chambers for quadrupole, PUE[6], sextupole, bellows and the transition with ports connecting to UHV pumps. To minimize the chamber impedance and rf leakage, the ports will be lined with fins.

Vacuum Pumps: The designed ring vacuum will be achieved by the combination of the titanium sublimation pumps and ion pumps. Titanium cartridges with three filaments will be mounted in the UHV bodies. Each pump body has over 3000 cm^2 area for the sublimed titanium. The total pumping speed in the ring is over 50,000 ℓ/s for active gases. The non-getterable gases such as methane and argon will be removed by ion pumps with a total pumping speed over 1000 ℓ/s.

VACUUM PROCESSING

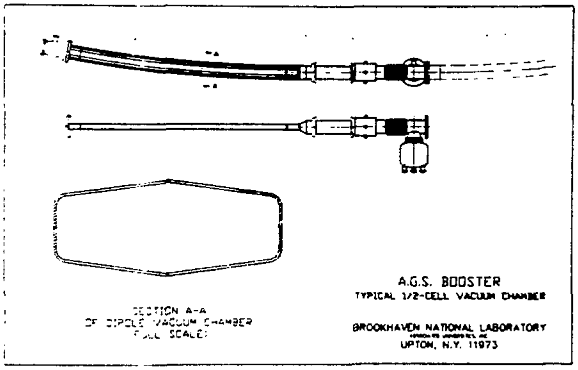

Fig. 2 The standard halfcell vacuum chamber for Booster.

Several degassing treatments will be applied to reduce the outgassing of the vacuum chambers and components located inside them.

Before assembly, they will be chemically cleaned and vacuum fired. The chemical cleaning consists of the standard vapor degreasing and rinse cycles. Vacuum firing will be done at the in-house vacuum furnace. The furnace has a 5 m long hot zone and is capable of low 10^{-5} Torr at over 1000°C. After assembly, each halfcell chamber will be baked individually to ensure both vacuum reliability and the achievement of the designed vacuum level. The assembly will also be treated with nitric oxide[7,8] gas during the bake, which removes any hydrocarbon contamination due to handling. After installation, the whole vacuum sector then will be baked insitu.

Conflat type flanges made of 316LN steel are used through out the ring vacuum system. To prevent knife-edge rounding after vacuum firing and high temperature bake, these flanges have a 90° knife edge. Copper gaskets with 0.1% Ag are used to prevent leaks caused by the recrystallization of pure copper after repeated high temperature bakes. The vacuum chambers and components within are designed to be bakeable upto 300°C. In practice, they will be baked insitu at 200°C which was found to be quite adequate to achieve the designed vacuum. High outgassing beam components such as the ferrite kickers, and septums will be baked at 300°C. The chambers will be wrapped with custom heating blankets having redundant heating elements and E type thermocouples.

The bakeout will be carried out using a commercially available PC-based system with portable local controllers. These local controllers will be wheeled to the vacuum sectors prior to the bake. The system will initiate and maintain control over the programmed bake cycles, and alarm the operators when abnormal or failure conditions occur.

Portable turbopump stations will be utilized during system pump down, bakeout and conditioning. They consist of a Balzers turbopump package, the necessary valves, Pirani and ion gauges, and a control chassis. The stations monitor the pump down and bakeout and will shut down in the events of component failure, avoiding damage and contamination to the beam vacuum. The pump stations will be monitored by the Booster computers through Datacon drops in the tunnel.

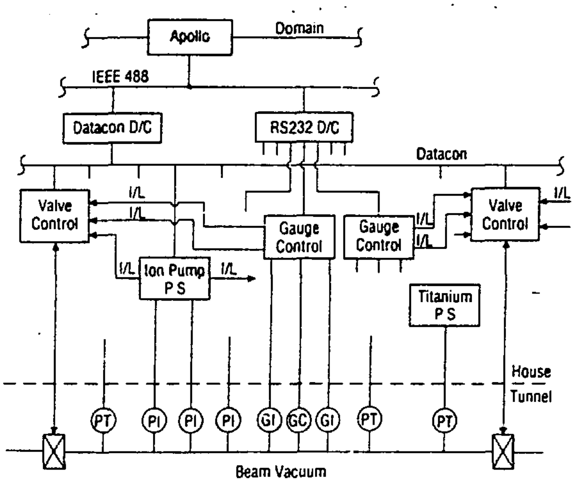

Fig. 3. The vacuum instrumentation and control for a typical vacuum sector.

