UPGRADING THE SNS COMPRESSOR RING TO 3 MW*

W.T. Weng, M. Blaskiewicz, A. Fedotov, Y.Y. Lee, D. Raparia, J. Wei, BNL, Upton, NY 11973, USA, V. Danilov, S. Henderson, J. Holmes, N. Holtkamp, ORNL, Oak Ridge, TN 37830, USA

Abstract

The initial performance goal for the SNS compressor ring is 1.4 MW with 1.0 GeV linac beam. During the design phase many considerations and provisions have been made to allow progressive increase in power level of the ring, ultimately to 3.0 MW and beyond after years of improvements. The most important provision for future higher power operation is an increase in beam energy from 1.0 to 1.3 GeV. Other possible upgrades covered in this report include ion source current, new stripper foil material, injection and extraction systems, transverse damper, barrier cavity, and electron clearing to avoid e-p instability.

1 INTRODUCTION

The performance goal of the SNS accumulator ring (AR) consistent with the baseline parameters is 1.4 MW with 1.0 GeV linac beam [1] . This requires the ion source delivering 38 mA peak current for 1.0 msec at 60 Hz. There are many ways to estimate the higher reach in beam power of the SNS AR depending on which factor is deemed to be fundamental. For example, if we assume that the incoherent space charge tune shift is the most important limiting factor in the achievable intensity in the AR, then for a constant tune shift of $\Delta Q=0.2$, the energy dependence of the achievable beam power can be represented as in Fig. 1.

$$\Delta Q = 3 r_p N / 2\pi\beta\gamma^2 \varepsilon_N B_f \,, \tag{1}$$

where r_p is the classical radius of proton, N is the number of proton, B_f is the bunching factor and ε_N is the normalized 95% emittance of the Gaussian beam.

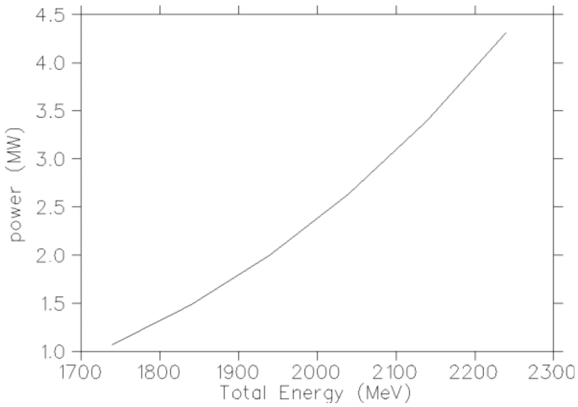

Figure 1: The energy dependence of achievable power in the SNS AR for the constant tune shift

In 1999, the superconducting technology was adopted for the SNS linac from 185.6 MeV to 1.0 GeV. At that time, it was already anticipated that the SNS linac is capable of reaching 1.3-1.5 GeV based on CEBAF and LEP experience of delivering higher gradient after several years of beam conditioning and extra space reserved for 3 more cryo-modules in case needed. Due to this possibility, the HEBT injection line and the AR itself were made 1.3 GeV compatible in the geometric layout and lattice design.

It is clear from the Fig. 1 that the ring can reach about 4 MW if the space charge tune shift is the only limiting factor. Here we try to delineat what has to be done, if our aim is 3 MW at 1.3 GeV, not the ultimate power can be reached by the SNS ring. That question can only be realistically answered after several years of operation. In the following, we will review those upgrades which may play important role in raising the beam power of the SNS AR. Some of the mentioned upgrades may only be needed for higher than 3 MW, but are included for completeness.

2 THE MODE OF INJECTION

In the current scenario, the AR will accept 1060 turns of H- linac beam at peak current of 38 mA for 1 msec to reach $1.5*10^{14}$ ppp which will deliver 1.4 MW at 1.0 GeV. If injected at 1.3 GeV, there are two possibilities. One is to increase the linac pulse length to 1.6 msec for the AR injection of 1625 turns to accumulate $2.3*10^{14}$ ppp which will deliver 3.0 MW at 1.3 GeV. The other way is to increase the source peal current to 58 mA and keep the pulse length at original 1.0 msec. Since the duty factors of the source and linac are much harder to change, it seems that increasing the source current may be the easier way to achieve more charge in the AR.

3 H^- STRIPPING

In the current design, the traditional carbon stripping foil is assumed. Since the typical accelerator application never reached the intended power limit the SNS requires, we started a foil accelerator program to understand the life time of carbon foil at the SNS power regime. Several carbon foils were put in the AGS linac beam line after the RFQ where the proton beam energy is 750 KeV. At 6.7 Hz, the equivalent average current is 2 mA to simulate the foil integrity of SNS 2 MW operation at 1.0 GeV. The typical life times reached were about 20 to 30 hours of various types of carbon foils [2]. Even with the in situ foil replacement mechanism, this is still too short a life time to be reliable.

