CHALLENGES FOR THE SNS RING ENERGY UPGRADE *

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Abstract

The Oak Ridge Spallation Neutron Source accumulator ring presently operates at a beam power of about 1 MW with a beam energy of about 910 MeV. A power upgrade is planned to increase the beam energy to 1.3 GeV. For the accumulator ring this mostly involves modifications to the injection and extraction sections. A variety of modifications to the existing injection section were necessary to achieve 1 MW, and the tools developed and the lessons learned from this work are now being applied to the design of the new injection section. This paper will discuss the tools and the lessons learned, and also present the design and status of the upgrades to the accumulator ring.

INTRODUCTION

The Oak Ridge Spallation Neutron Source (SNS) comprises a 1 GeV H^- linac followed by an accumulator ring designed to deliver 690 ns, 60 Hz pulses to the mercury target with an average beam power of 1.4 MW. Beam delivery began to users in 2006 and the beam power was steadily increased to 1 MW in 2009. Further increases in beam power are on hold to allow resources to focus on other areas of improvement.

The long-term plan for SNS includes a beam energy upgrade to 1.3 GeV and a second target station. In this paper we will focus on the energy upgrade. The high energy beam transport line from the linac to the ring, the ring itself, and the beam transport line from the ring to the target, were all originally designed to support 1.3 GeV beams. Consequently, relatively few modifications are needed to these areas.

Most of the modifications are to the ring injection region, which will receive three new magnets and upgraded injection kicker power supplies. The extraction area will receive two new kicker magnets. There will also be some minor electrical and water utility systems upgrades to support the increased demands on the ring systems. In this paper we will discuss the modifications to the ring systems. The linac systems upgrades are summarized elsewhere [1].

RING INJECTION

The most challenging part of the ring upgrade is the injection system. The beam optics in this area are complex and over-constrained. Six different beams must be accommodated: the incoming H^- ion beam, the stripped H^+ beam, the circulating H^+ beam, the unstripped H^- beam, the partially stripped H^0 beam including its excited states, and the convoy electrons stripped off the incoming H^- beam. All these beams must be properly controlled within a few meters of available space, as shown in Fig. 1.

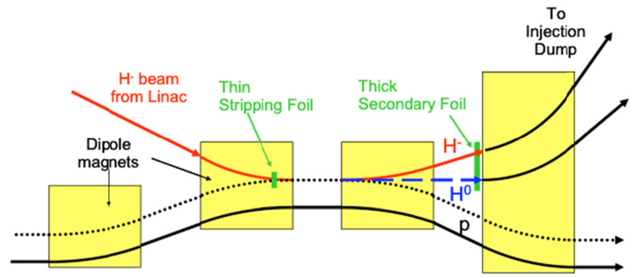

Figure 1: Schematic diagram of the ring injection area, showing the four chicane magnets (D1 through D4) in yellow.

Chicane Magnets

Two of the four injection chicane magnets (the second and third ones, D2 and D3) must be replaced. The new magnets must have lower magnetic fields to avoid magnetic field stripping of the incoming H^- ion beam, since, for a given magnetic field, the stripping length is inversely related to the beam energy, and because the existing magnets already have the maximum allowable field for a 1 GeV beam. To achieve the same bend angles for the increased beam energy and with decreased magnetic fields means substantially longer magnets. The iron length of the existing D2 and D3 magnets are 110.1 and 104.1 cm, to be compared to the new lengths of 145.0 and 129.2 cm, as shown in Table 1.

Magnetic field overlap is an issue with these two magnets because they are so close together, in order to have sufficient space between the first and second magnets, and between the third and fourth magnets, to achieve the desired 100 mm four-magnet bump for the circulating beam. The magnetic field strength falls to 4.0% of the peak D2 field between the second and third magnets in the original 1.0 GeV design [2]. In the new 1.3 GeV design it is 6.4%. A key design goal of the new magnets was to minimize this overlap, since, among other reasons, the field distortion can interfere with the collection of the stripped convoy electrons. These electrons follow a helical trajectory to the bottom of the vacuum chamber where they are intercepted by a carbon-carbon electron collector [3]. If the magnetic field is distorted too much the electrons will reflect off the field and travel back up into the path of the circulating beam, causing damage to the stripper foil mounting bracket, the upper surface of the vacuum chamber, etc.

