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SNS PROTON POWER UPGRADE STATUS*

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Abstract

The Proton Power Upgrade (PPU) project at the Oak Ridge Spallation Neutron Source (SNS) aims to double the beam power capability of the accelerator, from 1.4 to 2.8 MW. This will be done by a 30% increase in beam energy (from 1.0 to 1.3 GeV), and a 50% increase in beam current (from 25 to 38 mA averaged over a macropulse). The project is now well underway, after receiving approval to start preliminary design in April 2018. In this paper we will discuss recent technical developments in the project, including the warm linac RF system upgrade, a new topology for the high voltage converter modulators, and recent changes in the accumulator ring project scope.

INTRODUCTION

The SNS facility [1] accelerates 60 Hz, 1-ms long, H^- ion beam pulses to 2.5 MeV in a Radio Frequency Quadrupole (RFQ), to 87 MeV in a Drift Tube Linac (DTL), to 186 MeV in a Coupled Cavity Linac, and finally to 1 GeV in a Superconducting Linac (SCL). The pulses are then compressed to ~700 ns in an accumulator ring before directing them to a liquid mercury neutron spallation target.

Construction was completed in 2006, followed by a beam power ramp up to the design value of 1.4 MW, which was achieved at a continuous and reliable production level just last year in 2018. We are now working on two upgrade projects – the Proton Power Upgrade project (PPU), and the Second Target Station project (STS). The PPU project achieved CD-1 status (conceptual design approved by the Department of Energy, and permission given to proceed to preliminary design) in April 2018. The conceptual design of the STS project is now in progress.

The PPU project aims to double the beam power capability to 2.8 MW, although until the STS project is complete the power will be limited to 2 MW on the one target station now in place. A combination of increased beam energy to 1.3 GeV, and average current to 38 mA, will be used to realize the doubled power.

Since this upgrade was envisioned during the original SNS design, the accelerator requires only a few modifications. The major components comprise replacing three DTL klystrons with 3.0 MW units, adding seven cryomodules to the SCL with their associated RF systems, replacing three magnets in the ring injection section, upgrading the mercury target, and some conventional facility upgrades [2]. In the last year the PPU project has made impressive progress on all fronts, and in this paper we will concentrate on the latest developments, with a focus on the Ring portion of the project.

WARM LINAC

The DTL is powered by six 2.5 MW, 402.5 MHz klystrons. At the time of the CD-1 review last year the final selection of klystrons that require an upgrade to 3.0 MW units was not yet clear. Since that time a series of high-current (and short pulse) beam measurements have been made, in addition to a series of klystron power curve measurements made by operating each klystron into a calibrated load. The final result is that the DTL-3, DTL-4, and DTL-5 klystrons will receive the upgrade. The waveguide circulators and waveguide loads may or may not be upgraded, depending upon the results of an engineering review. Eventually all six DTL klystrons, plus the RFQ klystron, plus all the circulators and loads, will be replaced with upgraded units for compatibility, spares considerations, and components availability issues.

The higher-power klystrons require upgraded modulators. Each DTL modulator powers two klystrons, so the three new 3.0 MW klystrons will require two upgraded modulators. The upgrade primarily consists of replacing the boost transformer and capacitors. Tests are now in progress to validate this approach. Additionally the modulator that powers the RFQ klystron plus the first two DTL klystrons will receive an upgrade to allow any combination of 2.5 and 3.0 MW klystrons to be used in this portion of the linac.

SUPERCONDUCTING LINAC

Space in the linac tunnel for nine additional cryomodules was reserved during the original construction. Due to advances in superconducting RF technology the beam energy increase to 1.3 GeV can be achieved by adding only seven cryomodules. It is not practical to increase the beam energy beyond 1.3 GeV due to the consequent excessive beam loss in the downstream arc due to magnetic stripping.

In the last year a partner laboratory (Jefferson National Accelerator Laboratory) was selected to design and build these high-beta cryomodules. Numerous components have already achieved final design status and procurement has begun on the superconducting cavities. Figure 1 shows some of the new design features.

