

## PROCESSING AND EVALUATION OF THE AGS BOOSTER ULTRA-HIGH VACUUM SYSTEM\*

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### VACUUM SYSTEMS

#### ABSTRACT

The AGS Booster is a synchrotron for the acceleration of both protons and heavy ions. To minimize the beam loss due to charge exchange of the partially stripped, low  $\beta$  very heavy ions with the residual gas molecules, pressure of low  $10^{-11}$  Torr is required for the 200 m Booster ring. To achieve this ultra high vacuum, chemical cleaning, vacuum furnace degassing and insitu bake were employed for all chambers and beam components. Using these procedures, vacuums of low  $10^{-11}$  Torr have been routinely achieved during the testing of individual half cells and beam components, and during the commissioning of the vacuum sectors. In this paper, the design and layout of chambers, flanges and bakeout hardware is briefly described. The vacuum processing of different components and the results of bakeout and evaluation are summarized. The experience gained during the construction and commissioning of this ultra-high vacuum system is also given.

#### INTRODUCTION

The recently completed AGS Booster [1] 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  $6 \times 10^{13}$  ppp)
- 2) to increase the AGS polarized proton intensity by a factor of twenty (to  $10^{12}$  ppp)
- 3) to accelerate partially stripped 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 [2] between the very heavy ions and the residual gas molecules, an ultra-high vacuum of low  $10^{-11}$  Torr is required. At this vacuum, the estimated beam loss for  $\text{Au}^{+33}$ , which is the worst case for Booster, is less than one percent.

The details of the Booster vacuum system can be found in reference 2. Some major components are briefly described below.

**Ring Vacuum Chambers:** The Booster ring has 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. The vacuum layout of one sextant of the ring near the injection area is shown in Figure 1. A typical half cell chamber is about 4.2 m long, made mostly of Inconel 625 and consists of chambers for dipoles, quadrupole, PUEs, sextupole, bellows and a transition with ports connecting to pumps, gauges and valve. The standard half cell chamber is shown in Figure 2.

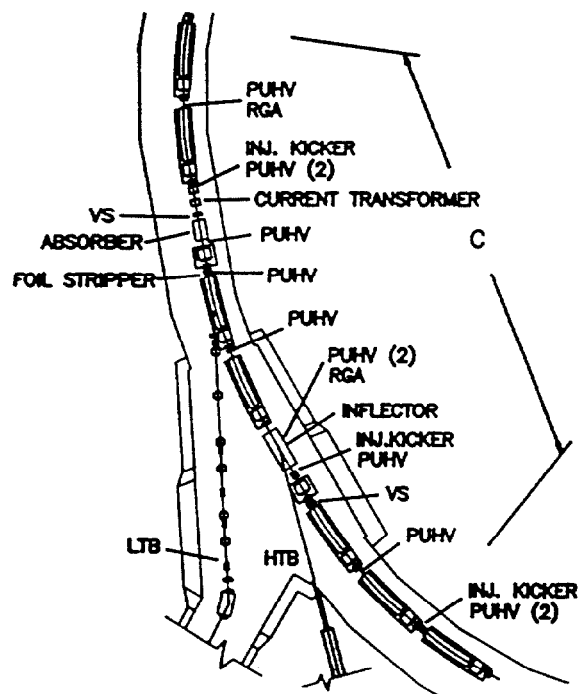


Figure 1

Vacuum Layout of Sextant C of Booster Ring near the Injection Area; PUHV represents the titanium pump/ion pump/ion gauge package in the UHV pump body.

\* Worked performed under the auspices of the U. S. Dept. of Energy.

