4.2 K OPERATION OF THE SNS CRYOMODULES*

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Abstract

The Spallation Neutron Source being built at Oak Ridge National Laboratory employs eighty one 805 MHz superconducting cavities operated at 2.1 K to accelerate the H⁻ beam from 187 MeV to about 1 GeV. The superconducting cavities and cryomodules with two different values of beta (.61 and .81) have been designed and constructed at Jefferson Lab for operation at 2.1 K with unloaded Q's in excess of $5x10^9$. To gain experience in testing cryomodules in the SNS tunnel before the final commissioning of the 2.1 K Central Helium Liquefier, integration tests are being conducted on the cryomodules at 4.2 K. This is the first time that a superconducting cavity system specifically designed for 2.1 K operation has been extensively tested at 4.2 K without superfluid helium.

INTRODUCTION

The Spallation Neutron Source (SNS) includes a superconducting-cavity linac for the acceleration of H⁻ ions from 187 MeV to 1 GeV. The linac consists of 11 medium beta cryomodules (each containing three cavities) and 12 high beta cryomodules (each containing four cavities).

The cavities were designed at Thomas Jefferson National Accelerator Facility (JLab), where testing of the components and the assembly of the cryomodules were also performed.

A number of cryomodules were tested at JLab to ascertain that the design requirements were met [1]. Those tests were performed on one cavity at a time and at a temperature of 2.1 K.

Early in 2004 the installation of cryomodules in the SNS tunnel started as the production at JLab was in full swing. However, due to a number of unavoidable technical and manufacturing delays, it appeared that the Central Helium Liquefier at SNS would not be ready for testing of cryomodules until late in 2004 or even in 2005. Thus, alternative methods of testing cryomodules in situ at SNS became important, which could provide a full integration demonstration of all the cold linac systems, as well as to demonstrate that the transportation of complete

cryomodules from JLab to SNS did not adversely affect the performance. Moreover, a number of cryomodules were not tested at JLab, so that the success of the cryomodule production needed to be confirmed through tests at SNS.

A number of scenarios that were considered are reported here. They included the use of local dewars for cryomodule cooldown with or without subatmospheric cooling as well as cooldown to only 4.2 K using the standard atmospheric part of the SNS refrigerator. Details of the various scenarios and the results of the chosen configuration tests are reported.

LOCAL CRYOMODULE COOLING MODE

Contingency plans were drawn for the cooldown and testing of the first installed cryomodule at SNS using local dewars and a scheme for cooling one cryomodule for a few days only in order to perform functionality tests of all the cryomodule systems and controls. The analysis and the details of the setup are contained in reference [2].

That plan was never implemented but it was kept available in case of additional delays in commissioning the cryogenic plant. However, the exercise of understanding the behavior of the cryogenic system and of the cryomodules at 4.2 K was very valuable in planning and in dealing with the following tests which were performed with the aid of the CHL operated in a refrigeration mode.
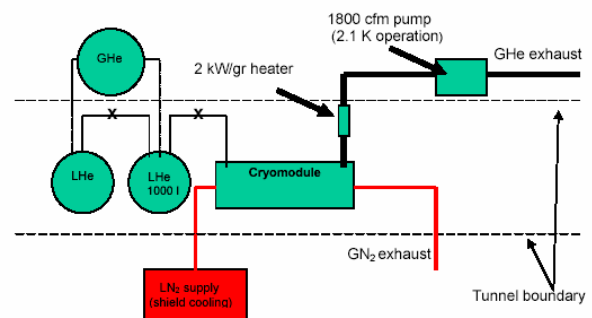

Figure 1: Schematic of the local cooldown configuration considered for the first cryomodule cooldown. This solution was never implemented but the study led us to the 4.2 K testing.

4.2 K CRYOGENIC OPERATION

In August 2004 the cooldown of a medium beta cryomodule was implemented using the CHL. The tests of

that cryomodule were extremely successful and all of the features of the cryomodule system, including low level RF, high power RF, controls, and vacuum integrity were tested satisfactorily. In that occasion, the three cavities in the cryomodule reached fields of 10-12 MV/m at a 3.9% duty cycle and 30 pps repetition rate, half the nominal 60 pps.

During the following run at the end of 2004 and in January 2005 additional cryomodules and cavities were cooled down and tested and the installation and testing is now reaching completion [3].

