# PRESSURE DISTRIBUTION SIMULATION FOR SNS RING VACUUM SYSTEMS*

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*Abstract*

Brookhaven is responsible for the design and construction of the US Spallation Neutron Source (SNS) accumulator ring and beam transport lines. Ultrahigh vacuum of a few nano-Torr is required for the accumulator ring to minimize the residual gas ionization. To size the pumps and to optimize the pump locations, the pressure distribution in the vacuum systems has to be calculated based on chamber conductance, the static and dynamic outgassing of the chamber walls and the beam components. A computer program, based on finite differential approximation, was used to model the pressure in the accumulator ring, using the measured outgassing rates of chambers with and without TiN coating. The simulation results indicate that the designed vacuum will be achieved after prolonged pumping due to the high outgassing associated with the low secondary electron yield coatings.

## INTRODUCTION

The SNS accumulation ring, with a circumference of 248m, consists of 4 arc sections of 34m each and 4 straight sections of 28m each for injection, collimators, extraction and RF & diagnostics [1]. The vacuum systems are conveniently divided into eight vacuum sectors isolatable with all-metal electro-pneumatic gate valves located at the interface of the arc sections and the straight sections. The ring schematic layout is shown in Fig.1 and a list of ring vacuum components and their parameters are given in Table 1.

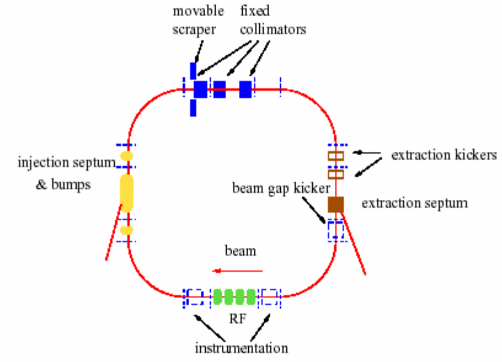


Figure 1. Schematic layout of the SNS accumulator ring. The four straight sections are designed for beam injection, collimation, extraction, and RF systems, respectively.

**Table 1. Accumulator Ring Vacuum System Parameters**

| Description | # Unit | Length |
|---|---|---|
| Design Vacuum Level | | $< 1x10^{-8}$ Torr |
| Arc Half Cell Chamber | 32 | 4 m |
| Arc Quarter Cell Chamber | 4 | 2 m |
| Straight Region Doublet Chamber | 8 | > 3 m |
| Straight Region Special Chambers | 16 | 0.5-4 m |
| Sputter Ion Pumps, 300 l/s | 50 | |

Only UHV compatible metals and ceramics will be used in the construction of the ring vacuum system for their vacuum properties and radiation resistance. No organic materials are allowed. To minimize the RF impedance, the chambers will have tapered transitions wherever significant changes in cross sections occur. All the pump ports will be shielded with RF screens (thin mesh), which has little effect on the available pumping speed. Conflat type flanges and seals, for their cost and reliability, will be used to join the arc chambers. Quick-disconnect chain clamps, flanges and metal seals will be used at the straight sections where the expected beam loss will be higher, therefore minimizing the personnel radiation exposure during vacuum maintenance and repair. To reduce the secondary electron yield (SEY), the inner walls of the ring chambers are being coated with ~100nm titanium nitride (TiN).

Vacuum is obtained using lumped pumps (i.e. pumps appending the beam line at periodic intervals), thereby simplifying the mechanical design and improving serviceability (i.e. ALARA considerations). Often, vacuum systems of this design require special attention in determining the relationship of pump speed and spacing to avoid a condition of conductance limitation or unnecessary cost. An analysis of periodically pumped, longitudinal vacuum systems can be carried out using rudimentary vacuum formulas, assuming uniform outgassing, conductance and pump spacing, which can yield acceptable results for predicting general performance for many applications. One such analysis is given by Welch [2]. With the advent of vacuum simulation code, factors such as non-uniform outgassing, unequal pump spacing, and varying conductance, as is the case within regions of the SNS accumulator ring, can be more easily accommodated. The software used is a program called VACCALC, which solve the differential equations for the pressure piecewise [3]. This software

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was used to estimate the pressure profile in the upgraded HERA interaction regions [4].

