STATUS OF THE SNS PROTON POWER UPGRADE PROJECT *

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Abstract

The Proton Power Upgrade (PPU) project [1,2,3] will double the accelerator power capability at Spallation Neutron Source (SNS) [4], from 1.4 to 2.8 MW. This project received initial funding in 2018, and plans have been formulated to complete equipment installation and begin beam commissioning in 2024. The project plans and status, with an emphasis on recent progress, are summarized for the different sub-systems.

INTRODUCTION

The SNS is a short pulse neutron scattering facility with a 1.4 MW capable accelerator powering the neutron source. The SNS accelerator complex includes a linear accelerator, an accumulator ring and transport lines. This accelerator complex was constructed with built-in upgrade provisions, and these are being exploited to double the power capability to 2.8 MW. High level parameters are shown in Table 1, indicating the strategy to double the power by increasing the beam energy by 30% and the linac beam current by ~ 50%. The higher power will allow new science capabilities and will also increase capacity by increasing beamline throughput [5].

The PPU project is organized into primary subsystems of Superconducting RF cryomodules, RF equipment, Ring systems, Conventional Facilities, and Target systems. Controls efforts are distributed throughout these systems. Much of the project upgrade is focused in the SNS linac and consists of providing additional equipment similar to presently operating equipment (for example, RF equipment and superconducting cryomodules). This aspect reduces project risks and permits early movement on the design and procurement of some linac associated equipment. The sections below describe the upgrade approaches in the PPU sub-systems, and recent progress.

PPU SUB-SYSTEMS

Superconducting Linac (SCL)

The increased beam energy will be provided by the addition of 7 new cryo-modules in existing empty slots at the high energy end of the linac [6]. These cryo-modules will be similar to a spare cryomodule built at SNS, installed and operated since 2012, and has demonstrated the required PPU gradient level [7]. This cryomodule is shown in Fig. 1. The cryomodules will be fabricated by Thomas Jefferson Accelerator Facility, through a partnership. SNS will oversee the cavity fabrication, and this is part of a recently initiated Long Lead Procurement strategy to minimize schedule risk. The cryomodules will be installed in seven of the nine available empty slots.

Table 1: PPU High Level Parameters

Parameter	Present operation	PPU
Beam power (MW)	1.4	2.8
Beam energy (GeV)	1.0	1.3
Average linac current (mA)	1.6	2.3
Linac macropulse current (mA)	25	39
Beam repetition rate (Hz)	60	60
Linac pulse length (ms)	1	1
Medium beta cryomodules	11	11
High beta cryomodules	12	19
High beta cavities	48	76

Figure 1. The spare SNS cryomodule, in operation since 2012 and demonstrating PPU gradient.

Key changes in the PPU cryomodules from the operational high beta cryomodules already installed in the SNS linac are: improved Nb material quality for the cavity end groups, higher power capability for the RF couplers, and elimination of the Higher Order Mode couplers. A prototype cavity with high quality end groups and no HOM coupler was recently fabricated and tested, and successfully demonstrated gradients required for PPU (see Fig. 2.)

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* ORNL is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy. This research was supported by the DOE Office of Science, Basic Energy Science, Scientific User Facilities.

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Figure 2: An SNS cavity with PPU modifications.

RF Systems

The RF systems includes scope for upgrading existing systems to accommodate the increased beam loading (higher beam current) and adding new equipment to power the new cryomodules. Additionally, the low-level RF is being upgraded to accommodate handling 2 types of beam pulses headed to either the existing present First Target Station (FTS), or to a future Second Target Station (STS) [8].

Over the past year a task force has performed equipment measurements to better understand the installed equipment power capability, and to understand the PPU needs. These also include tests with beam at the PPU beam current levels (albeit at reduced duty factor). Results have helped refine the existing RF systems PPU will need to upgrade. Fig. 3 shows a test setup for a Drift Tube Linac (DTL) RF station. The tests show that three of six DTL systems will require increased power capability (from 2.5 to 3.0 MW.) The Coupled Cavity Linac (CCL) systems and the existing Superconducting RF systems are adequate for PPU.

Figure 3: Test setup for the SNS warm linac high power RF.

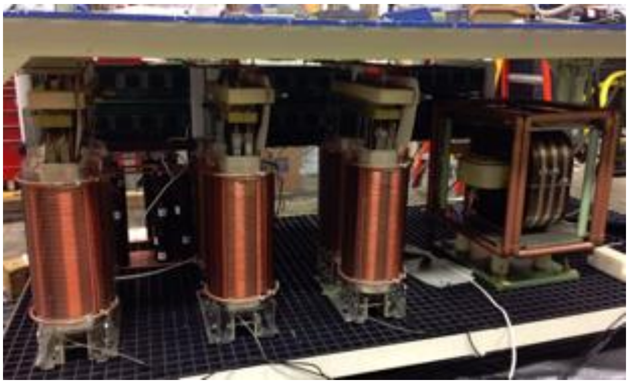

Figure 4: Alternate topology HVCM prototype.

