SNS SUPERCONDUCTING LINAC POWER RAMP-UP STATUS AND PLAN

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Abstract

The Spallation Neutron Source (SNS) is a second generation pulsed-neutron source and designed to provide a 1-GeV, 1.44-MW proton beam to a mercury target for neutron production. Since the initial commissioning of accelerator complex in 2006, the SNS has begun neutron production operation and beam power ramp-up has been in progress toward the design goal. Since the design beam power is almost an order of magnitude higher compared to existing neutron facilities, all subsystems of the SNS were designed and developed for substantial improvements compared to existing accelerators and some subsystems are first of a kind. Many performance and reliability aspects were unknown and unpredictable, for which it takes time to understand the systems as a whole and/or needs additional performance improvements. A power ramp-up plan has been revised based on the operation experiences and understandings of limits and limiting conditions through extensive studies with an emphasis on machine availability. In this paper the operational experiences of SNS Superconducting Linac (SCL), the power ramp-up status and plans will be presented including related subsystem issues.

INTRODUCTION

Table 1 compares the high level beam parameters achieved individually and altogether for neutron production with the design ones. The column of 'Individually achieved' in Table 1 correspond to maximum values with other parameters at a lower condition [1-2]. For example, the beam current was about 10 mA at 1 Hz for 1.01-GeV linac output energy. The beam power on target is presently about 0.86 MW and will be ramped up to 1.0 MW at the end of this fiscal year. The SCL is stably providing 0.93 GeV beam with 99 % availability.

Table 1: High-level Beam Parameters Achieved to Date

Parameters	Design	Individually achieved	Highest production beam
Beam Energy (GeV)	1.0	1.01	0.93
Peak Beam Current (mA)	38	40	40
Average Beam Current (mA)	26	26	23.6
Beam Pulse Length (µs)	1000	1000	670
Repetition Rate (Hz)	60	60	60
Beam Power on Target (kW)	1440	860	860
Linac Beam Duty Factor (%)	6	4	4
SCL Cavities in Service	81	80	80

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SCL OPERATIONAL EXPERIENCES

Extensive testing has been conducted on the SNS superconducting RF modules starting in late 2004 [3]-[5]. Behavior peculiar to the SNS cavities and the overall design, as well as due to the pulse nature of the operation, have been observed. Some components have shown peculiar behaviors.

Operational Flexibility

One of the main characteristics of the superconducting linac is its flexibility and adaptability to adding or removing cavities. On many occasions, cavity fields had to be temporarily or permanently changed, or in some cases, cavities had to be removed from service. The linac flexibility has demonstrated itself in allowing complete retuning and rephrasing of the linac over times on the order of a few minutes [6].

Limits and Limiting Factors of SRF Cavities

Eighty cavities are in service out of 81 cavities, and the SCL is operating at 0.93-GeV output energy with an energy reserve of 10MeV. Most of the cavities exhibit heavy field emission and/or multipacting, which directly or indirectly (through heating of end groups) limits the gradients achievable in normal operation with the beam. The overall phenomena are complex, and the final operational cavity gradients need to be determined individually for each cavity based on the equilibrium between electromagnetic, electron emission, and thermal phenomena, each affecting the overall stability of the system on a pulse-by-pulse basis. In addition to individual cavity field emission limitations, collective effects have been observed, which affect neighboring and second neighbor cavities. Heating of cavity elements are driven not only by the amplitude, but also by the relative phase of neighboring cavities. Since in the SNS linac, neighboring cavities' amplitudes and phases are correlated, operation in a heavy field emission region is prevented, thus limiting the final available energy. Figure 1 plots the operating gradients of the SRF cavities in the SNS SCL. Due to the lack of the final linac output energy, the gradient of each cavity is set to maximize the gradient based on the collective limiting gradients achieved through a series of SRF cavity/cryomodule performance test at SNS, rather than setting uniform gradients as designed. As seen in Figure 1 cavities in the medium-beta section of the SCL are operating above the design gradient of 10.2 MV/m, whereas those in the high-beta sections of the SCL are operating below the design one of 15.8 MV/m, mainly due to radiation and related heating effects.

