

## STATUS AND PERFORMANCE OF THE SPALLATION NEUTRON SOURCE SUPERCONDUCTING LINAC\*

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### Abstract

The Superconducting Linac at SNS has been operating with beam for almost two years. As the first operational pulsed superconducting linac, many of the aspects of its performance were unknown and unpredictable. A lot of experience has been gathered during the commissioning of its components, during the beam turn on and during operation at increasingly higher beam power. Some cryomodules have been cold for well over two years and have been extensively tested. The operation has been consistently conducted at 4.4 K and 10 and 15 pulses per second, with some cryomodules tested at 30 and 60 Hz and some tests performed at 2 K. Careful balance between safe operational limits and the study of conditions, parameters and components that create physical limits has been achieved.

### INTRODUCTION

The Spallation Neutron Source at the Oak Ridge National Laboratory is designed to provide a 1 GeV, 1.4 MW proton beam to a mercury target for neutron production. Approximately 81% of the beam energy is achieved in the superconducting part of the linac, where H<sup>-</sup> ions are accelerated in two different sections with 33 and 48 superconducting RF 6-cell cavities operated at 805 MHz (Table 1).

Table 1: Major Design Parameters of the SNS SCL

Cryomodule Parameter	Medium Section	Beta	High Beta Section
Output Energy (MeV)	379		1000
No. of Cryomodules	11		12
No. of cavities per cryomodule	3		4
Cavity Parameter	Medium Cavity	Beta	High Beta Cavity
Geometric beta	0.61		0.81
EoT (MV/m)	10.1 at $\beta=0.61$		15.9 at $\beta=0.81$
Epeak (MV/m)	27.5		35.0
Hpeak (kA/m)	46.2 (580 Oe)		59.7 (750 Oe)
Q*Rs ( $\Omega$ )	176		228
r/Q at design beta	279		483
Equivalent Cavity Length (cm)	68.2		90.6

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Most of the superconducting linac cavities have been at 4.2 K for over two years and the accelerator has been operating with beam since August 2005 at energies between 840 MeV and 1.01 GeV. The linac, designed to operate at 2.1 K, has been running mostly at 4.4-4.5 K, since the Helium mass flow generated by the RF losses at 4.5 K could be handled by the cryogenic system at the lower repetition rates (up to 15 Hz), used for initial operation.

### SUPERCONDUCTING CAVITIES PERFORMANCE

#### Single Cavity Limits

Limits for all the superconducting cavities were originally established in the spring of 2005 based on the maximum achievable gradient at 10 pulses per second at 4.4 K. Stable beam operation was achieved with gradients lower than the maximum ones, due to the limitations listed below [1]. Some cavities operated at 4.5 K reached gradients corresponding to a surface magnetic field at a substantial fraction of the critical magnetic field for niobium (Fig. 1)

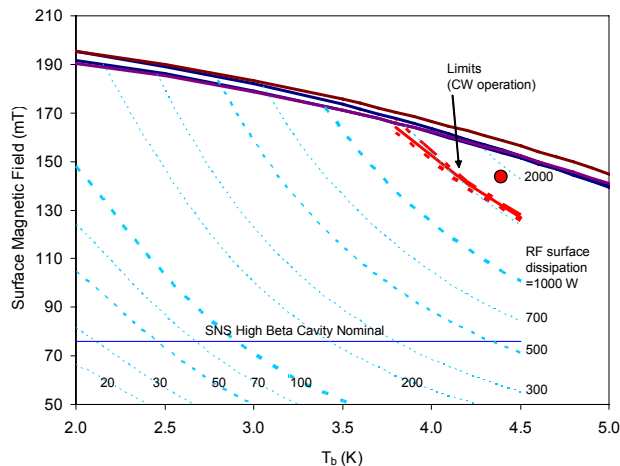


Figure 1: Peak surface magnetic field for Nb and levels of dissipation for the SNS cavities as a function of temperature. The red dot represents the surface magnetic field of the best installed medium beta cavity.

#### Field Emission Limitations

Most of the cavities exhibit heavy field emission which directly or indirectly (through heating of end groups) limits the gradients achievable in normal operation with

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.

Figure 2 shows that at least in some cavities the field emission phenomena are not simply due to the presence of high fields in the cavity's cells, but are the result of complex transient conversion of electromagnetic energy into radiation and heat. In this case, radiation is detected not when the fields in the cavity are maximum, but when the wave in the transmission line feeding the cavity is fully traveling in either direction.