## PRESSURE DISTRIBUTION COMPUTATION

In this section the pressure profile and average pressure of SNS ring arc and straight sections are calculated using VACCALC code. Varying the size, number and spacing of pumps for various outgassing rates will permit the design of a minimum cost accelerator vacuum system for predetermined vacuum performance requirements The real residual gas composition is not known precisely, however, for relative comparisons we assume the gas composition is $H_2$(40%), $H_2O$(40%),and CO(20%). The gas desorption loads from special beam components, such as stripping foil and the extraction kicker ferrite, limit the accuracy of the simulation to a factor of 2 or more.

### *Pressure Profile in Arc Section*

Each ring arc section (Fig.2) has 8 halfcell chambers and one quartercell chamber. The vacuum chambers and the magnets are grouped symmetrical to the middle quadrupole, such that they are mirror images to each other. Five ion pumps will be installed in the Arc section for day-one operation. Pump ports are available at each halfcell chamber for future upgrade.

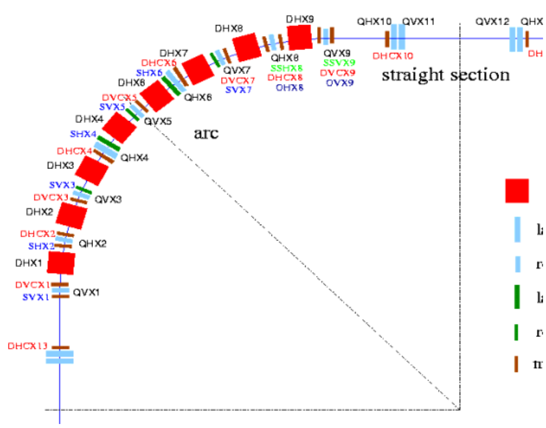


Figure 2. Schematic layout of arc sections.

The outgassing rate of stainless steel is well understood and confident estimates can be made for a wide variety of conditions. However, because of the required TiN coating to reduce SEY, outgassing data for coated chambers is needed for vacuum simulations and to meet design requirements. The ring vacuum system will not be baked, so of particular interest is the outgassing data without *in-situ* bake. The outgassing rate of several SNS chambers was measured by means of the orifice method and summarized below [5].

The purpose of TiN coating is to minimize the SEY from the chamber wall, thus avoid the so-called e-p instability caused by electron multi-pacting. TiN-coated coupons were sent to CERN for SEY measurements. The results [5] show that TiN films generated at higher sputtering pressures have an SEY ~ 50% lower than those films generated at a lower pressure. However, the outgassing rate of the higher pressure film is, on average, an order of magnitude higher than that of the low pressure film. Both the low SEY and high outgassing is a result of the increased surface roughness of the film. Because electron cloud effects will be more deleterious to accelerator operations than the increased pressure, chambers will be coated at higher pressure. The pressure profiles, with the specific outgassing rate of $1.2\times10^{-10}$ Torr.l/s.cm$^2$ (with TiN coating) and $8.5\times10^{-12}$ Torr.l/s.cm$^2$ (without TiN coating) are shown in Fig.3.