A new program was started to manufacture a new type of foil which has diamond-like structure and is capable of much better mechanical properties under high

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temperature. The preliminary test showed a much improved life time of higher than 400 hours . Such a foil should have life time better than 250 hours at the suggested 3 MW operation at 1.3 GeV.

The AR lattice was changed in 1999 to have matched long straight section of 12.5 m without interruption. When the laser stripping [3] method become viable such a long straight section will be sufficient for the new method with no need of foil.

4 BARRIER CAVITY

The estimated incoherent space charge tune shift for 3 MW beam at 1.3 GeV is less than 0.16 which should not generate excessive beam loss due to non-linear resonances. This low tune shift is achieved by second harmonic cavity in addition to the fundamental one. Such an arrangement increases the bunching factor (B_f in equation 1) from 0.35 to 0.42. In fact, the bunching factor can be further reduced by using barrier cavity for the RF system [4]. In that case, the realizable bunching factor can be as low as 0.56 with the associated maximum tune shift of about 0.12. Although such a low tune shift may not be needed for 3 MW operation, it can be useful for higher power, in case the research program requires it.

5 THE TRANSVERSE DAMPING SYSTEM

It is likely that a wideband transverse damper system will be necessary at beam intensities beyond the baseline design. We expect to require transverse damping in three frequency ranges. First, the resistive wall impedance will excite the lowest betatron sideband, which lies in the range 0.2-0.8 MHz (depending on operating point) with growth rates of ~5 msec^{-1}. The extraction kicker impedance will drive a transverse instability in the frequency range 5-30 MHz with growth rates of 10-15 msec^{-1}. Finally, the e-p instability results in coherent motion in the 100-200 MHz band with growth rates in the range 30-100 msec^{-1}.

We focus on parameters of a feedback system which can damp transverse motion in the range 0.2-40 MHz. To achieve the necessary high-frequency response, the stripline kicker length is set to 1m. Free space is provided in the accumulator ring for the addition of multiple kickers, if required. We assume that a single RF power amplifier can excite both kicker plates (with 50 Ohm impedance) by using a power-splitter. Assuming optimal phase-advance between pickup and kicker is achieved, and assuming that the maximum expected transient is 1mm (which results in the maximum power delivered to the kicker), two stripline kickers each driven by a 1 kW RF power amplifier would provide the required 15 msec^{-1} damping rate in the vertical plane. Figure 2 shows the dependence of vertical damping rate for SNS parameters on the total RF amplifier power. The horizontal damping rate is greater for the same power, due to more favorable beta-functions. Further damping rate can be delivered by increasing the RF amplifier power, or with the addition of more stripline kickers.

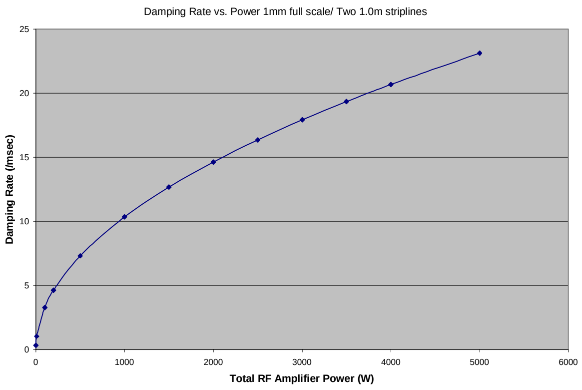

Figure 2: Damping rate verse power.

6 THE ELECTRON CLOUD EFFECT

Primary electrons due to losses can be amplified by the time varying field of the proton beam in combination with a secondary emission yield exceeding one, for some range of incident electron energy. For a fixed location in the ring the electron density rises sharply as the bunch passes and then decays owing to the space charge field of the electrons and the finite probability for electron reflection from the wall. The net line density of electron (λ_e) surviving the abort gap in the proton beam depends on wall conditions. For reasonable parameters λ_e < 2 nC/m [5]. Figure 3 shows threshold h=1 voltage versus beam intensity for λ_e =2nC/m and variety of electron cloud instability models.