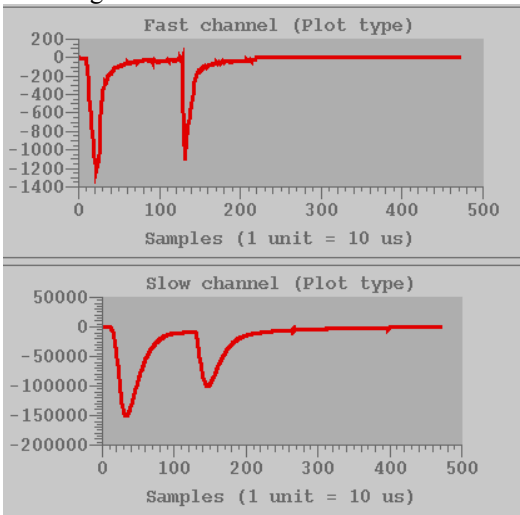


Figure 2: Radiation detection response during pulse operation of some SNS cavities.

*Interlocks*

Besides the intrinsic limits due to physical phenomena related to superconductivity, electronic and thermal effects, some cavities are limited in the operating gradients because of tight interlock constraints imposed to

prevent catastrophic failure of key components. For example, the fundamental power coupler window is protected by a vacuum interlock based on the measurement of local pressure by a Cold Cathode Gauge (CCG). In a large fraction of the cavities, the CCG's are not responding at the low pressure of the beamline vacuum, until, either by real pressure increase or by discharge triggered by local multipacting, the response of the CCG gauge drives the system unstable. Gradients need to be adjusted to maintain arc detector and CCG interlock under control, thus limiting the available operating gradient.

*Higher Order Mode Filters Behavior*

The Higher Order Mode Filters designed to damp longitudinal modes at the bunch harmonics have shown behavior which may lead to failure of their RF feedthroughs. They also show electronic phenomena related to multipacting and discharges which prevent the full utilization of the associated cavities' gradients due to concern of catastrophic failure. This concern has led us to either decrease gradients or temporarily or permanently turn off cavities showing anomalous behavior [1]

**SRF MODULES: COLLECTIVE BEHAVIOR**

*Field Emission Effects*

In addition to individual cavity field emission limitations, collective effects have been observed which affects 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 into heavy field emission is prevented by stability concerns, thus limiting the final available energy.

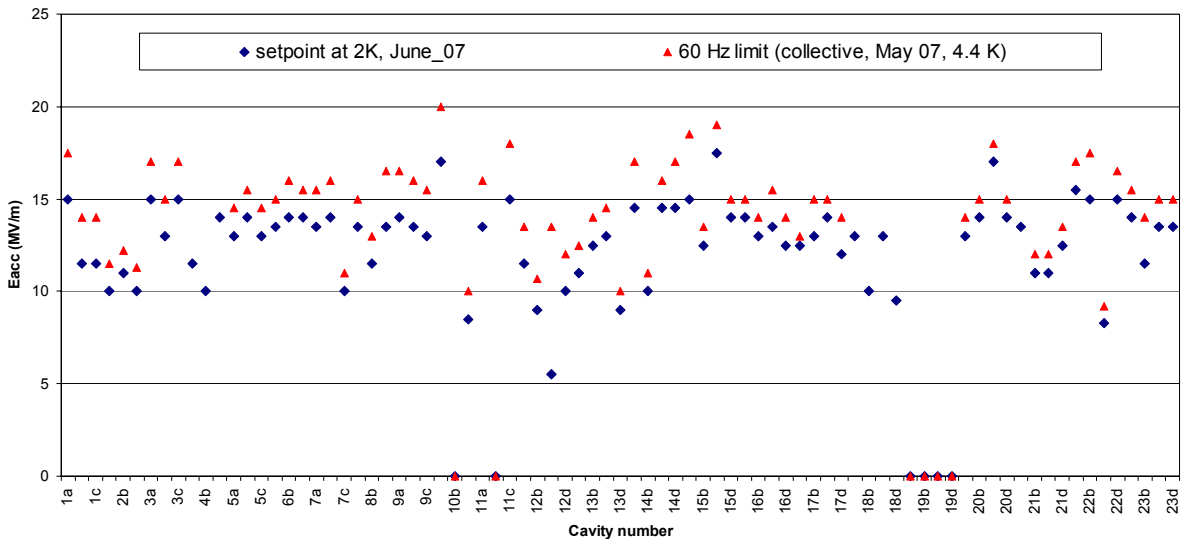


Figure 3: Accelerating gradients of SCL cavities: collective limits established at 60 Hz and 4.4 K and 2.1 K setup for the beam run in June 2007.

