ACCUMULATOR RING DESIGN FOR THE NSNS PROJECT *

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Abstract

The goal of the proposed National Spallation Neutron Source (NSNS) is to provide a short pulse proton beam of about 0.5μs with average beam power of 1MW. To achieve such purpose, a proton storage ring operated at 60Hz with 1×10^{14} protons per pulse at 1GeV is required. The Accumulator Ring (AR) receives 1msec long H^- beam bunches of 28mA from a 1GeV linac. Scope and design performance goals of the AR are presented, other possible technological choices and design options considered, but not adopted, are also briefly reviewed.

1 INTRODUCTION

The Oak Ridge National Laboratory is leading a conceptual design for a next generation pulsed spallation neutron source, the National Spallation Neutron Source (NSNS) [1]. There are three major accelerator systems included in Brookhaven's area of responsibility. First is the High Energy Beam Transport (HEBT) system [2]. Secondly, the Accumulator Ring (AR) system and thirdly, the Ring to Target Beam Transport (RTBT) system [3]. This paper describes the design of the AR itself whose magnet and tunnel layout is shown in Fig. 1.

The proton Accumulator Ring is one of the major systems in the design of the NSNS. The primary function of the AR is to take the 1GeV H^- beam of about 1msec length from the linac and convert it into a 0.5μs beam through a stripping foil in about one thousand turns. The final beam should have 1.0×10^{14} protons per pulse, resulting in 1MW design average beam power at 60Hz repetition rate. Provisions have been reserved for a future upgrade to 2MW beam power by doubling the stored current to 2.0×10^{14} proton per pulse without changes in both the magnet and vacuum system.

One of the major performance requirements is to keep the average uncontrolled particle loss during the accumulation time to less than 2.0×10^{-4} per pulse. The reason of this stringent requirement is to keep the residual radiation to such a level that the hands-on maintenance is possible except for a few localized areas, such as: injection, extraction and collimation. To achieve this goal, special care have been exercised in the H^- stripping, the RF stacking, and the collimator design.

This paper describes the final product of the intensive R&D efforts in the past two years. During that pe-
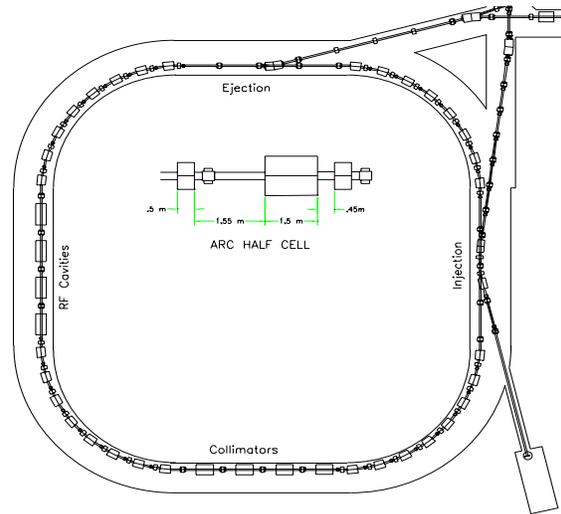
Figure 1: Layout of the accumulator ring.

riod, we have studied many possible technologies and design choices. Some of the considerations and rationals of choices are given here for comparison.

a. *Accumulator Ring vs Rapid Cycling Synchrotron.* The AR option is chosen for better injection efficiency, no eddy current effects and shorter beam-in-ring time to avoid coherent instabilities.

b. *One vs Two Ring Tunnels.* Separate tunnels for future upgrade is chosen for its simplicity in mechanical design, reliability in future operation, accessibility for maintenance, and low initial capital investment. Both the performance goal and specific design of the second ring can be decided at the time of upgrade.

c. *FODO vs Triplet Lattice.* A FODO lattice is chosen for its smoothness in betatron function variation around the ring. Such a property will minimize the possible envelope oscillation for beam with large space charge tune shift.

d. *Normal vs Isochronous Lattice.* Our choice is for a normal lattice, even if, at a first look, isochronous lattice may offer the advantage of constant longitudinal extend of the injected beam. However, it hurts in many other ways. For example, the higher order chromatic effects in lattice, reduction in dynamic aperture, and the reduction in Landau damping for transverse instabilities.

e. *Single, Dual, Barrier Cavity RF Systems.* The dual harmonic RF system is chosen for its advantage in

higher bunching factor and established performances. The barrier cavity system holds promises of keeping the beam within the confine of the RF bucket and leaving the gap clean. However, it requires more RF stations and the beam dynamics related to beam loading and coherent instabilities is not well-understood.

