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ACCELERATOR SYSTEMS MODIFICATIONS FOR A SECOND TARGET STATION AT THE OAK RIDGE SPALLATION NEUTRON SOURCE*

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Abstract

A second target station is planned for the Oak Ridge Spallation Neutron Source. The ion source will be upgraded to increase the peak current from 38 to 49 mA, additional superconducting RF cavities will be added to the linac to increase the H^- beam energy from 938 to 1300 MeV, and the accumulator ring will receive modifications to the injection and extraction systems to accommodate the higher beam energy. After pulse compression in the storage ring one sixth of the beam pulses (10 out of 60 Hz) will be diverted to the second target by kicker and septum magnets added to the existing Ring to Target Beam Transport (RTBT) line. No further modifications will be made to the RTBT so that when the kicker and septum magnets are turned off the original beam transport lattice will be unaffected. In this paper we will discuss these and other planned modifications and upgrades to the accelerator facility.

INTRODUCTION

A Second Target Station (STS) for the Oak Ridge Spallation Neutron Source has been part of the overall site plan from the very beginning. Work on the STS has recently re-started and many design details have been clarified. The design refinements incorporate lessons learned from our experience operating a megawatt-class neutron source. In this paper we will discuss the modifications to the accelerator systems. The neutron instrument suite, target system and the moderator designs have also been greatly refined, and these are described elsewhere [1].

Today the SNS accelerator systems deliver 1.25 MW, 938 MeV proton pulses to the neutron spallation target at 60 Hz, and the beam power is being gradually increased to the design value of 1.4 MW. An H^- ion beam with 1-ms long pulses is first accelerated in a linac to the full energy, and then the beam pulse length is compressed down to 800 ns in an accumulator ring.

The Second Target Station design calls for increasing the total beam power to 2.8 MW capable and beam energy to 1.3 GeV. Since the Second Target Station was envisioned from the beginning, most of the required accelerator systems are already in place. Space was reserved in the klystron gallery and the linac tunnel for the additional rf cavities and their associated support systems. The beam line from the linac to the ring is already capable of transporting the higher energy beam. The accumulator ring requires only minor modifications, mainly to the injection and extraction sections. The beam transport from the ring to the First Target Station requires no modifications, other than to add a kicker and septum magnet to divert 1/6 of the 60 Hz beam pulses to the Second Target Station.

The accelerator system modifications therefore fall into four main categories: an H^- ion source upgrade to increase the 1-ms average current from the present 24 mA to 38 mA, 28 additional superconducting rf cavities and their associated rf systems, minor modifications to the accumulator ring, and a new beam line to the Second Target Station. The high-level parameters are summarized in Table 1.

Table 1: Beam Parameters

Parameter	**First Target today**	**First Target after upgrade**	**Second Target after upgrade**
Beam power [MW]	1.25	2.0	0.47
Beam energy [GeV]	0.938	1.3	1.3
Rep rate [Hz]	60	50	10
Avg. (chopped) 1-ms linac current [mA]	24	33	38
Energy per pulse on target [kJ]	21	40	47

LINAC

During construction the linac tunnel was made long enough to accommodate 9 extra cryomodules (equivalent to 36 superconducting rf cavities). Due to recent advances in superconducting rf cavity fabrication and conditioning, only 7 additional cryomodules will be required to raise the beam energy to the required 1.3 GeV. The new cavities will be fed by power couplers capable of 700 kW rather than the existing couplers rated for 550 kW. This will allow the higher beam currents from the upgraded ion source to be accelerated at high rf cavity gradients.

The existing superconducting linac (SCL) comprises two types of rf cavities – medium beta and high beta. In practice, each cavity is operated at its maximum allowable gradient, limited by field emission, multipacting, power coupler limit, etc. The medium beta cavities are typically operated at gradients that exceed their design values ($E_{acc,des}$ = 10.2 MV/m), and the high beta cavities are typically operated below their design gradients ($E_{acc,des}$ = 15.8 MV/m) [2], as shown in Fig. 1.

The new high-beta cavities will be operated at 16 MV/m. A recently built high-beta cryomodule has been swapped for a poorly performing cryomodule, and

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this new cryomodule demonstrates that the 16 MV/m requirement is met for all four rf cavities contained within.

Figure 1 shows that some of the existing SCL rf cavity gradients will need to be lowered from their present values. This is due to the higher beam loading from the higher STS beam currents. Some other gradients will be increased. This will be done by plasma processing cavities in-situ [3].

