PROGRESS IN THE DEVELOPMENT OF HIGH LEVEL RF FOR THE SNS RING*

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Abstract

A High Level RF (HLRF) system consisting of power amplifiers (PA's) and ferrite loaded cavities is being built by Brookhaven National Laboratory (BNL) for the Spallation Neutron Source (SNS) project. Four cavities were built and are being tested. Each cavity has two gaps with a design voltage of 10 kV per gap and will be driven by a PA directly adjacent to it. The PA uses a 600kW tetrode to provide the necessary drive current. All the PA's were built and are being tested at BNL prior to shipping to ORNL. A dynamic tuning scheme used to help compensate for the effect of beam loading was implemented and tested.

1 INTRODUCTION

Main tasks of the HLRF system for the SNS ring are to capture proton beam during 1 ms injection from the 1GeV linac and to maintain a gap for the rise time of the extraction kicker. The HLRF system consists of three harmonic one cavities running at 1.05 MHz and one harmonic two cavity at 2.1 MHz.

The HLRF is required to operate at wide dynamic ranges of the gap voltage (20 dB) and from no beam loading at the beginning of the cycle to the heavy beam loading (75 Amps peak current) at the end.

This paper will describe progress in the development and testing of all the key components of the HLRF system.

2 SYSTEM PARAMETERS

High beam loading and reliability of the system were the determining factors for the system configuration and parameters.

To achieve these requirements, a set of parameters was developed. These parameters take into consideration beam loading, reliable high voltage design, availability of components (ferrites, tubes, etc.), space in the ring and maintainability.

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*Work performed under the auspices of the United States Department of Energy

System parameters are tabulated in Table I.

Table I

RF system type	Dual harmonic
Cavity length	2.3 m
Accelerating gaps per cavity	2
Harmonic 1 frequency	1.058 MHz
Number of harmonic 1 cavities	3
Harmonic 1 total voltage	40 kV
Harmonic 2 frequency	2.115 MHz
Number of harmonic 2 cavities	1
Harmonic 2 total voltage	20 kV
Beam loading compensation	Dynamic tuning and feed forward
Harmonic 1 cavity shunt impedance	800 Ω

3 CAVITY AND POWER AMPLIFIER

Reliability, conservative design and easy maintainability were the prime consideration in the development of the SNS RF system.

Small samples, as well as full size ferrite rings, were evaluated for power dissipation, permeability and instabilities. The best choice for the ferrite for this application was Philips 4M2. The highest flux density is at the lowest frequency and on the inner surface of the ferrite ring. Each gap consists of 21 rings, and each ring measured 50cm O.D x 25cm I.D. x 2.72cm thick.

$$V_{gap} = 2 \cdot \pi \cdot f \cdot B_{rf} \cdot l \cdot a \cdot \ln(b/a)$$

$$B_{rf\ \max} = \frac{10^4}{6.28 \cdot 1.05 MHz \cdot 21 \cdot .0272 \cdot .125 \cdot \ln \frac{50}{25}} = 310 \cdot Gauss$$

Tests of the ferrite showed no instabilities at flux density in excess of 400 Gauss.

In our design, four capacitors of 750 pF each provide a total gap capacitance of 3 nF. Because removing 3 of 4 gap capacitors from the h=1 cavity will convert it to h=2 cavity, we are able to utilize the same cavity for both systems.

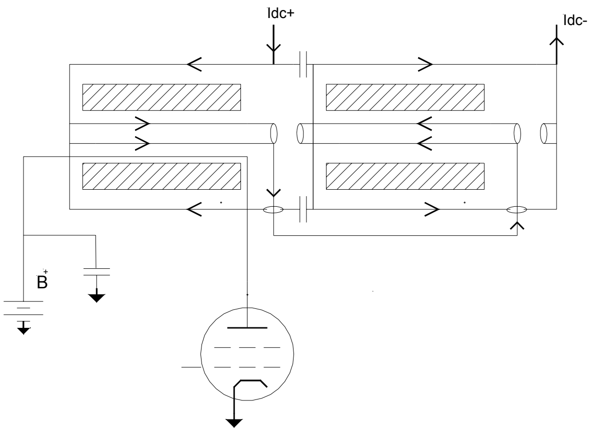

Figure 1

Figure 1 shows a functional diagram of the RF cavity and the PA. Ferrite rings are dc biased whereas the outer can, beam pipe and the gap connecting buswork form a single turn bias winding. Because two halves of the cavity are in series to the dc bias, but in parallel to the RF drive, the RF will be cancelled (figure eight).