**Table2. Outgassing for chambers under various conditions.**

| **Description** | **Q** | **Hours** |
|---|---|---|
| Chamber #2A(VD, no TiN) | 8.5E-12 | 120 |
| Chamber #2A(VD,HP, TiN) | 1.2E-10 | 120 |
| Chamber #5B(VD,LP, GDT, TiN) | 9.6E-12 | 120 |

(VD: vacuum degass at 450°C, HP: TiN coated at 4 mTorr, LP: TiN coated at 1.5 mTorr, GDT:post glow discharge treatment)

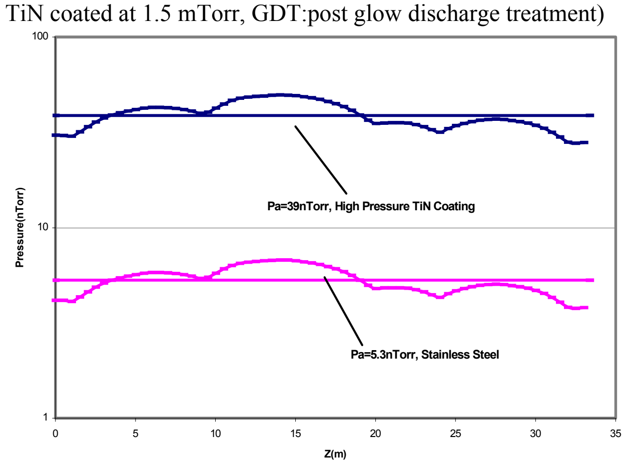


Figure 3. Pressure profiles in arc sections.

### *Pressure Profile in Injection Section*

The SNS injection section has eight injection kickers, one injection septum, one dump septum, four injection bending magnets and two quad doublet assemblies. The layout is shown in Fig.4. The injection bending magnet No.2 has a thin carbon foil to strip the electrons off the $H^-$ beam. This foil will be heated by the proton and the two accompanying electrons. Therefore an additional factor of 5 in gas desorption at B2 region is used in the simulation. Figure 5 shows the pressure profiles in the injection section.

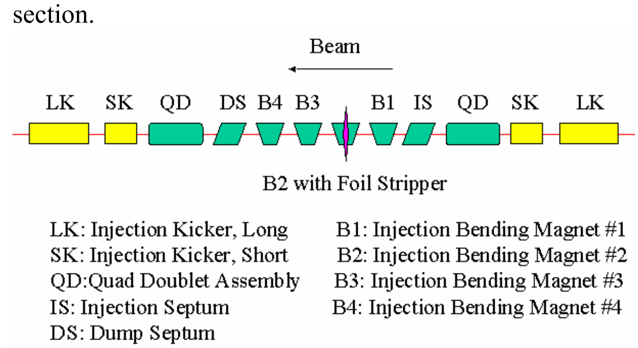


Figure 4. Schematic layout of injection section.

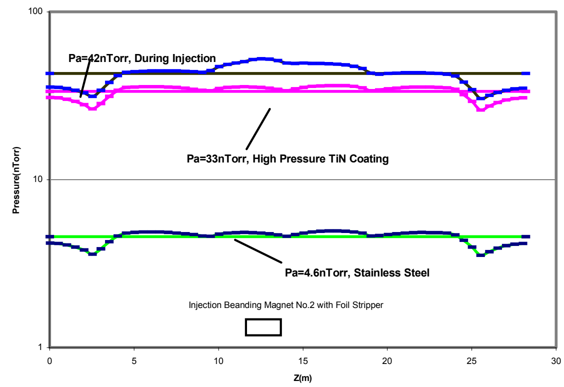


Figure 5. Pressure profiles in injection section.

## *Pressure Profile in Collimator Section*

In the SNS accumulator ring, a straight section is dedicated to transverse collimation. The present ring lattice uses one primary and two secondary collimators (Fig.6) to mitigate beam halo caused by space charge and other collective effects. The collimator system is designed