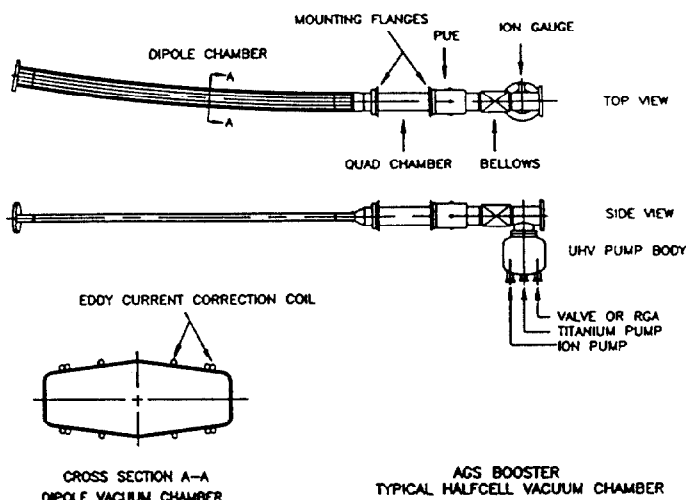


Figure 2

Schematics of Half Cell Vacuum Chamber

**Flanges/Seals:** Conflat type flanges with 90° knife edges made of 316LN steel are used throughout the ring vacuum system. Copper gaskets with 0.1% Ag are used to prevent leaks caused by the recrystallization of pure copper after repeated high temperature bakes. Commercial "EVAC" type flanges and in-house developed "Chain-Clamp" type flanges, both with 90° Conflat knife edges which can be disconnected and/or jointed quickly, are used at areas with high expected residual radiation. In our lab test they were repeatedly baked up to 300°C with no creeping and leakage.

**PUE:** Worth mentioning here is the construction of the PUEs. The PUE location has to be accurate within 0.1 mm after vacuum firing and repeated insitu bake. This leads to the double gimbaled suspension which allows the electrodes to be rigidly supported while being free to move radially and longitudinally during vacuum firing or bakeout. The position accuracy achieved were within 0.2 mm in the transverse directions and less than 1 mrad in rotation.

**Vacuum Pumps:** The designed ring vacuum was achieved by the combination of titanium sublimation pumps and ion pumps. Fifty-five titanium cartridges are mounted in the UHV bodies, each with 1000 l/s pumping speed for active gases. The non-getterable gases such as methane and argon are removed by small ion pumps. Portable turbo-pump stations were used during pump down, bakeout and conditioning.

**Instrumentation and Control:** Due to the presence of high radiation levels in the Booster tunnel, all the power supplies and controls [3] 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 gauge controllers are capable for

reading vacuum of  $1 \times 10^{-11}$  Torr, and 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 an IEEE-488 compatible interface. The D/Cs communicate with the Apollo system via a station drop. The SCR based titanium power supplies are operable locally, since they are energized periodically for a few minutes only.

## VACUUM PROCESSING

To reduce outgassing, various degassing treatments were applied to vacuum chambers and components located inside them.

Before assembly, they were chemically cleaned and vacuum fired. The chemical cleaning consisted of degreasing, detergent soak and rinse cycles. The components were welded and assembled in a Class 1000 clean room before vacuum firing. The chambers were usually vacuum fired at 950°C for two hours.

The treatment of beam components, depending on the material involved and the assembly/testing sequence, could be quiet different. For instance, the nickel-zinc ferrite used in the kicker magnets was to be fired at 950°C, however, due to the decomposition of oxides at high temperature which reduced the ferrite impedance, the ferrite was fired at 400°C. The vacuum firing temperature for various components is summarized in Table I.

Table I Furnace Degassing of Beam Components

Material	Temp(°C)	Duration (hr)
Stainless and Inconel	950	2
	500	24
Ferrite	400	50
Feedthroughs and Ceramic w/ Brazing	500	24
Graphite	950	2
Copper	500	24

## VACUUM EVALUATION

The assembly and vacuum evaluation of half cells began in March, 1990, when the first set of production magnets was available. The tunnel was ready for component installation in June, 1990. The assembly and testing of beam components began during the Summer of 1990. The whole ring components, with the exception of the heavy ion inflector and cavities, were installed by the end of April. The pump-down and bakeout of the sector began when all the components in the sector were installed.

The vacuum chambers and the components contained within were designed to be bakeable at 300°C. They were baked at 250°C before installation and 200°C insitu, which was adequate to achieve the designed vacuum. The bakeout was

controlled and monitored with PC-based programmable logical controllers (PLC). These controllers were wheeled to the appropriate vacuum sectors prior to the bake and removed after bake. The PLCs initiate and maintain control over the programmed bake cycles, and alarm the operators when abnormal or failure conditions occur.

**Half Cells and Quarter Cells:** After cleaning, welding and vacuum firing, eddy current coils, thermocouples and heating blankets were mounted on the chambers. After inserting chambers into the pre-aligned magnets, the PUEs were aligned against the quadrupoles. Of the thirty-six half cell chambers, two had to be reworked to meet the  $\pm 1$  mrad rotational tolerance of the PUEs. The downstream vacuum flange was welded after PUE alignment and electrical test. The associated vacuum components, pumps, gauges, valve and residual gas analyzer, were then mounted for pump-down and bakeout. The bakeout usually began on day 1 and terminated on day 3. Degassing, conditioning and turning-on of the pumps followed.

