

SNS LINAC UPGRADE PLANS FOR THE SECOND TARGET STATION *

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Abstract

The Second Target Station (STS) upgrade proposal for the Spallation Neutron Source (SNS) [1] adds a short pulse, long wavelength neutron scattering station. In order to provide world-class neutron intensity at the additional station, the SNS linac beam power capability is doubled, to 2.8 MW. This will be accommodated by a 38% increase in the operational beam energy to 1.3 GeV and a 42% increase in beam current. The beam energy increase will be provided with the addition of 7 additional cryomodules and supporting RF equipment in space provided during the original SNS construction. Improving the ion source and reducing the chopping fraction will provide the beam current increase. Increases in the RF and high voltage modulator systems are needed to accommodate the additional beam loading. Initial plans are presented.

INTRODUCTION

In order to double the intensity per pulse delivered by the SNS accelerator, we plan to increase the linac beam energy from the present 940 MeV to 1.3 GeV and to increase the average macro-pulse beam current from 27 mA to 38 mA. The repetition rate will remain at 60 Hz, and the macro-pulse length will remain at 1 ms. All linac pulses will still be time-compressed in the SNS storage ring to support short-pulse neutron source generation, however one-sixth (10Hz) of the extracted pulses from the ring will be redirected towards the new target station.

In the following sections we describe the linac improvements required to support this power upgrade, and the general plans to implement these improvements. High-level STS linac parameters are listed in Table 1, along with operational parameters from the recent 1.4 MW operation in June 2014.

BEAM ENERGY INCREASE

Provisions to accommodate a beam energy upgrade were provided in the original SNS construction. There are 9 empty plots at the end of the superconducting RF linac section in the tunnel, and space for the accompanying high power RF in the high-energy end of the RF equipment “klystron gallery” that parallels the linac.

Table 1: Machine parameters to support the STS power upgrade

	1.4 MW Operation	STS / 2.8 MW
Final energy (MeV)	940	1300
Average macro-pulse current (mA)	27	38
Peak macro-pulse current – RFQ exit (mA)	34.6	48
Un-chopped fraction	0.78	0.80
Repetition rate (Hz)	60	60
Macro-pulse length (ms)	0.97	1.0
High beta cryomodules	12	19

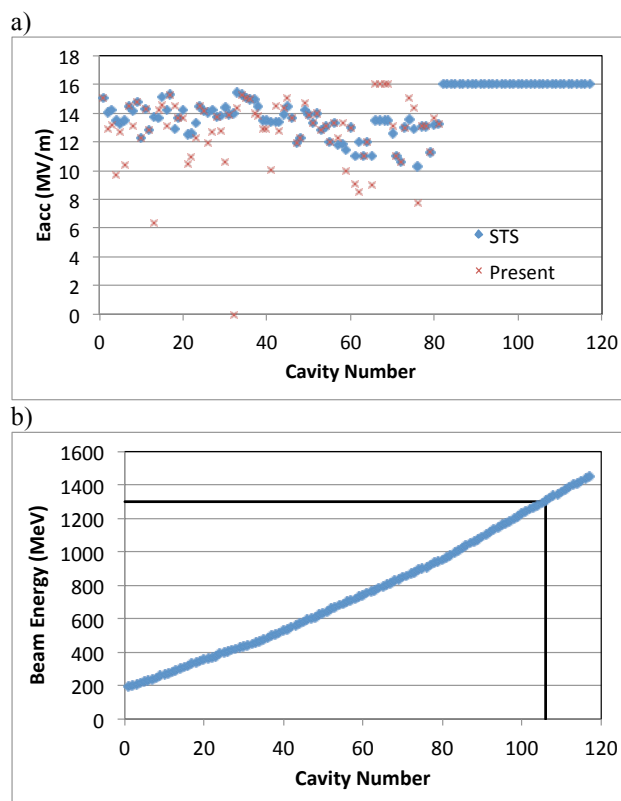


Figure 1: a) Cavity gradients for the SNS superconducting linac (SCL), b) the energy vs. cavity along the SCL.