VACUUM INSTRUMENTATION AND CONTROL

Due to the presence of high radiation levels in the Booster tunnel, all the power supplies and controls are located in the instrumentation building. They consist of the power supplies for ion pumps and titanium pumps, controllers for vacuum gauges and valves and the computer systems. The layout of a typical vacuum sector is depicted in Fig. The gauge controllers will communicate with the device controllers(D/C) through RS232 links. The ion pump power supplies and valve controllers are linked to the D/Cs through IEEE-488 compatible Datacon interface cards. The D/Cs communicates with the Apollo system via a station drop.

Titanium Pump Power Supply: The titanium pump power supplies will degass the titanium filaments during pumpdown and bakeout, and sublime the titanium to the UHV bodies when the needs arise. These supplies consist of SCR based controllers which power and regulate the sublimation rate through the constant current mode. The filament current will be stepped up by transformers located in the tunnel near the cartridges. At 48 A filament current, the sublimation rate, depending on the age of the filaments, will be approximately 1 mg/min. Approximately one gram of titanium can be sublimed by using this constant current mode.

Ion Pump Power Supply: The power supplies develop potentials up to 5 KV and are current limited to 200 mA using ferroresonant transformers. Both voltage and current are measured for pressure monitoring and for diagnostics. Current down to 1 µA can be reliably measured through the linear and log amplifiers. The measured current and voltage are converted to frequencies and fed to Datacon interface cards for computer monitoring and display. Opto coupling is used for ground isolation in outputting the interlock and status signals for valve control and other equipment.

Vacuum Monitoring: The vacuum will be monitored by the combination of Bayard-Alpert type ion gauges and ion pump currents. The ion gauges have a thin collector of 0.05 mm diameter and an X-ray limit of 5×10^{-12} Torr[9]. Commercially available vacuum process controllers will be used to power, monitor and interlock these gauges. To overcome losses over the long cable run(up to 200 m), large gage wires and bigger transformers will be used to power the filaments. To minimize EMI/RFI, fully shielded collector cables and the grid and filament wires will be placed in a single twisted and shielded jacket. Ferrite attenuator beads will be utilized where needed. Process control outputs from each ion gauge will be utilized for sector valve interlock. A residual gas analyzer will be installed at each vacuum sector to measure the gas composition of the beam vacuum and for trouble shooting.

Valve Control and Interlock: The beam vacuum is protected by sector valves. A fault detected by one ion pump or two ion gauges in the same sector will cause the valves to close, thus minimizing the loss of vacuum in adjacent sectors. This voting scheme will eliminate the false triggering due to noise or malfunctioning of individual controllers. Auxiliary interlock I/O in the valve controllers also allow for the cross coupling and interlock of other valves or equipment.

PERFORMANCE OF VACUUM HALFCELLS

Up to this date, several halfcell chambers have been constructed for mechanical and vacuum evaluation. Outgassing levels of low 10^{-13} Torr. ℓ/s.cm^2 were routinely achieved for stainless and Inconel chambers after vacuum firing and 200°C bake. The effectiveness of nitric oxide in removing hydrocarbon from the vacuum system has been successfully tested. It will be used for on-line cleaning of Booster vacuum half cells. The pump down of a prototype half cell chamber is shown in Fig. 4. One week after the 200°C bake, a base pressure of 1×10^{-11} Torr was reached with no measurable hydrocarbon down to 10^{-13} Torr levels.

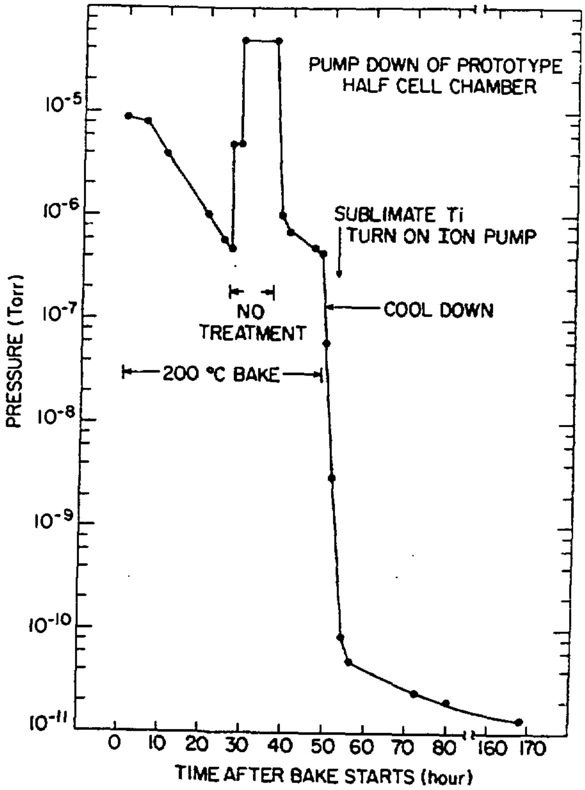

Fig. 4. The pumpdown curve of the prototype half cell vacuum chamber.

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