2 LATTICE, H^- INJECTION AND RF STACKING

The accumulator ring of the National Spallation Neutron Source (NSNS) will have a four-fold symmetric lattice. The lattice will accommodate the long straight sections required for the injection system, the extraction system, the RF cavities, and the beam scraping system. The straight sections will be dispersion free, which is desirable, especially for the RF cavities and the injection system. The lattice will provide ease of betatron tuning and flexibility of operation. Unlike lattices of lower symmetry, a lattice of four-fold symmetry will assure that there are no dangerous betatron structure resonances other than for the integer tune. Details of lattice design is given in ref. [4]. Lattice functions and other salient performance and design parameters of the accumulator ring are summarized in Table 1.

Table 1: NSNS Accumulator ring parameters

Beam Average Power	1.0 MW
Kinetic Energy	1.0 GeV
Average Current	1.0 mA
Repetition Rate	60 Hz
Ion Source Peak Current	35 mA
Linac Peak Current	27.7 mA
Beam Duty Cycle	6.18 %
Linac Pulse Length	1.03 msec
Beam Loss (Controlled/Uncontrolled)	< 2 / 0.02 %
Number of Turns Injected	1225
Revolution Period	0.8413 μsec
Revolution Frequency	1.1886 MHz
Circumference	220.688 m
Space-Charge Tune-Shift	< 0.1
Bunching Factor (Dual RF Systems)	0.405
Number of Protons/Ring	1.04×10^{14}
Beam Emittance (Transverse, norm.)	217 πmm-mr
Tunes ν_x/ν_y	5.82 / 5.80
β_{max}(x/y)	19.2 / 19.2 m
Dispersion X_p(max/min)	4.1/0.0 m
Transition Energy γ_t	4.93
RF Voltage (1st Harmonic)	40 kV
RF Voltage (2nd Harmonic)	20 kV
RF bucket	17 eV-sec
Beam Emittance (Longitudinal)	10 eV-sec
Beam Gap (injection)	295 nsec
Injected Pulse Length	546 nsec
Vacuum	10^{-9} Torr

The most demanding system in the design of the 1MW short pulse spallation neutron source is the H^- multi-turn injection into the storage ring. For the NSNS accumulator ring, a carbon foil of 400μg/cm^2 is assumed. The stripping efficiency for 1GeV incident H^- beam is about 99.8%. The temperature rise for the 1MW design is estimated to be about 3200^oC. In addition, it has been found that [5]

a. Stripping losses in passage of the H^- beam through the B=3kG field in a DC bump dipole magnet upstream of the stripper foil are negligible.

b. A fraction $f(H^o)$ =8.19$\times 10^{-3}$ of the incident H^- beam will emerge as H^o from a 400μg/cm^2 carbon stripper foil and must be disposed of in an external dump.

c. Field ionization of the H^ocomponent in the B=2.41kG field of a quadrupole downstream of the foil will lead to negligible uncontrolled losses.

d. Fractional losses from nuclear non-elastic interactions in the foil as low as 1.26×10^{-5} can be realized with rapidly (exponentially) collapsing injection bumps and "smoke-ring" injection scheme which result in very small multiple foil traversals of $< N_t >$=2.43 traversals/injected proton.

e. Multipole Coulomb and nuclear elastic scattering fractional losses out of a ring acceptance of $A_{x,y}$=330πmm-mrad for the above injection conditions are 1.35×10^{-5}, well below our loss criterion of $<10^{-4}$. With the small area stripper foil (8mm H $\times$ 4mm V) used for the above estimates, 2.2% of the incident H^- beam misses the foil and will be deflected by a magnet to an external dump.

To accumulate all the particles needed and keep them in proper azimuthal distribution, a dual harmonic RF system is employed. The fundamental RF system will provide 40kV and the second harmonic RF system will provide 20kV to form a flattened RF bucket for particle trapping with resulting bunching factor of about 0.4. Such a RF system will reduce the incoherent tune shift by 25%. The 4-dimensional multi-particle tracking program *Accsim* is needed to follow the 1200 turns of particles in the ring. The resultant beam distributions in real space and in RF phase space are shown in Fig. 2 and Fig. 3 respectively [6]. Much more work has to be done in this exercise to determine the optimal combination of RF waveform and injection strategy.

3 BEAM LOSSES AND THEIR CONTROLS

There are many possible beam loss mechanisms in addition to the foil stripping mentioned above. The important ones include:

