SPALLATION NEUTRON SOURCE STATUS AND UPGRADE PLANS*

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Abstract

The Spallation Neutron Source (SNS) has demonstrated beam power operation of 1MW after a rapid ramp-up period of three years. Recent results from high intensity beam studies have demonstrated the linac and storage ring will operate at the design current and linac at its design pulse width without difficulty. Preliminary measurements of beam loss at full current were promising, and now SNS is ready to operate at beam powers close to or at 1MW. During this beam power ramp-up period a good understanding of the superconducting linac operating parameters, issues was obtained and current limitations to operating gradients will be presented in this paper as well as some of the planning details to prepare for the machine power upgrade over the next few years.

CURRENT MACHINE STATUS

During the last machine run period, the beam power was increased to 865KW for the first time. While running at this beam power, problems were uncovered with the stripping foil after several premature foil failures. The beam power was then reduced to 400KW to protect additional foils for the last two months of the run period until the problems could be identified. At the end of this run a high intensity beam run was performed to determine if the operating parameters of the linac, mainly the RF pulse could be increased in the following run to reach 1 MW beam power operation, the Department of Energy (DOE) design goal. The linac was setup for full pulse width at design current and ran to demonstrate design parameters. During this study it was determined that the storage ring could adequately store and extract the full beam intensity of 1.5x1014 protons per pulse. The extraction screen is shown in Fig. 1.

The machine was then shutdown for the scheduled summer maintenance period. During this extended maintenance period the stripper foil system was opened and the problem wre identified and new foil holders and foils were installed. When the machine was brought back online in mid September as scheduled and the beam power was steadily increased to 1 MW on September 18th and ran there for an extended period. Currently the machine is operating at a beam power of 820KW. In Fig. 2, the operations metrics chart for the beam on target is shown.

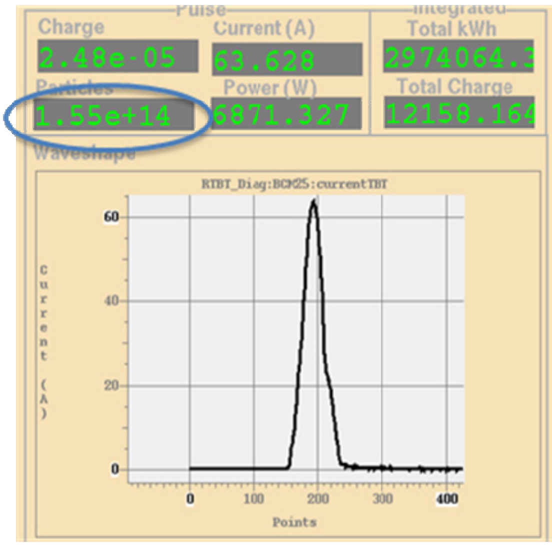

Figure 1: Screen shot demonstrating full beam intensity in protons per pulse, extracted from the storage ring.

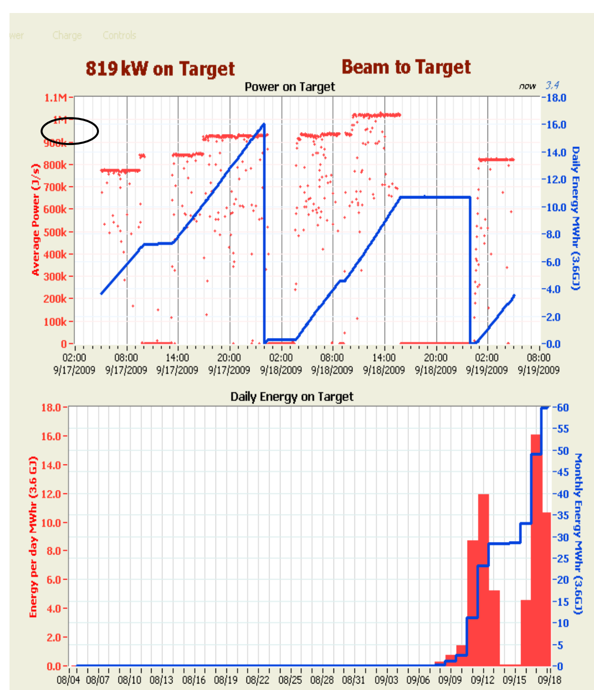

Figure 2: Current SNS operating status, beam to target metrics charts from operations web page.