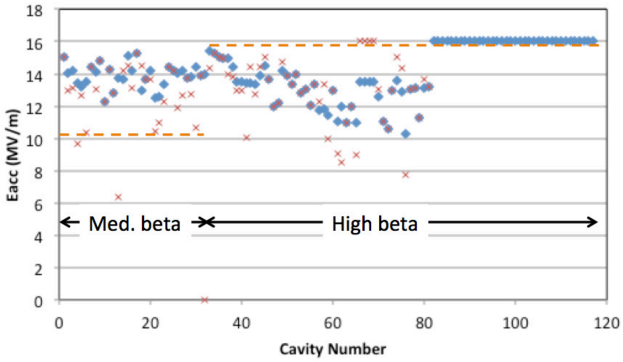

Figure 1: SCL cavity gradients before (red x's) and after (blue diamonds) the STS upgrade. The orange dashed lines show the original design gradients.

ACCUMULATOR RING

Most of the accumulator ring is already capable of operating at 1.3 GeV. The exceptions are the injection and extraction sections. In the injection section two of the four chicane magnets will be replaced. These chicane magnets cannot be simply operated at higher magnetic fields since to do so would cause excessive beam loss due to magnetic stripping of the H^- ion beam and improper handling of the excited H^0 states [4]. The injection dump septum magnet will also be replaced since the existing magnet saturates at the magnetic fields needed for the 1.3 GeV beam. Additionally, the injection kicker power supplies will be upgraded for a maximum current of 1600 A, to be compared to the existing value of 1400 A.

The extraction section upgrade comprises two additional extraction kicker magnets, to be added to the existing 14 magnets. One magnet will be added to each bank of seven kickers. The associated equipment building already has enough floor space and rack space for the new pulse forming networks and the electronics that controls them. The electrical and water cooling services for the equipment building will also be upgraded.

SECOND TARGET BEAM LINE

A new kicker and septum magnet system will kick 10 out of every 60 beam pulses from the existing beam line (RTBT) for the First Target Station into a new beam line (R2T2) for the STS. These magnets will be inserted into existing inter-magnet spaces within the RTBT beam line, such that when the R2T2 magnets are turned off, the RTBT beam transport will be unaffected.

Two kicker / septum options were considered. The first option is to kick the beam vertically upstream of a vertically defocussing quadrupole magnet, and then use a Lambertson septum magnet downstream of this quadrupole magnet to bend the beam horizontally into the new R2T2 beam line. The second option is to kick the beam horizontally upstream of a horizontally defocussing quadruple magnet, and then use a normal septum magnet to bend the beam horizontally. In practice, two short kicker magnets will probably be used rather than one long one to minimize the cost and technological risk. There is not enough space between the existing RTBT quadrupole magnets to install the kicker and septum magnets entirely between two quadrupole magnets.

Each of the two options has its own set of advantages and disadvantages. The Lambertson septum magnet option has the advantage that it reduces the required beam deflection at the entrance to the septum magnet, but a disadvantage is that to counteract the vertical angle of the beam the most practical solution is to rotate and pitch the septum magnet, and then follow it by another vertical dipole magnet to fully cancel the vertical angle. Another disadvantage is that the consequent vertical dispersion must be cancelled. The fact that Lambertson septum magnets lack median plane symmetry further complicates the beam transport by creating cross plane coupling unless the higher-order multiple components are precisely cancelled [5].

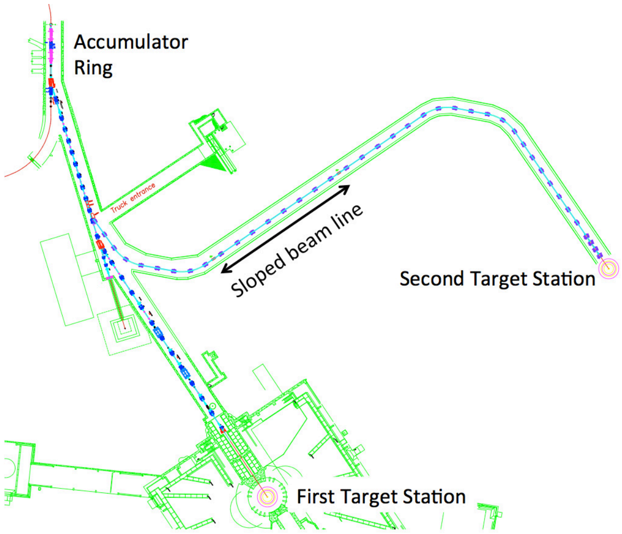

Figure 2: The RTBT and R2T2 beam lines.

The normal septum magnet option has the advantages that the beam optics are simpler and the cross-plane coupling issue is minimized. The main disadvantages are that a bigger beam deflection at the entrance to the septum magnet is required, and the magnet coils are exposed to the beam tails.

