THE SPALLATION NEUTRON SOURCE ACCUMULATOR RING RF SYSTEM*

T. Hardek, M. Piller, M. Champion, M. Crofford, H. Ma
Spallation Neutron Source, ORNL, Oak Ridge, TN 37831, U.S.A.
A. Zaltsman, K Smith, BNL, Upton, NY 11973, U.S.A.

Abstract

The Spallation Neutron Source (SNS) accumulator ring is a fixed-frequency proton storage ring located at the output of the SNS Linear Accelerator (Linac). Its purpose is to redistribute the 1 millisecond long H- beam pulses from the SNS Linac into high-intensity 695 nanosecond long pulses of protons for delivery to the neutron target. The RF bunching system controls longitudinal beam distribution during the accumulation process and maintains a 250+ nanosecond gap required for beam extraction. The RF system consists of three stations which operate at the beam revolution frequency of 1.05 MHz and a fourth station providing a second harmonic component at 2.1 MHz. The beam pulse at extraction consists of 1.6e14 protons representing a peak beam current of 52 amperes. The system utilizes four 600 kW tetrodes to provide the RF current necessary to produce the 40 kV peak fundamental frequency bunching voltage and to control phase and amplitude at high beam current. A 20 kV peak second harmonic voltage is intended to control longitudinal beam distribution to control the peak circulating current. In this paper we review the design concepts incorporated into this heavily beam-loaded RF system and discuss its commissioning status.

INTRODUCTION

The main purpose of the SNS Accumulator Ring RF system is to maintain longitudinal beam distribution and control the peak current during injection of beam into the SNS accumulator ring. The system consists of high power RF amplifiers, ferrite-loaded bunching cavity structures, dynamic cavity-tuning hardware and a low level RF control system. The system was designed and assembled by Brookhaven National Laboratory [1,2,3] and installed at SNS by Oak Ridge personnel in 2005. We have been operating the system as designed for the past year and a half and have demonstrated its ability to control accumulated beam intensities of greater than 9.6e13 protons per pulse, limited only by other accelerator restrictions. This paper will focus on the equipment installation at SNS and provide some preliminary operational results.

INSTALLATION AT SNS

Figure 1 shows the location of RF cavities and amplifiers relative to other accumulator ring components. The cavities are all located in a straight section just downstream of the extraction kicker region.

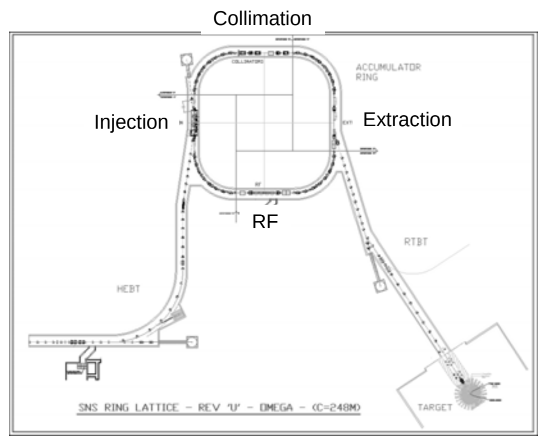

Figure 1: Location of RF Cavities

Figure 2 is a photo of the cavities and amplifiers as installed in the ring tunnel. The stations are numbered to designate their harmonic number and item number. Station RF-11 refers to the first fundamental component station while station RF-21 refers to the first second-harmonic component station. The first three cavities in the photo are fundamental component cavities and the final cavity is the lone second-harmonic cavity.

Figure 2: Cavities and Amplifiers installed in the SNS Accumulator Ring tunnel.

Figure 3 shows the installation of support power supplies for station RF-21 in the Ring Service Building. The equipment is installed in 4 rows, one for each RF station. Cooling water lines run overhead with most connections made to the top of the racks. The large

*SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

cabinet on the left is the cavity tuning supply, followed by the anode capacitor bank, anode power supplies, and filament supply.