Multipole field components are also an inevitable issue, since the field at the stripper foil inside the second chicane magnet must have a strong longitudinal component to achieve the required helical convoy electron trajectories. This is to prevent the problem of convoy electrons circling around and passing through the foil many times, which would overheat the foil and cause foil

ISBN 978-3-95450-115-1

failure. One of the improvements we've made in the 1.3 GeV design is to cancel these multipoles by fine-tuning the upstream pole tip shapes of this magnet, shown in Fig. 2, such that the overall magnet has very little multipole content. This is in contrast to the 1.0 GeV design, where the third magnet D3 is used to cancel the multipole components of the second magnet D2, which places a constraint on the relative set points of these two magnets (a constraint which we had to violate in order to commission and operate the ring). Also, canceling the multipoles within the second magnet makes the design of the third magnet, shown in Fig. 3, much simpler and straightforward.

The peak field in the third chicane magnet must also be low enough to avoid stripping the electrons off the H^0 excited states. The field at the foil strips the n>4 states within a few mm of the foil, and the n≤4 states must survive the 2.63 m path from the foil, through the third magnet, to the thick secondary stripper foil. In the 1.0 GeV design the peak field is 0.25 T, and in the 1.3 GeV design it is just 0.17 T.

Another consequence of increasing the lengths of the second and third magnets is a shorter drift distance between the first and second (D1 and D2), and between the third and fourth (D3 and D4), chicane magnets. This lowers the closed orbit bump amplitude. In the 1 GeV design the bump amplitude is 100 mm. Just replacing D2 and D3 with longer-length magnets causes the amplitude to be lowered to 88 mm. To recover the 100 mm bump amplitude we chose to move the first chicane magnet upstream 32 cm. The alternatives were to accept the lower bump amplitude or move the linac-to-ring beam transport line, but these options were judged to be less desirable. One problem with moving the chicane magnet is a small, approximately 4 mm, mechanical interference with the injection septum magnet. Either the chicane magnet, or the septum magnet, or perhaps both, will have to be shifted transversely. Magnetic interference is also a concern now that these magnets will be side-by-side. These issues will be addressed in future design work.

Dump Septum Magnet

The injection dump septum magnet will also be replaced with a new design. The existing magnet and power supply are not sufficient to achieve the required bend angles for the 1.3 GeV beam. The new magnet design is not yet complete, but it will likely be similar to the existing magnet, with more iron to prevent saturation, and more coil turns to increase the magnetic field without requiring a new power supply.

Injection Kickers

Four horizontal and four vertical injection kickers are used to paint the injected beam into the ring acceptance. Although these magnets were designed for 1.0 GeV, thermal measurements under high-duty-factor loads show that they should perform adequately at 1.3 GeV. However, four of the eight pulsed power supplies will require modifications to increase the maximum current from 1400 to 1600 A. Since this modification is relatively inexpensive, and because it is desirable to have identical supplies for ease of maintenance, all eight supplies will receive the modifications.

The programmable time structure of the current waveforms will also require modifications since the power supply upgrade allows higher currents but not higher duty factors. The existing rise time will change from 2 ms to 1 ms, and the flat top length of 1 ms (just prior to start of injection) will be shortened to 0.5 ms.

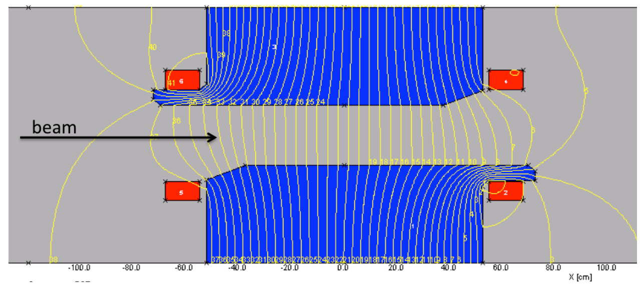

Figure 2: Pole tips shapes and field lines for the new second chicane magnet D2. The multipole components are now cancelled within the magnet.