One aspect of the operation at 4.2 K is the fact that the pressure cannot be maintained stable within a fraction of a millibar, as it is done in subatmospheric operation. At the beginning of the testing, we experienced a strong collective synchronous frequency modulation of approximately 300 Hz (a significant fraction of the 1.1 kHz bandwidth) in all the cavities that were tested (Figure 2). That modulation was attributed to pressure fluctuations in the return lines by about 3 torr. After an investigation of the 23 mHz oscillation, it became apparent that it was due to thermo-acoustic oscillations in the unbalanced half of the return line, which was not yet being loaded by the presence of cryomodules. That oscillation was later removed and presently the maximum frequency excursions experienced are less than 30 Hz, well within the control capability of the Low Level RF system. This observation is of importance for the potential operability of the superconducting linac at 4.2 K.
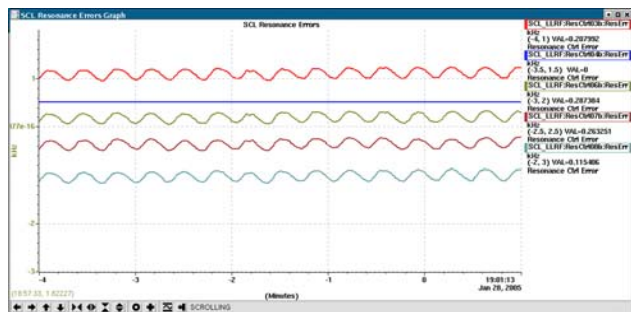

Figure 2: Frequency detuning of a number of cavities in the SNS linac as a function of time. The amplitude is about 300 Hz at a modulating frequency of about 23 mHz.

RF MEASUREMENTS

The RF measurements are being conducted at 4.2 K using the Low Level RF system designed for SNS [4]. Figure 3 shows the traces of a cavity with a closed loop implemented by the control system.

Through the controls system all the relevant parameters of the cavities are being measured: forward and reflected power are monitored, together with power transmitted through the field probe and the Higher Order Mode filter ports. The power coming from all the ports is used to determine the fields in the cavities using a variety of techniques.

The estimated unloaded Q_o of the cavities at 4.2 K is approximately 7×10^8, completely determined by the BCS

surface resistance at that temperature. The original design for the 2.1 K operation was done for a Q_o of 1.7×10^{10}, with the possibility of operating in field emission regime down to a Q_o of 5×10^9. Due to the inherently lower Qo at 4.2 K, operation at that temperature in heavy field emission is possible without inherent Qo degradation. Only at extreme field emission loading the indirect electron heating can cause cavity quenches, most likely occurring in the cavity end groups.
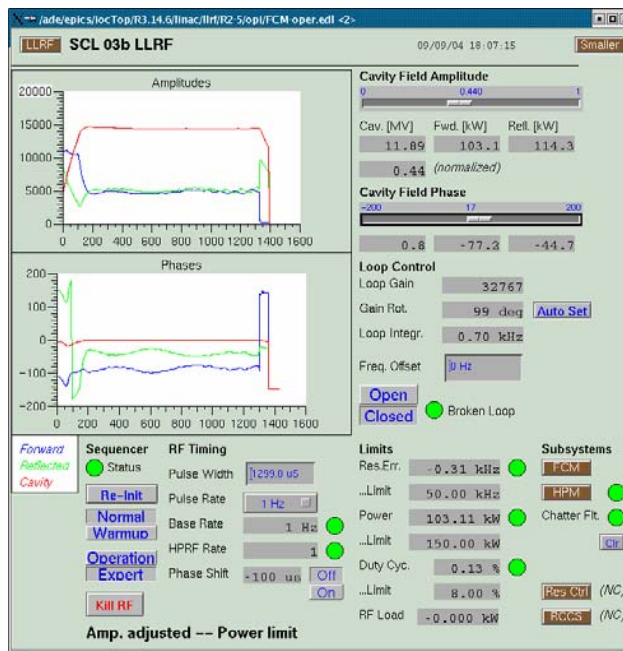

Figure 3: Low Level RF control screen showing a cavity operated in closed loop. The transmitted field amplitude (red trace, upper screen) gives the stabilized flat top over the 1 msec beam pulse length.
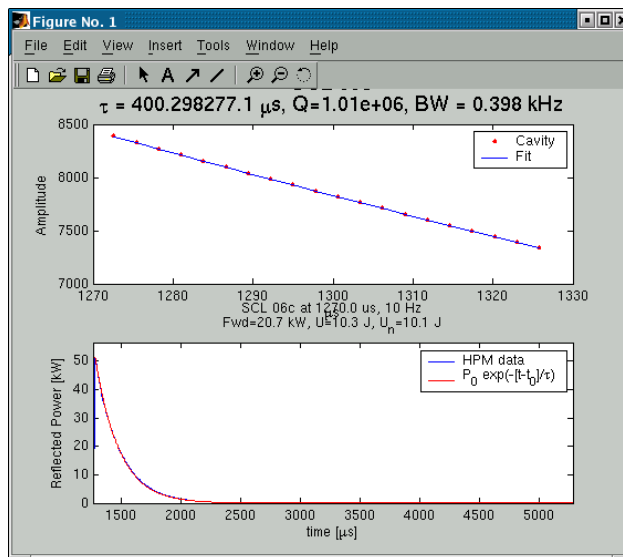

Figure 4: Logarithmic scale decay of the transmitted RF signal (upper) and linear plot of the emitted power during cavity discharge. The loaded Q and the cavity stored energy are calculated from the plots.