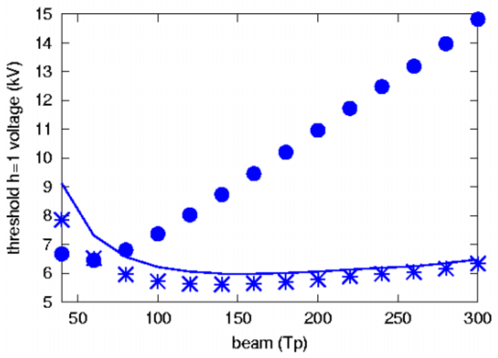

Figure 3: Threshold voltage verses number of stored protons for λ_e =2nC/m and rms bunch length σ_t =144 ns. The star were calculated using a transverse mode coupling instability (TMCI) code for barrier bucket RF, the solid line is the coasting beam threshold using the same momentum distribution as the TMCI code, and the circles are coasting beam estimates assuming a parabolic momentum distribution which has the same rms width as one assumed in the TMCI code.

The proton kinetic energy is 1 GeV and rms transverse emittance is 30 π mm mrad. Since the design value for the h=1 RF voltage is 40 kV the calculations predicts more than a factor of 2 safety margin. For the LANL PSR, the coasting beam estimate using the parabolic distribution predicts a threshold voltage 3 times that observed in the real machine [5]. Therefore, the calculation errors on the side of caution and it is unlikely that the electron cloud instability will become a problem at 3 MW.

7 POWER LIMIT AT ALTERNATING WORKING POINT

For the present choice of working point (6.23,6.20) and energy of 1.3GeV,the highest possible power with low-level beam loss is about 3.5MW, limited by crossing of half-integer resonance [6]

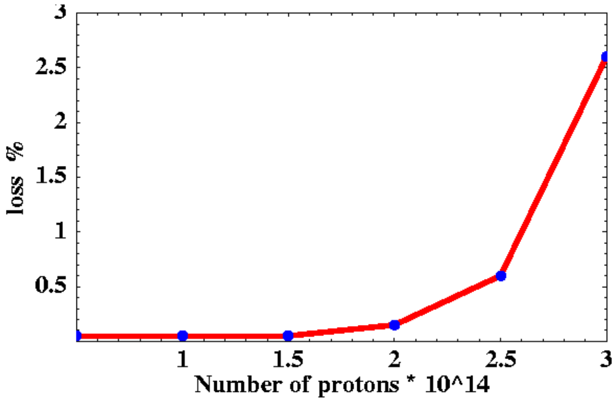

Figure 4: Resonance driven beam loss as a function of bam intensity for working point (6.23,6.20) for 1 GeV.

If another working point (6.4,6.3) is adopted, the beam power limit can be raised to about 5MW, provided sufficient stop band corrections are instrumented to compensate the 3rd and 4th order resonances. The estimate of the loss pattern (without resonance compensation) is shown in Figs. 4 and 5 for the two working points, respectively.

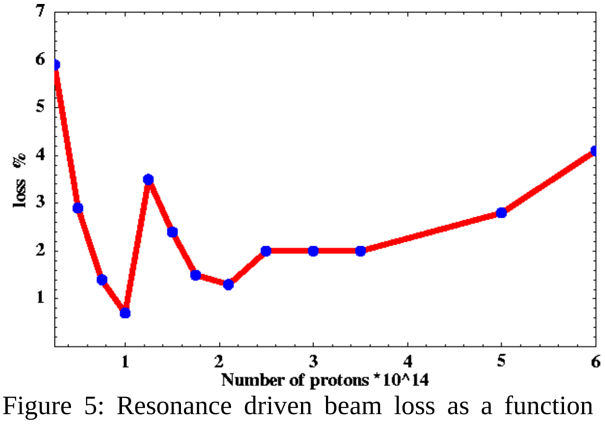

Figure 5: Resonance driven beam loss as a function of beam intensity for working point (6.4,6.3) for 1 GeV.

Recently, it was shown that more strict intensity limitation is given by the transverse collective instability, for example, due to the extraction kickers impedance [7].

The energy increase from 1.0 to 1.3 GeV moves the instability threshold to only slightly above 2MW. The goal of 3MW still seems feasible provided that either transverse impedance is decreased by 50% and/or the feedback system is effective.

8 INJECTION, EXTRACTION, AND COLLIMATION

The baseline design for the injection and extraction kickers are only compatible with 1 GeV operation and have to be upgraded for 1.3 GeV. Especially two of the orbit deformation dipoles at the injection point have to be redesigned to provide proper end field for the electron collection at the stripping foil.

According to the analysis given above, the SNS AR is capable of reaching 3 MW and beyond at 1.3 GeV. Another issue has to be considered is the function of the collimator which is designed to contain the stray primary protons in the order of about 10^{-3} and the associated secondary particles at 1.0 GeV[8]. The efficiency of the collimators at 1.3 GeV will be reduced which can be corrected by using new stopping material, or by extra shielding around the collimators and adjacent beam components.

9 REFERENCE

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