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Another important factor to control and understand with proton machines is the beam loss which must be minimized to avoid high activation rates for beam line components. High activation rates can affect the ability to perform routine maintenance activities by increasing the complexity of the setups and procedures used. This is especially true for the storage ring where losses are typically higher.. During the high intensity beam run the ring beam losses were monitored for 1MW equivalent beam which was comparable to that of the production run at 865KW. Additionally the losses were captured for the 24uC case with no additional beam tuning which showed higher losses but these could be improved by further tuning. In Fig. 3 the ring beam loss comparison is presented which shows no major concerns for 1MW operation in the ring.

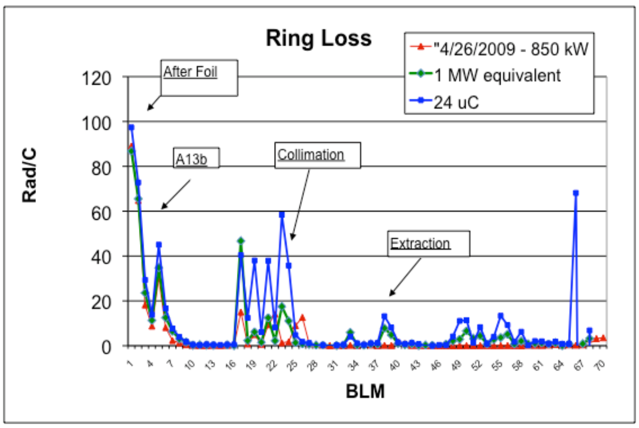

Figure 3: Beam losses comparison for the storage ring.

To date many of the SNS machine design parameters have been met and others are very close to their design specifications [1]. In Table 1, a comparison of parameters achieved to that of the machine design parameters is presented.

Table 1: Comparison of design parameters to that achieved for SNS.

Parameters	Design	Highest Produc-tion Beam
Beam Energy (GeV)	1.0	0.93 + 0.01
Peak Beam current (mA)	38	40
Average Beam Current (mA)	26	24
Beam Pulse Length (ms)	1000	670
Repetition Rate (Hz)	60	60
Beam Power on Target (MW)	1440	**1.01**
Linac Beam Duty Factor (%)	6	4.0
Beam intensity on Target (protons per pulse)	1.5×10^{14}	1×10^{14}
SCL Cavities in Service	81	80

SUPERCONDUCTING LINAC STATUS

The superconducting linac consists of 11 cryomodules each holding 3 medium beta cavities and 12 cryomodules each holding 4 high beta cavities. This allows for a design energy gain from 185MeV to 1GeV. Currently the 33 medium beta (MB) cavities are operating slightly above specifications of 10MV.m and 47 of the 48 high beta (HB) cavities are operating slightly below design specifications of 15.5 MV/m. One of the HB cavities has never been operated due to a damaged higher order mode coupler. The superconducting cryomodule operating gradients are shown as a function of position in the linac in Fig. 4. Cryomodule 12 was out of service and was repaired and installed in the linac in the January of 2009. Cryomodule 12 had several problems including high fundamental power coupling out HOM couplers in two of the cavities as well as vacuum leaks on the helium circuit and cavity to insulating circuit. Repairs were made to this cryomodule and during the qualification testing plasma cleaning of the niobium surface was performed [1]. This was to test if this method would be useful for reducing field emission. The plasma test was successful with gains of a few MV/m for some of the cavities after applying a very light processing equivalent to 1 minute of plasma on the surface. Cryomodule 12 was then installed in the tunnel were it has been operating with gradients around the average for High Beta Cavities. With the repair of cryomodule 12, 80 of the 81 superconducting cavities are operating in the linac. Most of the cavities installed in the superconducting linac are primarily limited by field emission. Data collected during operation, tune up and physic study periods on these cavities has led to a full optimization of the linac gradients to maximize energy gain and reduce trip levels to a reasonable number. What was learned during this time was that the field emissions from one cavity can strongly all others in its cryomodule, what we call the collective effect. The linac is now one of the most robust systems installed in the machine with a few trips per day. So far no indication of degradation in gradient performance over time for these cavities has been identified. This infers that the cavity field emission is very stable; gradients are not reducing or increasing with time operating. With a successful attempt applying plasma cleaning to a fully assembled cryomodule, plans are to spend the next year studying plasma cleaning and developing procedures to apply this cleaning method to the installed linac cryomodules. Plans are to apply the plasma cleaning method to the HB and selective MB cavity in an attempt to achieve the superconducting linac design energy gain of 1GeV. Currently the linac produces 930MeV of energy gain with 10MeV of reserved control.