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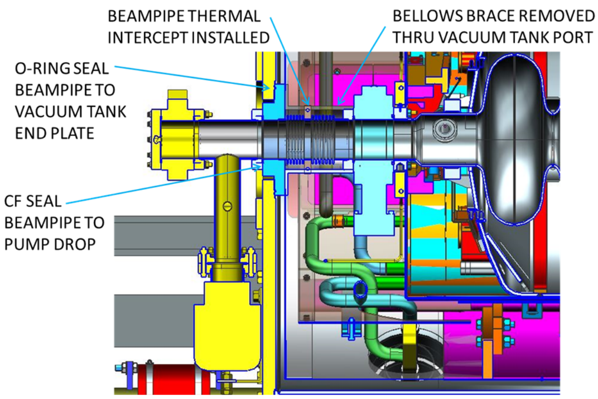

Figure 1: Some of the recent design features in the new PPU cryomodules [3].

ACCUMULATOR RING

Most of the magnets and power supplies (~96%) in the Ring and transport beam lines are already capable of 1.3 GeV operations. The exceptions are in the ring injection and ring extraction areas.

In the ring injection area two chicane magnets will be replaced due to magnetic stripping and excited-state H^0 beam loss considerations [4]. The new magnets are being designed by Fermi National Accelerator Laboratory (FNAL), and they are now at the preliminary design stage. A design requirement for the new magnets is that they will be compatible with the existing power supplies.

The injection dump septum magnet will also be replaced due to excessive magnetic saturation in the existing magnet when operated at 1.3 GeV levels. This magnet is also being designed by FNAL, is also at the preliminary design stage, and will also work with the existing power supply.

Recent Design Changes and Option Selections

Extraction Kickers The PPU baseline design called for adding two more extraction kickers to the existing set of 14, to provide the same net kick angle at the higher beam energy. One alternative that was under consideration was to replace the Pulse Forming Network (PFN) charging supplies with a resonant charger system that would charge the PFNs to about 20% higher voltages. This would allow the existing kicker magnets to provide the needed kick angle and eliminate the need for the two additional kicker systems.

At reduced rep rates the existing system is capable of charging the PFNs to the PPU voltage specification. This setup was used to perform beam-based measurements to check that the kicker magnets are still linear at these higher voltages.

In January 2019 the prototype resonant charging system development was advanced enough, and with good results, to accept the alternate choice. The resonant charger system also has the advantage that it saves the project about $2.7M and eliminates all the work in the beam tunnel.

Power Supply Water Cooling System The increase in beam energy will add an average of 20% to the required magnet power supply currents, and this will in turn increase the demand on the power supply water cooling system. The water cooling system in the Ring Service Building (RSB) therefore requires an upgrade. The water cooling systems for the magnets in the transport lines, and for the power supplies for those magnets, already have sufficient capacity and do not require any upgrades.

The PPU baseline design called for splitting the RSB power supply water cooling system into two separate loops; and adding additional pumps, heat exchanger, etc. However, as shown in Fig. 2, after a more detailed analysis of the optimum solution, we have chosen to not split the loop, and to replace the existing three pumps with two larger-capacity units. We will also expel the heat into a heat exchanger cooled by the chilled water system, rather than the tower water system.

Injection Dump Beam Line Quadrupole A recent addition to the PPU project is a second quadrupole magnet in the injection dump beam line. Operational experience has shown that the limited beam tuning range with just one quadrupole does not provide sufficient flexibility for the higher beam powers that will be delivered to the dump once the PPU project is complete. The new quadrupole will be the same type as the existing magnet, so no new magnet design is required and the additional cost will thus be minimized.