* ORNL is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.
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Figure 1 shows the gradients and the resulting beam energy gain along the superconducting linac (SCL). Cavities 1-81 represent the existing portion of the SCL, with red marks indicating present operational gradients and blue marks indicating planned gradients. Some of the poorer performing cavities have increased gradients for STS, with the improvement expected from on-going plasma processing activities [2]. Other strong performing cavities have reduced STS operational gradients, to lower the required RF power associated with the planned increased beam current. The exiting cavities are limited to an RF forward power limit of 550 kW (the fundamental power coupler limit for the existing cryomodules).

In particular, cavities 66-69 are the new “spare cryomodule” built at SNS, and represent the highest performing cryomodule. The 16 MV/m gradient demonstrated performance of the spare cryomodule is the design value used for the future STS cryomodules, and lessons learned in its manufacture will be employed in the STS cryomodule. The RF systems for the new cavities will support 700 kW per cavity operation, to accommodate the increased gradient and increased beam loading for STS operation.

In order to reach the design requirement of 1.3 GeV, with the cavity gradient distribution indicated in Fig. 1, 25 additional cavities are required. Since SNS high beta cryomodules have 4 cavities, this implies the addition of 7 additional cryomodules, with the last 3 cavities being used as spare cavities. This plan is a more aggressive strategy than the original SNS power upgrade plan [3], which called for 9 additional cryomodules. A primary basis for the more aggressive plan to only use 7 additional cryomodules is the demonstrated 16 MV/m gradient capability of the spare cryomodule, which serves as a prototype. This cryomodule also incorporates the necessary pressure code engineering upgrades that STS will need.

In addition to reduced cost of only requiring 7 new cryomodules, there is a simplification to the installation. Although there are 9 empty slots at the end of the linac in the tunnel, some of the chases for RF waveguide and cabling between the tunnel and RF klystron gallery have an excess of magnet and instrumentation cables, and are unsuitable for RF wave-guide. While the cables could be extracted, and deployed properly, this represents a significant operational impact. The flexibility provided by not requiring the use of all the chases, greatly alleviates the new cryomodule installation plan.

BEAM CURRENT UPGRADE

In addition to the ~38% beam energy increase, the average macro-pulse beam current is planned to be increased by ~42%, namely from 27 mA to 38 mA. This will be done by increasing both the peak current and reducing the fraction of the beam that is chopped to provide a clean extraction gap in the accumulator ring. As indicated in Table 1, the baseline parameters call for a 48

mA peak H⁺ beam current (at the RFQ exit), with 80% of the beam un-chopped. This is a substantially reduced peak beam current from the 59 mA called for in Ref. [3]. The primary reason for the reduction in the peak beam current requirement is the reduced fraction of the beam that is chopped in the present STS design. The reduced chopping fraction comes from improved equipment performance [4] and a plan to manipulate the longitudinal ring beam profile through RF ramping [5] and a more flexible chopping waveform pattern during injection. We note that with improved chopper performance, the operational experience at 1.4 MW operation used an un-chopped fraction of only ~22% averaged over the macro-pulse. This is a much smaller fraction than the 32% planned in the original SNS design. The further reduction of the chopped fraction to from 22% to 20% for STS is quite modest, and may be exceeded.

The required beam current input to the SNS RFQ is ~55 mA for the parameters in Table 1, and is based on the existing SNS design RFQ. We presently measure ion source capability of 45-50 mA for production sources, which is close to this requirement. We note that the present operational RFQ has a beam transmission estimated to be 10-20% degraded from design. This is a known issue, and a new RFQ has been fabricated and high power conditioned. Beam tests are planned soon.

In the original SNS power upgrade plans, a dual ion source concept was adopted to provide increased machine reliability [3], with one source to be used as a hot spare. This concept required development of a magnetic LEPT system to accommodate the switching magnets. The present STS plans to not include a dual source because: 1) the present source + electrostatic LEPT reliability is quite good, and 2) the required source improvement is relatively modest.

HIGH POWER RF SYSTEMS

RF Requirements

The increased STS beam current translates to higher beam loading and increased RF requirements. Figure 2 shows the SNS lower energy copper structure RF power requirements with present day operation (green), STS beam loading (blue) and the installed klystron available linear power (red). In general the impact of additional beam loading is not a strong driver, and the existing CCL klystron technology, with possible minor modifications, should be a reasonable approach. (The low available power for the third CCL klystron reflects a poor individual performer – not a design flaw). However, for the DTL case, the control margin becomes quite small with the additional STS beam loading and these klystrons will need to be upgraded from 2.5 to 3.0 MW capability.