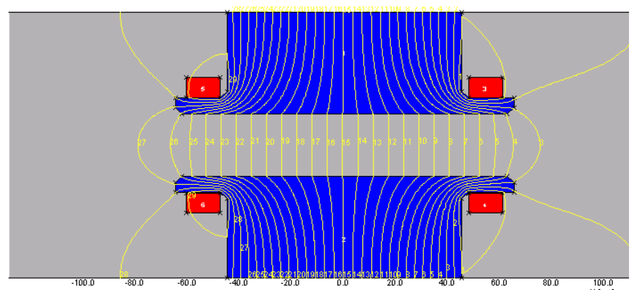

Figure 3: Pole tips shapes and field lines for the new third chicane magnet D3. The magnet is now longitudinally symmetric, unlike the old magnet.

RING EXTRACTION

The existing beam extraction is accomplished with two sets of seven fast kicker magnets, with each set mounted within a vacuum vessel. To achieve the same beam displacement at the higher beam energy, one more kicker magnet will be added to each vacuum vessel – one to the upstream end of the upstream vessel, and one to the downstream end of the downstream vessel. The existing vacuum vessels will be extended to accommodate the new magnets. Both of the new kicker magnets will be clones of existing kicker magnets.

In the ring equipment building, during the original installation, rack space was reserved to accommodate the two additional pulse forming networks, charging supplies, etc. needed for the two new kicker magnets.

The extraction septum magnet will probably require a small modification to its pole tip shims. In 2009 the pole tips shims were replaced to reduce a strong skew quadrupole component that was causing cross-plane coupling and a tilted beam distribution on the neutron production target [4]. However, these shims are optimized

ISBN 978-3-95450-115-1

for 1.0 GeV, and therefore may need to be replaced with shims optimized for 1.3 GeV. This design task has not yet started.

Table 1: Comparison of Selected Existing 1.0 GeV and New 1.3 GeV Design Parameters

Parameter	Existing 1.0 GeV design	New 1.3 GeV design
D2 iron length [cm]	110.1	145.0
D2 peak field [T]	0.31	0.25
D2 field at foil [T]	0.25	0.21
D2 largest multipole component (8 cm reference radius)	2.8 units, quadrupole, D2 and D3 together	1 unit, 14-pole
Field tilt at foil [mrad]	200	213
D3 peak field [T]	0.25	0.17
D3 iron length [cm]	104.1	129.2
D3 largest multipole component (8 cm reference radius)	2.8 units, quadrupole, D2 and D3 together	2.3 units, quadrupole

UTILITIES UPGRADES

The existing water cooling system in the ring service building does not have enough excess capacity to properly cool the magnet power supplies at their 1.3 GeV set points. The power supply cooling system will be split into two parts and a new pump skid will be added to achieve the required capacity.

The existing magnet cooling system already has the excess capacity needed to cool the magnets at the 1.3 GeV set points, so no upgrade is needed for this system.

The AC power for the ring systems will only require the addition of a fan package to the substation to provide the extra cooling capacity needed for the higher-power operation.

DESIGN TOOLS

During the first few years of operation several modifications were made to the ring injection region to improve its operation [5], and the tools and knowledge developed in this process have been applied to the new 1.3 GeV design. One invaluable tool tracks particles through magnet-model-generated 3D magnetic fields in the chicane and injection dump septum magnet, using the ORBIT [6] code. Initial testing of the new chicane magnet design, using these same tools, shows no problems. Initial results of sensitivity studies, to check that slight variations in magnet field strengths, magnet positions, and beam position and angle do not cause problems, also have not identified any issues. More tests and sensitivity studies are planned after the design is complete for the injection dump septum magnet.

Another tool we developed simulates and tracks the H^0 excited states [7]. This tool was used to set the requirement for the magnitude of the magnetic field at the foil, and the maximum field in the third chicane magnet D3.

Yet another tool, again using ORBIT, tracks the convoy electrons stripped off the incoming H^- beam [8]. This tool was originally developed to diagnose a stripper foil failure problem due to reflected convoy electrons. It was later used to design a new electron collector for the existing design. This same tool will be used to test the convoy electron trajectories for the new 1.3 GeV design.

SUMMARY

Design work for the 1.3 GeV beam energy upgrade has been significantly advanced. Two new chicane magnets and one new injection dump septum magnet are being designed. The basic magnet modeling of the new chicane magnets, and the basic layout work for all four chicane magnets, is almost complete. Basic layout work for the extraction kicker vacuum tank extensions is almost complete. Particle tracking studies through the new chicane magnets will be performed to verify the new design. The new design incorporates all the lessons learned during the design, commissioning, and subsequent modifications to the existing injection and extraction systems.

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