Figure 4 shows the loaded Q of a cavity calculated from the decay at the end of the RF pulse, together with the stored energy, obtained from the integration of the emitted power. Since the coupling coefficient is of the order of 1000 and the dissipation during the decay is negligible, the accuracy of the determination of the stored energy at the end of the pulse is of the order of 1/1000, much better than the typical RF calibration errors.

OPERATIONAL HEAT LOADS

The original design of the SNS cryogenic system was based on operation of 117 cavities (the present design includes 81 cavities with the possibility of an energy upgrade with 36 additional cavities) at nominal gradients of 10.1 MV/m for the medium beta cavities and 15.6 MV/m for the high beta cavities.

Table 1. Total thermal loads for the SNS superconducting linac under three temperature and Qo scenarios. All the 117 cavities for the SNS Power Upgrade are included.

Nominal Thermal Load	2.1 K Qo 1E10	2.1 K Qo 5E9	4.2 K
Static	640	640	640
Couplers	120	120	120
Dynamic	308	616	4300

Table 2. Total thermal loads of the SNS linac at the maximum field values measured experimentally for an upgrade scenario. We assume that 48 high β and 3 medium β cavities not tested can run at design gradients.

Maximum Thermal Load	2.1 K Qo 5E9	4.2 K
Static	640	640
Couplers	120	120
Dynamic	820	5800

At the maximum duty cycle of 7.8 % each medium beta cavity will dissipate 2.6 W at 10.1 MV/m at the minimum Q_o of 5×10^9. A high beta cavity operated at the nominal 15.6 MV/m gradient will dissipate 6.3 W. Operation that is free of field emission would decrease the dynamic thermal load by a factor between 2 and 4. The total dynamic load at nominal gradients due to medium beta cavities (33 of them) amounts to 87 watts in the worst case. The load due to the high beta cavities will be 302 W for the present configuration (48 cavities) and about 530 W for the SNS power upgrade (84 cavities). The static

heat loads are about 20 W per cryomodule. Tables 1 and 2 give reference numbers for operation of the cryogenic plant for the SNS linac.

FIELD EMISSION STUDIES

To determine stable operating points for all the cavities, a radiation detection scheme is being implemented, which uses phototubes and scintillators (Figure 5). Through it, we will be able to set the gradients for each cavity by knowing the threshold for field emission. The system is being tested on the first high beta cryomodule, which presents excess radiation as a consequence of a feedthrough failure during testing at Jefferson Lab. The threshold for intense field emission from the cavities is 7-8 MV/m. Operation above 13 MV/m generates radiation dose rates of the order of 1 kR/hr for the whole cryomodule.
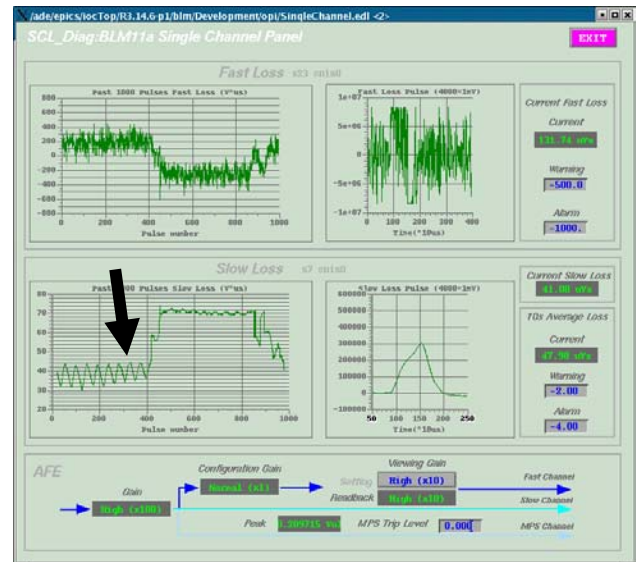

Figure 5: Control panel for a phototube detector. The time sequence (arrow) corresponds to the radiation modulation induced by the field amplitude oscillations caused by the changes in Figure 2.

REFERENCES

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