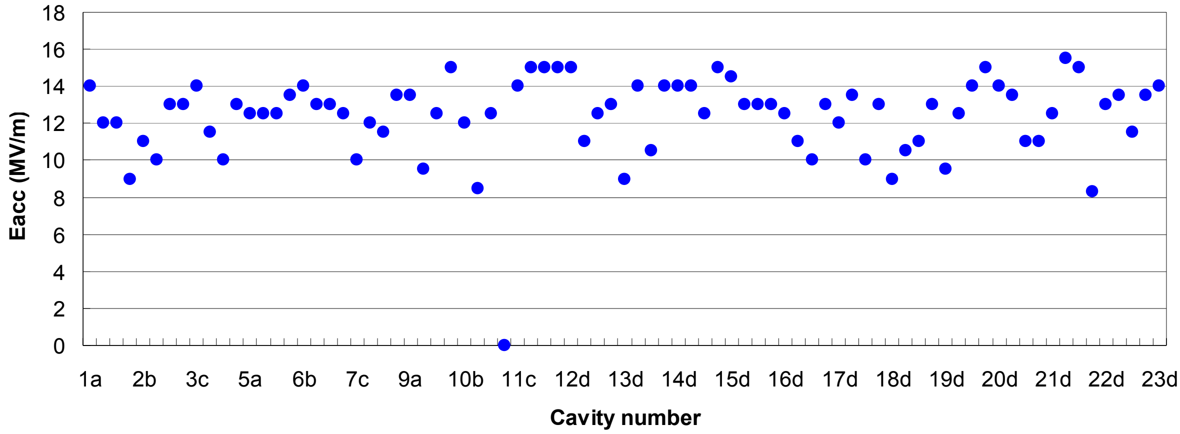

Figure 1: Operating setpoints of the SCL SRF cavities at 60 Hz for the neutron production in 2009.

POWER RAMP-UP

Most of the equipment in the SNS requires substantially higher operational ratings compared to existing accelerators, because the design beam power is almost an order of magnitude higher compared to existing neutron facilities. As the beam power was increased at higher duty factor during previous runs, down-times of some equipment led to lower machine availability than the plan. Some systems like the SNS SCL are the first attempt for pulsed operation. Many of the aspects of its performance are unknown and unpredictable, for which it takes time to understand the systems as a whole, and/or need additional performance improvements. The power ramp-up plan has been revised based on the operational experiences and on understandings of the limits and the limiting conditions through extensive studies, with more emphasis on machine availability (Figure 2). The plan covers the main driving factors for beam power, such as the chopping efficiency, ion source improvement, high-voltage convertor modulator (HVCM) improvement, and the SCL output energy. The followings are short descriptions of the issues and the plans for the SCL power ramp-up.

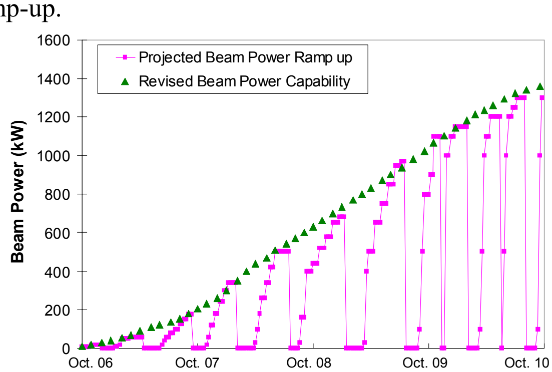

Figure 2: SNS beam power ramp-up plan.

Output Beam Energy

The final output beam energy mainly depends on the SCL gradients. Presently, eighty cavities out of eight-one cavities are in service and the SCL is providing output energy of 930 MeV with about 10-MeV energy reserves, which is lower than the design energy due to the facts mentioned in the previous section. The plan is to achieve 1-GeV output energy, with 30- to 40-MeV energy reserve for fast recovery of operation from unexpected long-lead down time of not only cavities but also related systems.

Available PF Power for a High Intensity Beam

Each SCL cavity is fed by an individual klystron rated at a 550-kW RF output at saturation and has independent RF control systems. The eighty-one klystrons for the SCL are powered by HVCMs; four HVCMs were running at 69 kV for twelve klystrons each and three HVCMs were running at 71 kV for eleven klystrons each. The voltage of the HVCMs needs to be increased up to 75 kV to utilize the rated RF power of the klystrons. To have high-power ramp-up as planned with good machine availability, one additional HVCM was installed for the SCL early this year so that most of the SCL HVCMs power 10 klystrons at 75 kV with fair reliability.

Pulse Width

The beam pulse width is presently a major driving factor for the SNS power ramp-up and depends mainly on the HVCM pulse width, the stability of the chopper, and the warm linac conditioning especially the RFQ for a longer pulse.

In SCL there is another beam pulse extension which is obtained by reducing the SCL cavity filling time from 300 µs to 250 µs with an additional HVCM for the SCL, as mentioned above.