The klystrons powering the new SRF cavities will be 700 kW klystrons, identical to ones presently in operation, so there is minimal risk here. The high voltage pulse modulation will be provided by a High Voltage Convertor Modulator (HVCM) that is a new design, an “alternate topology” HVCM [9]. A prototype (see Fig. 4) has been built and initial testing is promising.

Ring Systems

About 96% of the transport line and ring magnets and power supplies are capable of supporting 1.3 GeV operation and were successfully tested at this level during the summer of 2018. Three magnets in the ring injection area (see Fig. 5) and their vacuum chambers will be replaced for 1.3 GeV operation, to accommodate handling the excited state H^0 transport at higher beam energy [10]. PPU is partnering with Fermi National Accelerator Laboratory (FNAL) for the design and manufacturing oversight of these magnets. The baseline plan for the extraction region is to add 2 additional extraction kicker magnets (see Fig. 6). An alternative and simpler approach is being investigated to upgrade the existing extraction kicker power supplies. Initial testing of a prototype power supplies indicated adequate voltage and rise time, and system reliability is now being addressed.

Figure 5: The SNS Ring injection region.

Figure 6: One of 2 extraction kicker magnet sets, with space indicated (red) for an extra magnet placement.

Another area of concern in the ring upgrades is the injection dump, which is presently rated for 150 kW. This represents ~5.3% of 2.8 MW which is adequate, but more headroom in the allowable dump power will provide operational margin. A thermal analysis and the measurements of the operational injection dump system are being conducted to assess whether the dump power limit can be increased. Also, a new diagnostic to image the waste beam position on the injection dump is included in PPU, to provide better confidence in proper handling of this high-power waste beam.

Target Systems

Beyond providing for 2.8 MW accelerator power capability, PPU also provides a 2.0 MW capable target (the remaining power is planned to be delivered to a new Second Target Station [8]). The PPU 2.0 MW target design is influenced by operational lessons from the present 1.4 MW target design. The key issues addressed are reduction of the large pressure pulse from the short pulse proton beam, and mitigation of cavitation induced erosion on the inner surfaces of the upstream target vessel. Fig. 7 shows the PPU 2 MW target design, which has a tapered nose feature that provides more effective flow in the nose corners (an area of erosion concern.) Other features include elimination of a center baffle, inclusion of a gas wall curtain in the nose region, and swirl bubblers to provide increased gas bubble dispersion in the bulk mercury flow. The gas curtain provides erosion mitigation and the gas bubble injection is aimed at pressure pulse and erosion mitigation [11].

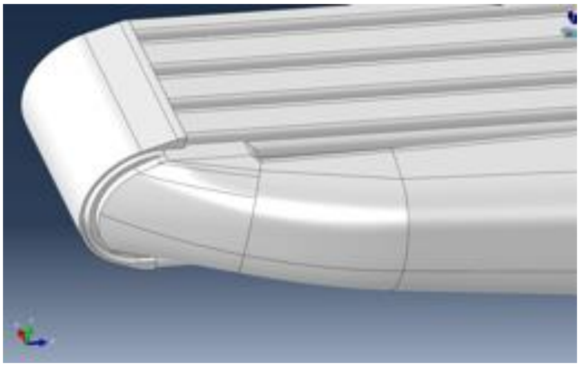

Figure 7: The PPU 2 MW target.

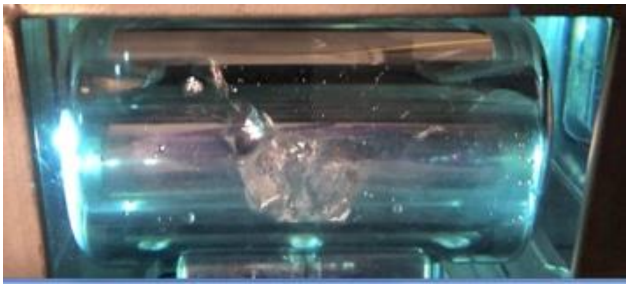

Figure 8: A test loop for the gas-curtain concept, with gas bubbles visible in the nose center region.

Target R&D is primarily aimed at understanding the gas wall and bubble injection. Tests are being performed on a full scale mercury loop and on visible water flow setups to measure the bubble coverage based on gas injection orifice geometry, gas flow, mercury flow etc. Fig. 8 shows a test of the gas wall concept in a mercury flow test loop, designed to measure gas coverage on the inner target wall surface.