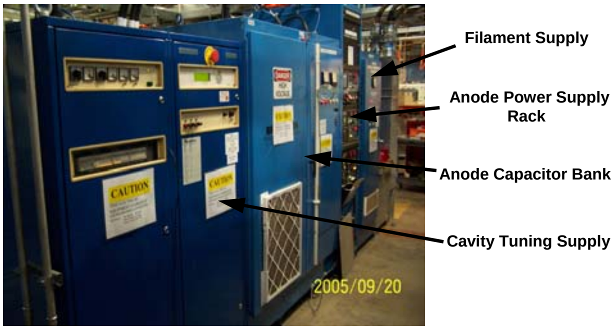

Figure 3: Layout of the support power supplies for Station RF-11

Figure 4 is a photo of the major system Low Level RF (LLRF) components as installed in a separate control room area of the Ring Service Building. Controls for the High Power RF equipment are located at the left while the LLRF equipment is distributed throughout the central and right side racks.

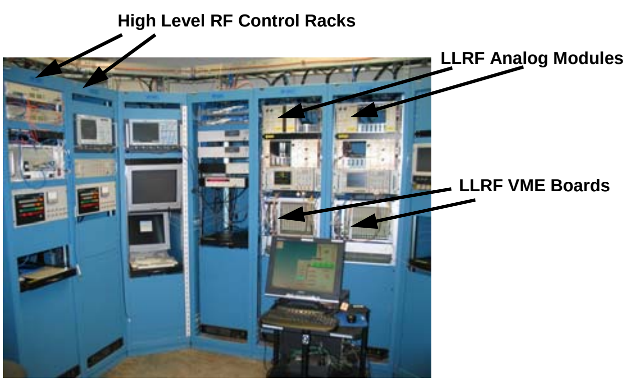

Figure 4: Ring RF Control Room

SYSTEM PERFORMANCE

The high power portions of the system performed well from the very first operation. We verified gap voltage calibrations and demonstrated bunching in January 2006. First beam on target occurred on April 28, 2006. We followed with an operational run providing 6 kW of beam on target with the ring RF system operating with a single cavity.

During machine development periods we have increased beam intensity and found that the Low Level RF system (LLRF) was limited in dynamic range to about 5e13 protons per pulse. During early system testing we had inserted attenuation between the LLRF output and the power amplifier chain to limit available power. Removing some of this attenuation (10 dB) provided the necessary dynamic range to allow operation at the present maximum intensity of 9.6e13 protons per pulse.

Figure 5 is a display of cavity voltage and phase with respect to the beam as we inject 9.6e13 protons per pulse. While a small beam-loading effect, about 500 volts, is visible in the upper amplitude trace it should be noted that no particular effort went into adjusting the LLRF system to minimize this effect. The transient occurring at extraction time in this trace can be controlled by removing RF drive at extraction.

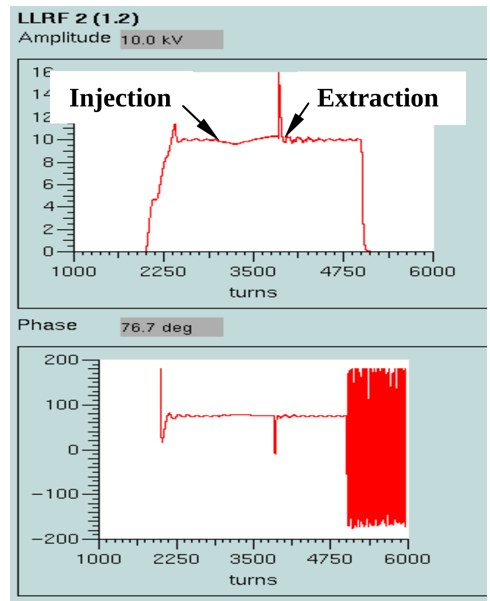

Figure 5: Amplitude and Phase display with 9.6e13 protons per pulse.

The system design included a cavity dynamic tuning capability to compensate for the effect of cavity detuning by the beam current at high intensity. A 180 Hz sinusoidal current, programmable in amplitude and phase, is supplied to the cavity tuning conductors. The roughly linear portion of the sinusoidal current, as the sinusoid crosses through 180 degrees, would be phased to counteract the linear ramp-up of beam current thus holding the cavity nearly on resonance. This approach reduces the final amplifier drive current easing the requirements on the LLRF dynamic range.