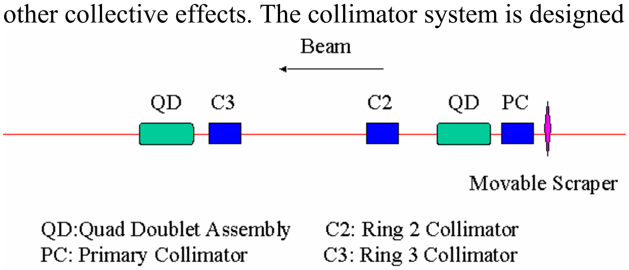


Figure 6. Layout of the collimation straight section

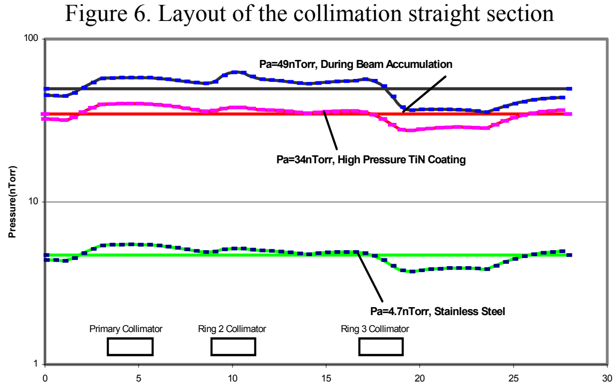


Figure 7. Pressure profiles in collimation section.

to handle the entire portion of the anticipated $2x10^{-3}$ fractional beam intensity. Therefore the simulation uses an additional factor of 5 for gas desorption and the result is shown in Figure 7.

## *Pressure Profile in Extraction Section*

Figure 8 gives the extraction section layout. The extraction system of SNS ring has 14 kickers (separated into two groups) and the apertures of those kickers were adjusted with the betatron function to yield the overall SNS ring acceptance [6]. A total of 168 ferrite blocks will be installed inside the vacuum chamber. The specific desorption rate of ferrite is $3x10^{-11}$ Torr.l/s.cm$^2$ (before *in-situ* baking) and $2x10^{-12}$ Torr.l/s.cm$^2$ (after *in-situ* baking) [7]. The pressure profiles are shown in Fig. 9 with and without in-situ baked ferrites.

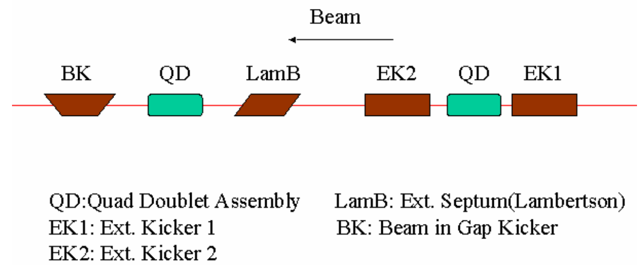


Figure 8. Schematic layout of extraction section.

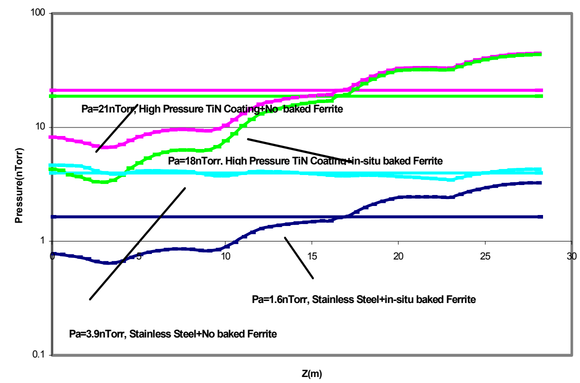


Figure 9. Pressure profiles in extraction section.

## SUMMARY AND DISCUSSION

Pressure distribution simulation on the SNS ring vacuum system has been presented. Our simulation results show that the average pressure will be 3~4 times higher than the design value of $<1x10^{-8}$ Torr due to higher outgassing rate with TiN coating done at higher sputtering pressure. The pressure will decrease with SNS beam conditioning based on CERN SPS beam scrubbing experience [8]. The pressure may also be reduced by adding titanium sublimation pumps and ion pumps at existing pump ports of vacuum chambers in future upgrade.


## ACKNOWLEDGEMENTS

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