Approximately 80% of the chambers reached a vacuum better than  $5 \times 10^{-11}$  Torr one day after bakeout. Most chambers with higher pressure were found to have leaks at the Conflat gaskets. Two chambers had leaks at the welds and had to be repaired. By using residual gas analyzers, we were able to identify the source of residual gases immediately and take necessary corrective action.

**Beam Components:** Every beam component for the ring was evaluated for UHV before installation. Among the fifteen beam components evaluated, ten had reached vacuum of  $10^{-11}$  Torr one day after bake. Two kickers had to be rebaked at higher temperature ( $300^\circ\text{C}$ ) for several days to remove hydrocarbon contaminant inadvertently introduced during the assembly. Others had high hydrogen outgassing and might originate from parts that were not vacuum fired.

**Commission of Vacuum Sectors:** The insitu bake of vacuum sectors, similar to the half cell evaluation, began on day 1 and ended on day 3. Four of the seven ring sectors have been baked. Three reached the designed vacuum of low  $10^{-11}$  Torr one day after end-of-bake. One sector had a lot of hydrocarbon contamination and was rebaked. Using residual gas analyzers, the presence of leaks were identified immediately, even when the pressure was at the  $10^{-11}$  Torr level as evident in Figure 3. The presence of an argon peak at  $m/e=4$  in C Sector indicates leaks which were subsequently located at a bellows weld.

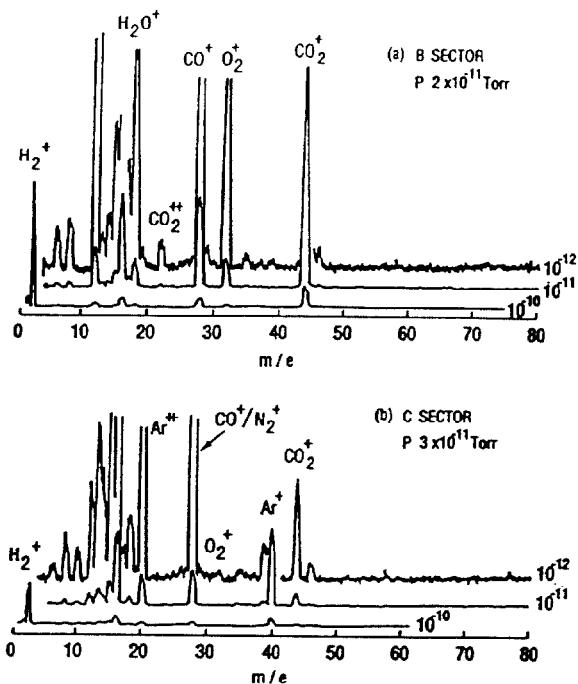


Figure 3

Residual Gas Spectra of Vacuum Sectors at  $10^{-11}$  Torr (a) without detectable leak, and (b) with  $10^{-10}$  Torr. 1/sec leak at bellows. The leak is evident by the presence of argon at  $m/e=40$ .

Due to the beam commissioning schedule, the remaining sectors were not baked as of this date and a vacuum of high  $10^{-9}$  Torr was maintained using a few small ion pumps. An overall vacuum of high  $10^{-10}$  Torr was achieved after opening of the sector valves. Propagating of pressure zones due to "poisoning" of baked sectors by the adjacent unbaked sectors requires the rebaking of the whole ring, which is planned during the coming summer maintenance period.

## CONCLUSION

With proper selection of material, pretreatment and insitu bake, most Booster ring ultra-high vacuum system has met its designed vacuum of low  $10^{-11}$  Torr. The tight space between the magnets and chambers, and the expected residual radiation will make the maintenance and upgrade of this system rather difficult. The cost of the bakeout system, including blankets, thermocouples, contactor boxes, PLCs, PC and labor, is approximately 25% of the total vacuum system cost. The use of RGAs as diagnostic tools at ultra-high vacuum levels has proven to be a very powerful tool in identifying the source of residual gas.

## REFERENCES

1. W. T. Weng et al., "Construction and Early Commissioning Results of the AGS Booster", *ibid.*
2. H. C. Hseuh, et al., IEEE 2669-0, p.574, 1989.
3. J. Gabusi, et al., "Instrumentation and Control of the AGS Booster Vacuum System", *ibid.*