### Other Operational Conditions

Operation of the machine during the initial phases has required RF repetition rate of only 10 Hz. In recent months more detailed measurements both at higher repetition rates (up to 60 Hz) and at 2.1 K have given a more comprehensive picture of the limitations of the superconducting cavities. In Figure 3 the present machine setup is shown. It is clear that the medium beta cavities by far exceed their design gradient, whereas the high beta ones cannot provide their full capability.

### BEAM ACCELERATION

Beam has been running in the SNS SCL since August 2005. A considerable amount of experience has been gathered on the operation of the highest energy “proton-like” linac. A considerable amount of work has gone into improving the speed, repeatability and reliability of the beam setup in the SCL [2, 3]. Recently, full rephrasing of the linac based on completely new gradient specifications has been achieved in only a few hours. The flexibility of the SCL individual cavity’s klystron amplitude and phase freedom has allowed variable energy operation with great ease and it will eventually make best use of the available gradients of cavities installed at present and in the future.

Excellent agreement between the estimated fields in the cavities and the energy gain independently measured via beam-based techniques makes it possible to accurately predict beam parameters via modeling (Figure 4).

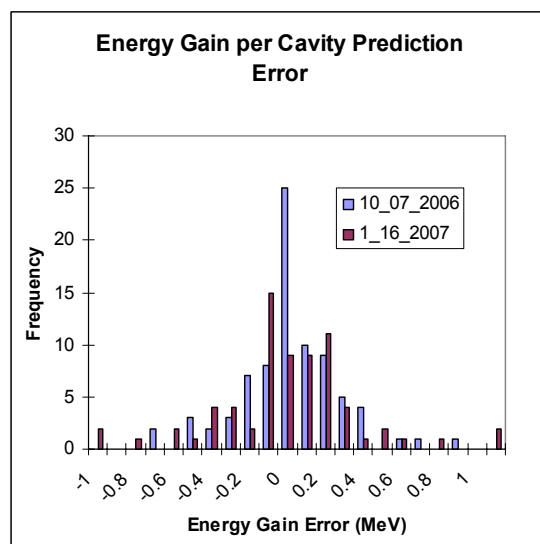


Figure 4: Relative difference between fields estimated from RF data and those derived from beam energy gain.

### 1 GeV RUN

Recently, at 4.5 K and a beam repetition rate of 15 Hz, a demonstration run that the SNS linac can meet the design specifications of 1 GeV beam energy was conducted for a few hours. Cavities which are normally maintained at low gradient or turn off were brought into

operation and the full energy of the SCL was achieved, even with three cavities still not operational. The flexibility of superconducting cavities setup was once again demonstrated, as the energy of the machine can be changed rapidly to achieve specific goals for demonstration or for neutron production

### FUTURE PLANS

The experience gained during the operation of the SCL in the past two years has led us to develop a plan of component improvement of cavities and SRF modules in order to provide reliable operation over the life of the machine.

In particular, replacement of CCG’s, use of different interlocks, HOM filter rework (feedthrough replacement, blank off, or filter removal), and SRF module cryogenic piping, will be part of a full improvement program. Acquisition of spare cavities and modules will allow us to sustain the ambitious power Ramp Up Plan to reach full beam power of 1.4 MW and high availability by the end of FY 2009 [3].

A facility is being readied at SNS to perform at least some of the improvements required by the beam power ramp up. This includes a clean room for cavity and cryomodule handling and assembly; a test cave for testing full cryomodules and for a single-cavity horizontal cryostat, used for cavity qualification [4].

### CONCLUSIONS

The SNS superconducting linac has been providing beam for neutron production in a reliable way. As time progresses, better understanding of pulse operation of superconducting accelerators is being gained and operational and hardware improvements are being implemented.

### ACKNOWLEDGMENTS

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