If successful with this plan we will have established a new cleaning method for superconducting cavities which could be applied at any step of the qualification process. Currently qualifying superconducting cavities suffer from high failure rates during the qualifying process mainly due to field emission.

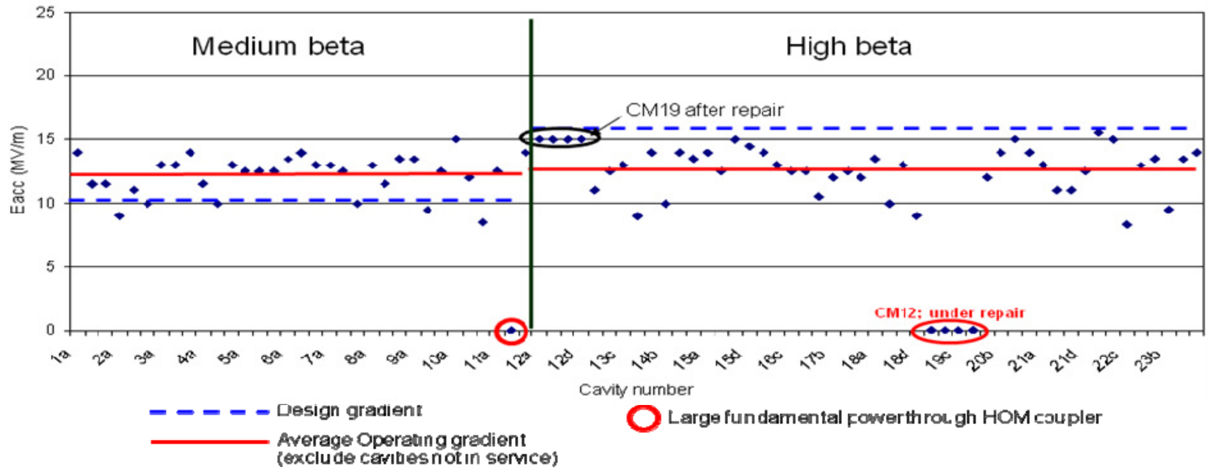

Figure 4: Superconducting cavity operating gradients optimized for collective limits.

THE POWER UPGRADE PLANS (PUP)

The power upgrade plan for the SNS beam energy was approved by DOE January of 2009 to critical decision 1 (CD1). The plan identifies an increase in the linac energy from 1 GeV to 1.3 GeV plus some reserve by adding 9 new HB cryomodules to the end of the superconducting linac. Along with the additional cryomodules, an accelerator improvement plan (AIP) for increasing the beam current from 26mA to 42mA was developed. In order to be ready for PUP, several critical efforts are underway with regards to the superconducting linac. First SNS would like to improve the performance of the linac cryomodules an collective energy gain of 930MeV to 1GeV by applying plasma cleaning to the installed cryomodules which a proof of principle has been demonstrated with reducing cavity field emission in the HB cavities. Reducing field emission is a critical step if one wants to maximize the usable (collective) gradient of modules produced. This development once demonstrated successful, can be directly applied to the PUP cryomodule fabrication plans. Currently however there is not a clear understanding of why the HB cavities performance is dominated by field emission. The second requirement before starting PUP is to adapt the existing cryomodule designs to meet 10CFR851 and more specifically the pressure vessel code. Currently SNS is taking steps towards building the first spare HB cryomodule and through this process both cavity concerns are being addressed by studying field emission during the processing of these cavities and redesigning the cryomodule outer vacuum shell for ASME pressure vessel code requirements. This first cryomodule is critical to developing solutions to the existing problems and gaining experience and training personnel prior to the start of PUP.