There is a more significant impact on the SCL RF power requirements with the increase beam loading. Indeed, some of the cavity gradients for the existing cavities indicated in Fig. 1 are limited by the available klystron and coupler power limit of 550 kW. The increased gradient new SCL region will require 700 kW

klystron and fundamental power coupler designs. The SCL klystrons being procured as spares now are 700 kW capable. The FPC for the STS has been designed with minimal change from the original one and the prototyping is completed.

HVCM Requirements

The high voltage pulse forming modulators will require higher operating voltages to support the additional RF power described above. We note that new controllers and pulse flattening improvements are on-going and should be in place before the STS project completion. For the warm linac HVCMs, the boost transformer turn ratio will be changed to increase the output voltage, and increased thermal handling implemented. For the SCL modulators, the baseline approach is to use existing HVCM technology with two 9:1 ratio (klystron to HVCM) modulators and one 10:1 ratio modulation. A backup plan is to adopt an alternate HVCM topology that eliminates the need for boost capacitors.

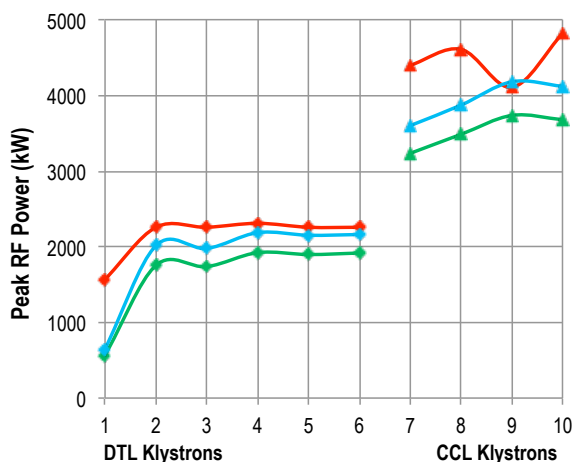


Figure 2. RF peak power requirements for the SNS warm structures for: 24 mA macro-pulse current (green), 38 mA macro-pulse current (blue) and the existing klystron available linear power (red).

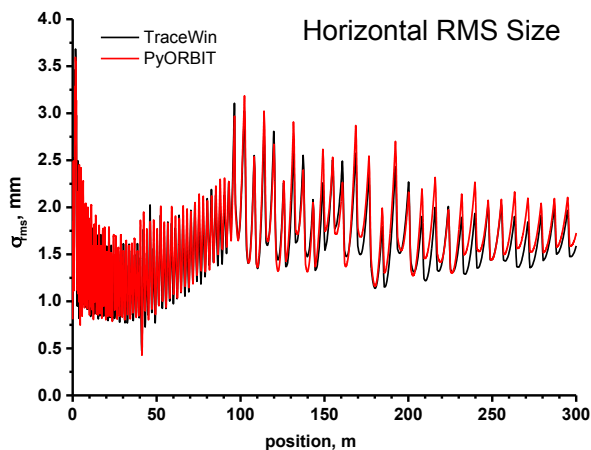


Figure 3. The horizontal RMS beam size from the RFQ exit to the SCL exit for STS beam intensities.

MULTI-PARTICLE SIMULATIONS

Initial multi-particle simulations for the SNS linac have started, using the increased beam intensity of STS and the new SCL cavity gradient distribution. Figure 3 shows representative output, namely the RMS beam size along the SNS linac for the case of STS intensities, calculated with Trace-Win [6] and the new Py-ORBIT codes [7]. There is good agreement between the models, and for the ideal case with no errors, no particles are found to be lost. This is an on-going activity, and will be closely coupled to machine studies with the SNS linac.

SUMMARY

A preliminary design for the SNS linac power upgrade needed to support the STS is presented. It is an extension of the SNS experience, with relatively modest extrapolations needed, as compared to the large steps already taken to achieve 1.4 MW operations. Modest development is required in the HVCM and ion source areas.

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