We have demonstrated the use of cavity dynamic tuning with beam. Figure 6 is a cavity phase display taken with about 1.6e13 accumulated protons. The 180 Hz sinusoidal dynamic tuning current has a peak-to-peak amplitude of 90 amperes to compensate for beam loading and is offset by 260 amperes to set the cavity at a nominal operating frequency. The upper trace displays the phase between the final amplifier grid and anode. One can clearly see the phase shift resulting from beam being injected into the ring (T2 to T3). The lower trace has the

1-4244-0917-9/07/$25.00 ©2007 IEEE

dynamic tuning current adjusted to minimize phase shift during the injection period (T2 to T3). Notice that the phase is shifting prior to beam injection (T1 to T2) and again during a short store time (T3 to T4). At extraction time (T4) an abrupt phase shift is seen as beam is extracted from the ring.

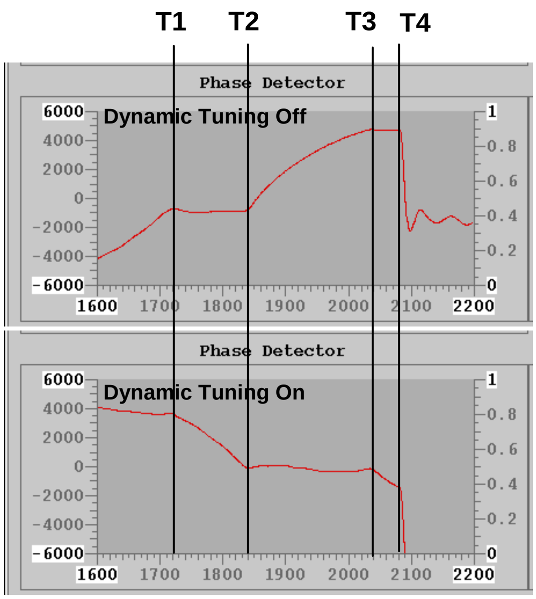

Figure 6: Phase between the grid and anode of the final amplifier stage with and without cavity dynamic tuning.

The LLRF system design included the ability to compensate for beam loading by sampling the beam current, inverting this signal with respect to the beam current, and feeding it into the amplifier chain to cancel the beam loading effects. We have been experimenting with this compensation approach and believe it can work, but more development time is needed before we can implement this feature.

The existing LLRF portion of the system, while it does perform well, is quite different from our linear accelerator hardware and control software. Changes to the software, firmware and hardware are difficult for us to accomplish and the operations staff must learn to operate a very different collection of control screens. We are therefore working on an updated LLRF system which would include the features of the existing system but utilize much of our LINAC hardware and software. The resulting system would look and feel much like the other RF controls in use throughout the accelerator and utilize much of the same hardware.

CONCLUSIONS

We believe the amplifier chain has enough available power to control beam loading at intensity levels well above our design intensity of 1.6e14 protons per pulse. The existing LLRF has the features and capability required to meet our design goals, but we have been troubled by the differences between the RF controls for the Linac portion SNS and those of the Ring RF. We have little local support for both the existing hardware and software. We are proceeding with a LLRF development effort to utilize much of the software and some of the hardware we presently use for the remainder of the SNS for the ring RF system. The updated LLRF system will include all of the features available in the existing system but will be easier for SNS operators to use and the SNS RF group to work with.

REFERENCES

[1] J. M Brennen J. Brodowski,, J. DeLong, M. Meth, K. Smith, A. Zaltsman, BNL, New York, “RF System for the SNS Accumulator Ring,” PAC 2001, Chicago, http://www.jacow.org.

[2] A. Zaltsman, M Blaskiewicz, J. Brennan, J. Brodowski, J. Butler, M. Meth, F. Severino, K. Smith, R. Spitz, BNL New York, “Progress in the Development of High Level RF for the SNS Ring,” PAC 2003, Portland Oregon, http://www.jacow.org.

[3] A. Zaltsman, M Blaskiewicz, J. Brennan, J. Brodowski, M. Meth, F. Severino, R. Spitz, BNL New York, “High Level RF for the SNS Ring,” EPAC 2002, Paris, France, http://www.jacow.org.