A key element of the target development is learning from the operational experience of the SNS high power target. There is a systematic Target Management Plan [12] that implements changes to the targets, the beam power and the injected gas level. Over the past year key lessons have been learned from the operational targets. In particular, two key observations from gas injection implementation are PPU relevant: 1) reduced strain on the target vessel that contains the mercury with the presence of injected gas [13,14] and 2) reduced cavitation induced pitting on the front inner wall of the target vessel. SNS plans to increase the gas flow in targets and these results will factor into PPU design considerations.

Conventional Facilities

The conventional facilities scope includes finishing out the high energy section of the linac klystron gallery and adding a “stub” to the Ring Target Beamline Transport (RTBT) line tunnel. This stub will accommodate a seamless tie into the future Second Target Station [8]. The high energy end of the klystron gallery has been cleaned out (it had been used for storage), and the passages to the linac tunnel (“chases”) have been fitted with inserts that house waveguide and conduit for cabling. This work was done during a maintenance outage in the Spring of 2018 and included moving magnet cables that had been routed in incorrect chases. Fig. 9 shows the klystron gallery after this preparation activity. The site-preparation of the klystron gallery permits handover of the building design and finishing work to an outside A-E construction management firm. This contracted work will include the coordinated design of conventional systems (e.g. utilities and HVAC) with the layout of co-located technical items (e.g. RF wave-guide, technical cooling systems, circulators, etc.) using a Building Information Model (BIM) approach. Cannon Design has been chosen as the A-E partner to perform the klystron gallery design.

Figure 9: Klystron gallery after the completion of the chase insert activity.

The stub in the RTBT is shown in Fig. 10. Construction of this stub will allow construction and connection of a new proton beamline transport line to a future Second Target Station (STS) [8] to proceed while SNS is operating, thus minimizing user support interruption. The stub will be constructed while the SNS needs to be shut down for other PPU activities, as discussed below.

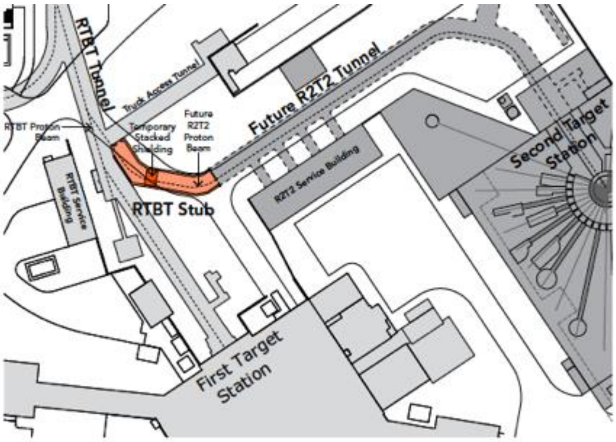

Figure 10: Layout of the RTBT tunnel stub (red) for connection to the STS.

PROJECT STATUS

Funding and Approval

PPU received Critical Decisison-1 approval April 4, 2018, which permits moving towards the baselining of the project and initiating the preliminary design process. A review for the approval of Long Lead Procurement of the superconducting RF cavities and associated equipment was held in August 2018, and approval is expected in Oct. 2018. Funding for FY 2018 was approved at $36M, and this represents the first year PPU has line-item funding approval. The next project approval step is Critical Decision 2/3b, which will permit movement towards final design for systems (CD-2 part) and approval of final design for many systems (CD-3b part). Final design will be sought for systems already in place, or prototyped and tested, such as much of the RF systems, and the superconducting RF cryomodules. Since PPU leverages existing equipment design and experiences, this should allow a faster approach to equipment procurement.

Cost and Schedule

PPU is in the process of baselining the cost and schedule for CD-2. The schedule presently calls for procurement and assembly of much of the superconducting cryomodules and RF equipment in 2020-2021. We plan to install RF equipment in the klystron gallery during normal machine operation, but cryomodule installation in the tunnel will begin during normal maintenance outages beginning in 2022. The normal operations schedule will remain unaffected through this period. PPU is however planning a 6-month long outage beginning in late 2023 to perform installation that requires a longer than usual machine-outage: cryomodule installation, target systems upgrades, ring injection system upgrade, and the RTBT tunnel stub. This approach minimizes the longest concurrent "dark-time" imposed by the PPU upgrade to only 6 months, and also is being planned to avoid having the SNS down during a planned upgrade for the ORNL reactor neutron source HFIR. Beam commissioning following equipment installation completion is scheduled to start in 2024. The Total Project Cost (TPC) point estimate is ~ $240M.

CONCLUSION

The PPU is aimed at doubling the SNS accelerator power capability to 2.8 MW and received initial line-item funding this year. The project leverages existing designs, equipment and experience to reduce risk. The project schedule minimizes operational disruption, and initial beam commissioning following final equipment installation is anticipated in 2024.

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