CRYOMODULE WORK

Repair & Improvements

Cryomodule repair work is in progress to get all 81 cavities in service. One cavity in cryomodule 11 is not operable due to large fundamental power coupling through the HOM port. One high-beta cryomodule (CM12), which had beam line vacuum leak and showed biggest radiation from RF operation, was removed from the linac tunnel to the SNS SRF test facility for repair.

Repairs revealed that the beam-line leaks were located at the HOM feedthroughs. Four leaky feedthroughs were removed out of eight HOM coupler ports in this cryomodule. After RF performance tests in the SNS SRF test facility, this cryomodule was brought in service. The other high-beta cryomodule (CM19) was removed from the tunnel and has been repaired by removing HOM coupler feedthroughs from one cavity in the SNS SRF test facility. This cryomodule has been back in service since March 2008 and is the best performing cryomodule in the SNS SCL. Very recently, one cavity, SCL-10b, which showed noisy field probe signals and had been turned off for about a year at 30- and 60-Hz operations, was repaired in the tunnel.

As mentioned above, high-beta cavities need about 2.5 MV/m additional performance improvements. An R&D effort is in progress to develop in-situ surface processing for the cryomodules in the tunnel without disassembly. As the first attempt, in-situ plasma processing has been applied to the CM12 in the SNS SRF facility after the repair work mentioned above. Cavities were mildly processed and radiation measurements are compared before and after the plasma processing (Figure 3). Results from this effort have shown that the plasma processing can significantly reduce field emission and surface contaminations on a fully assembled cryomodule.

Programs are under way to explore plasma processing parameter space for optimization of surface contamination reduction. R&D will focus on identification of contaminants and efficient removal utilizing a 3-cell medium beta cavity, a fast turn around plasma chamber for small samples, and a test cavity (TM020) that was specially design to have low Bp/Ep. The bottom plate of the test cavity is demountable and can be utilized in the plasma chamber and assembled to the 3-cell cavity at the FPC port.

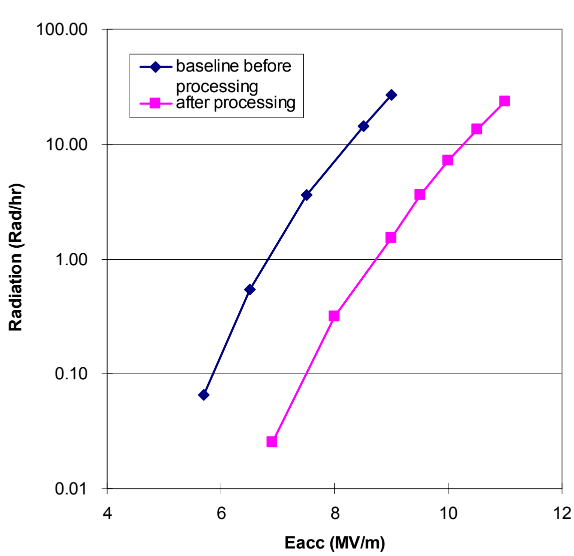

Figure 3: Comparisons of radiation in one of CM12 cavities before and after the plasma processing.

Spare Cryomodule

The SNS is planning to have 1 medium- and 2 high-beta spare cryomodules for operational support. The plans for the spare cryomodule fabrication are established. The experiences obtained from this effort will be directly applied to PUP (Power Upgrade Project) cryomodules.

Design efforts of the high- and medium-beta cryomodules for 10CFR851 compatibility are underway. The vacuum vessel was chosen to be the pressure boundary along with the redesign of the end-cans. The schematics are shown in Figure 4.

Fabrication of the first high beta cryomodule is underway. Helium vessel redesign and fabrication is completed, and the cavity string will be completed in summer of this year.

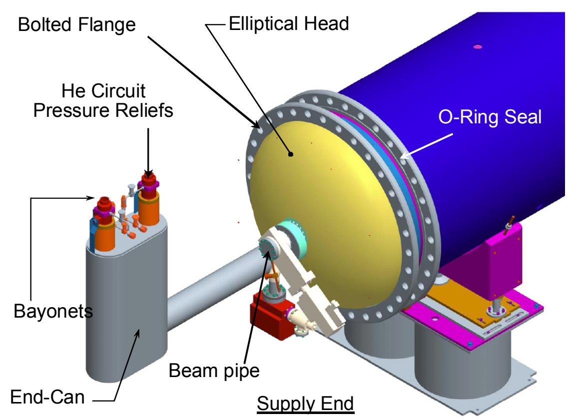

Figure 4: Schematics of new design for the SNS spare cryomodule.

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