For the Lambertson septum magnet option, each kicker must deflect the beam 0.8 deg. For the normal septum option it is 1.4 deg. Part of the increase in kick angle is due to the larger beam displacement requirement for the normal septum, and part is due to a larger distance from the kickers to the septum for the Lambertson septum option. This latter point is simply due to the layout of the RTBT beam line, which happens to have a larger quadrupole magnet spacing in the location where the Lambertson septum would be located.

The larger kick angle for the normal septum option has another consequence – a larger beam position displacement in the quadrupole magnet between the kickers and the septum. It is about 55 mm for the Lambertson septum option, and about 98 mm for the normal septum option. A new quadrupole magnet with a larger bore will therefore likely be required for the normal septum option.

It is interesting to note that the two options essentially describe the SNS Ring and the J-PARC RCS extraction systems. The SNS Ring has a Lambertson septum and the J-PARC RCS has a normal septum. Both options work, and the final choice depends on the specific details. In the present case of the STS beam line, our tentative choice is the normal septum magnet option.

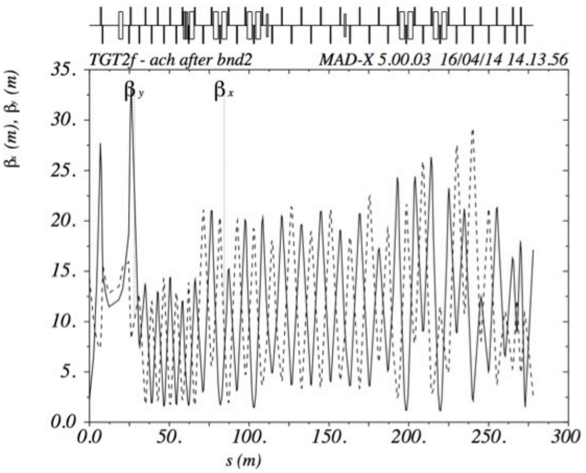

Figure 3: The horizontal (solid) and vertical (dashed) beta functions for the R2T2 beam lines.

After the R2T2 beam is kicked from the RTBT beam line it is bent a total of 106.8 deg. by a series of dipole and quadrupole magnets arranged to cancel the dispersion up to this point. After the bending section, within the long straight section, the beam line elevation is lowered 5.2 m to match the elevation of the new spallation neutron target. This is accomplished by two vertical dipole magnets at either end of the sloped section. The present design calls for the sloped section to be 49.8 m in length, with sufficient intervening quadrupole magnets to achieve a good achromat. However, as the design is further refined it may become desirable to increase the length of the sloped section, to decrease the angle of the slope, at the expense of increasing the quadrupole count required to maintain a good achromat.

After the sloped section another 90 deg. bend lines up the beam for the approach to the spallation target, and then the final focus section sets the desired beam dimensions on the target.

The R2T2 beam line is mostly a simple FODO lattice that is almost identical to the RTBT lattice. Almost all the quadrupole magnets are of the same type used in the existing RTBT beam line to reduce cost and add compatibility with the other accelerator systems. Figure 2 shows a schematic diagram of the RTBT and R2T2 beam lines, and Figs. 3-4 show the beta and dispersion functions for the R2T2 beam line.

Preliminary beam size requirements on the target call for an 8.6 x 3.5 cm^2 footprint. Simulations shows that this requirement can be easily met, for a wide range of initial Twiss parameters, by a final focus section consisting of four quadrupole magnets spaced 1 m apart, followed by a 5 m drift to the face of the target. The distance from the last magnet to the target, and the required footprint on the target are very rough parameters at this stage.

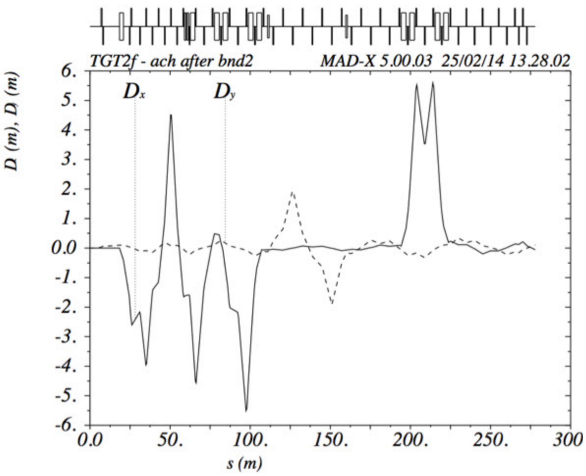

Figure 4: The horizontal (solid) and vertical (dashed) dispersion functions for the R2T2 beam lines.

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