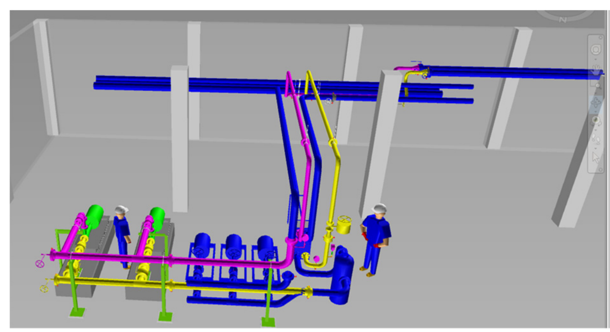

Figure 2: Ring Service Building power supply water cooling system upgrade. Existing pumps are shown in blue. They will be replaced by the pumps shown in green.

Ring Injection Dump Imaging System The PPU baseline design called for adding a beam imaging system just upstream of the Ring Injection Dump (RID). At present, there is no method to directly measure the beam distribution there. We can only extrapolate from upstream beam profile measurements. The baseline conceptual design called for placing a view screen in a few-cm-long space between the vacuum window and the entrance face of the beam dump. This was a complicated design with several obstacles that included, for example, a water-cooled view screen, image transmission through a fiber-optic cable, and replacement of several shielding blocks.

We have since selected a simpler design that leverages our experience with the Target Imaging System (TIS), which has been in place for several years. As shown in Fig. 3, the RID imaging system extends from the vacuum window to the Ring tunnel. It will utilize a light-emitting coating on the upstream face of the vacuum window, likely

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the same type used for the TIS (chromium doped Al_2O_3). The image will be viewed using a camera installed inside the Ring tunnel, using a turning mirror located about 11 m upstream of the vacuum window. The advantages of this design choice include relatively easy access to the optics system and no optics inside the harsh environment surrounding the beam dump.

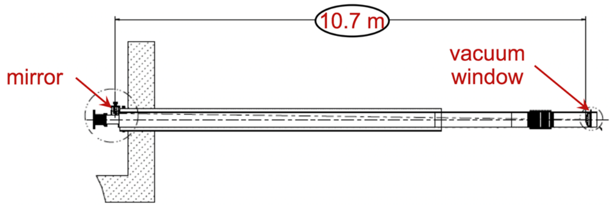

Figure 3: Cross section of the last part of the Ring Injection Dump beam line, showing the main components of the imaging system.

Air Conditioner for the Extraction Kicker PFN Room Another recent addition to the PPU project is an air conditioner system for the extraction kicker PFN room. The PFNs are located in a dedicated room attached to the Ring Service Building. This room has no air conditioning, and temperatures can exceed 43 C during the hot summer months. The common wall between the PFN room and the RSB is not completely sealed, and the lack of PFN cooling affects the RSB temperature, humidity and pressurization. Also, although the equipment inside the PFN room itself can operate sufficiently well, it is an unpleasant place for people to work. Two low-cost air handlers will be attached to the ceiling and will be locally controlled by manual thermostats. A side benefit is we expect improved equipment reliability due to the lower room temperatures during the summer.

Beam Power Limiting System Another recent addition to the PPU project is a beam power limiting system to be installed in the beam line upstream of the neutron spallation target. The targets used today are rated for 1.4 MW, and the targets designed for PPU will be rated for 2.0 MW. However, once the PPU project is complete the accelerator will be capable of 2.8 MW. The purpose of the beam power limiting system is to ensure the beam power never exceeds a pre-set limit, which will be no greater than 2.0 MW. This system will be a credited engineering control and will have a reliability rating similar to personnel protection systems. Due to the relatively high speed of the system needed to accommodate the 60 Hz repetition rate of the accelerator, it will be based on a FPGA. This will be the first FPGA-based credited engineering control at SNS.

SUMMARY

The PPU project achieved CD-1 status in April 2018, and since that time considerable progress has been made. Some portions of the project are now in the early stages of final design, while other portions have completed the final designs and initiated long lead procurements.

In the Ring area the final scope has been defined and alternatives that were identified early in the project have been chosen where appropriate. Overall the project is off to a great start and the SNS will soon benefit from the new science made possible by higher power operations.

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