a. Resonance crossing due to space charge tune shifts and magnetic imperfections. This will be minimized by controlling the tune shift to be less than 0.1 unit and provide all necessary multipole corrections up to order 3.
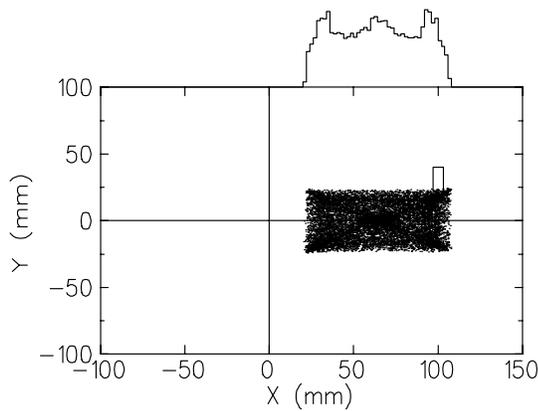
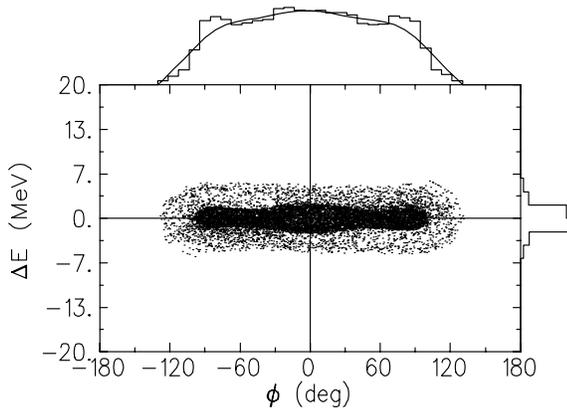Figure 2: The resultant beam distributions in real space. *Accsim* snapshot at 1200 turns. Pseudo barrier RF.

Figure 3: The resultant beam distributions in RF phase space. *Accsim* snapshot at 1200 turns. Pseudo barrier RF.

b. Coherent instabilities induced by impedance of the vacuum components. Careful studies have shown that all known instabilities will not occur with our design choices, except possible transverse instability. Further reduction of impedance will be attempted and a transverse damper will be provided to damp possible transverse instability [7].

c. $e - p$ instability can limit the achievable intensity if excessive e^- generation is allowed to occur. For the NSNS design, a vacuum pressure of less than 10^{-9}Torr and clear beam gap of 295 nsec should keep the neutralization coefficient below 10^{-3} which will keep the beam stable. TiN coating of the vacuum chamber has been considered to further reduce the secondary emission of the electrons [8].

d. Halo formation has been proposed as one of the possible beam loss mechanisms due to the particle-core resonance effect. Detailed studies will be carried out to better understand this phenomenon and its impact on the ring design and ultimate performance.

To contain those particles inadvertently migrating toward the wall, after all careful considerations and provisions, a collimator system is designed to catch the bulk of them before hitting the wall. Four collimators, 3.2m each, enclosing a 4π solid angle around the source point and stuffed with segmented material to capture all secondary particles generated by the incident protons will be provided to reduce the radiation effects by a factor of 100. This way, most of uncontrolled losses will occur at the collimator, leaving ring components relatively intact for reliable operation [9].

4 UPGRADE TO HIGHER POWER

The design presented in this paper is for initial performance of 1MW average proton beam power. All accelerator issues, such as: space charge, tune shift, coherent instabilities, $e - p$ instabilities, ...etc. have been considered and designed for 2MW capability. For phase I upgrade to 2MW performance, the peak current for the linac will be increased for 28mA to 56mA. No major changes in the ring will occur except modification in the kicker pulser and increase of shielding around high loss areas.

The most straightforward way to achieve 4MW is to build second identical ring and combine the beam power into single target station. In that case, the injection time into one ring will be reduced from 1msec to 0.5msec. If the community of the users require more peak power, a bigger accumulator ring or synchrotron to higher beam energies can also be contemplated.

5 ACKNOWLEDGMENTS

6 REFERENCES

[1] B.R. Appleton *et al.*: 'The NSNS Collaboration', Proc. of EPAC'96, p.575, Sitges, Spain, 1996.

[2] D. Raparia *et al.*: 'The NSNS high energy beam transport line', in these proceedings.

[3] D. Raparia *et al.*: 'The NSNS ring to target beam transport line', BNL/NSNS Tech. Note #6, October, 1996.

[4] Y.Y. Lee, C.J. Gardner and A.U. Luccio: 'Accelerator ring lattice for the National Spallation Neutron Source", in these proceedings.

[5] L.N. Blumberg and Y.Y. Lee: 'H^- charge exchange injection into the 1GeV NSNS accumulator', BNL/NSNS Tech. Note #3, November, 1996.

[6] A.U. Luccio, J. Beebe-Wang and D. Maletic: 'Proton Injection and RF Capture in the National Spallation Neutron Source', in these proceedings.

[7] A.G. Ruggiero: 'Space charge and coherent effects in the NSNS storage ring", BNL/NSNS Tech. Note #7, June, 1996.

[8] A.G. Ruggiero: '$e - p$ instability in the NSNS accumulator ring', in these proceedings.

[9] H. Ludewig, S. Mughabghab and M. Todosow: 'NSNS ring system design study, collimation and shielding', BNL/NSNS Tech. Note #5, November, 1996.