Field Emission Reduction

A series of HB cavities are currently being qualified at Jefferson Lab in Newport News Virginia. Currently what is known about the field emission in the HB cavities is that even though many of the processes have been improved since the original linac cavities were processed and qualified, the performance has not changed. What seems to be a mystery with these results is that the same procedures that are used on the ILC cavities (except for the chemistry) when applied to the HB cavities the HB cavities are still limited by field emission when ILC cavity performances are reaching 30MV/m with no sign of field emission. A complication to sorting this performance difference out (ILC and HB) is the heavy multipacting barriers encountered with HB cavity testing. The multipacting also generates many x-rays which can be confused with field emission. Also during the testing of these cavities one cavity has extremely high amounts of radiation produced during its test cycle. This cavity HB54 has had several processing cycles and the performance has not changed significantly even after extended high pressure rinses (68 hours) and cycles with no additional chemistry. HB54 has had a full internal inspection of the niobium surface an no defect or suspect defect was found.

One ways identified to reduce the multipacting in the HB cavity is to remove the higher order mode resonant form tile hook. One of the HB cavities has had both HOM hooks removed and is currently being E-beam welded to close the HOM post holes. Tests are planned to study the cavity with no hooks to see if this improves the understanding of the contribution of x-rays generated from the HOM hook multipacting.

Another avenue to reducing field emission seems to be to electropolish the cavity surface. Electropolished cavities statistically, achieve higher gradients and have less field emission. Plans are to also electropolish some of the HB cavities to determine if it should become part of the baseline procedure which is currently using a buffered chemical polish procedure.

Modifying the SNS Cryomodules Design for Pressure Vessel Compatibility

One year ago a decision made to move the pressure boundary of the SNS cryomodule from the cavity helium circuit to the cryomodule outside vacuum jacket and end-can envelope. The reason for this design change was due to the fact that the cavity and helium vessel materials are not listed materials in the ASME pressure vessel code. By moving the boundary to the outside vacuum shell the problem of applying the code to the cryomodule became achievable in a reasonable amount of time. This decision was also based on a code interpretation that refers to tube heat exchangers where the pressure boundary can be moved from the high pressure tubes inside to the envelope of the heat exchanger body. Advantages to moving the boundary condition to the cryomodule outside are many and here are a few important ones. All the SNS cryomodule vacuum shell materials are listed in ASME. This means that the code rules are clear and can be directly applied without additional material testing. The outside shell will never reach the cavity operating temperature of 2.1K due to flashing of the liquid. Stainless steel, the boundary material has excellent toughness at cryogenic temperatures and is corrosion resistant. Using the cavity and helium jacket vessel as the boundary puts the material testing requirements at very low temperatures. Additionally the outer vacuum shell and end can envelopes can be individually pressure tested without the cavity string inserted into the structure other words the all cavities may require pressure testing if the previous pressure boundary of the cavity helium circuit was utilized.

Currently the cryomodule vacuum shell and end-can designs are being modified for applying the pressure boundary to these components. Minor changes were required to material dimensions and flanged joints were added to the end of the vacuum shell. The end can design had more extensive changes including a dished head at the vacuum shell location and a round shape to the return and supply bayonet cans.

CONCLUSIONS

The Spallation Neutron Source has now demonstrated 1MW beam power and has in doing so reached its DOE design goal. This is a world record for pulsed neutron beam power and has established the SNS facility as a world class machine for neutron sciences experiments. Currently steps are being taken to prepare for the power upgrade plan for the linac and ion source. The superconducting linac is operating with good availability and plans are to develop a path forward to reduce field emission throughout the superconducting linac while building the first spare HB cryomodule. Along with this effort a redesign of the existing cryomodule is underway to meet 10CFR851 requirements. Plans are to build out the first spare cryomodule within the next year.

I would like to thank J. Galambos, S.H. Kim and S. Henderson for providing some of the materials to complete this document and for the many discussions explaining details of the machine performance and associated data and graphs. Also I would like to thank the SNS staff for all their hard work bringing this machine up to its design goal of 1MW, this effort has produced a world class facility for basic energy sciences.

REFERENCES

[1] S.H. Kim "JACoW, SNS Superconducting Linac Operational Experience and Upgrade Path", LINAC'08, Victoria, Canada , September 2008, MO103;http://www.JACoW.org