At the present time two out of four cavities were fully tested to 11 kV peak and are ready to ship to ORNL. The other two are fully assembled and ready for testing. Two amplifiers are fully tested and the remaining two are being assembled.

The amplifier is magnetically coupled to the cavity. B^+ link is inserted along the beam pipe. This technique eliminates the need for a plate choke. To reduce the downtime in case of the failure of this link a second one was installed and tested to the full RF voltage.

Cavity and the PA under test

4 DYNAMIC TUNING

The beam current in the accumulator ring is in quadrature with the generator current. During the accumulation the average beam current increases from 0 to 35 amperes. The peak amplitude of the first harmonic component is 50 amperes per gap with total 100 amperes per cavity.

$$I_b = 2\cdot 10^{14}\ ppp = 35 A_{dc} = 55 A_{pk}$$

By optimizing the resonant frequency of the cavity, the PA current may be reduced to the unloaded value.

Set the gap voltage to $V(t) = V_{rf}\sin(\omega t)$ and the PA current to $I_{pa}(t) = \left(\frac{V_{rf}}{R}\right)\sin(\omega t)$.

The beam current is $I_B = I_b\cos(\omega t)$.

The total driving current is the sum of the beam and PA contribution and is equal to the sum of the currents in the resistor, capacitor and inductor of the cavity.

$$\frac{V_{rf}}{R}\sin(\omega t) - I_b\cos(\omega t)$$

$$= \frac{V_{rf}\sin(\omega t)}{R} + \left(\omega C - \frac{1}{\omega L}\right)V_{rf}\cos(\omega t)$$

$$\text{so,}\quad I_b = V_{rf}\left(\frac{1}{\omega L} - \omega C\right)$$

The inductance is varied according to:

$$-\frac{\Delta L}{L} = \frac{(R/Q)\cdot I_b}{V_{rf} + (R/Q)\cdot I_b} \quad \text{where} \quad \left(R/Q = \frac{1}{\omega C}\right)$$

$$\frac{\Delta L}{L} = .35 = 35\%$$

$$\frac{\Delta f}{f} = -\frac{1}{2}\left(\frac{\Delta L}{L}\right) = 17\%$$

At 1.05 MHz it would represent 170 kHz frequency difference between the drive frequency and the resonant frequency of the cavity. The loaded Q of the cavity is 50 at tube quiescent current of 5 amperes, and drops to 38 at 10 amperes.

To simulate this mistuned condition the frequency was swept from 1.05 MHz to 1.22 MHz, while keeping the cavity tuned at the 1.05 MHz by the constant tuning current. AGC kept the voltage on the gap constant at 7 kV. (Figure 2)

Dynamic tuning PS

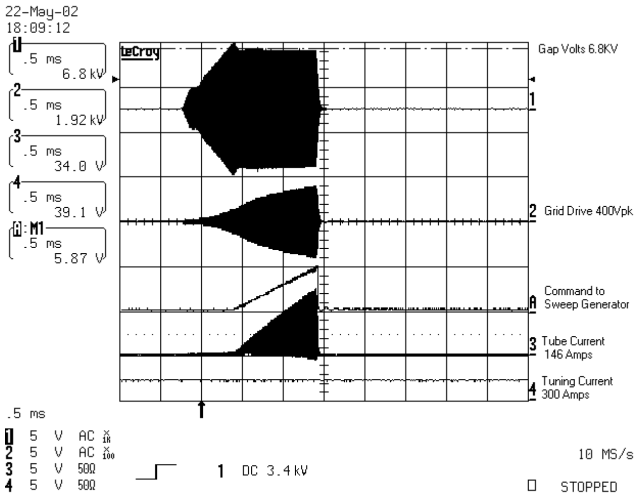

Figure 2

To reduce the effect of beam loading Dynamic Tuning was implemented. Dynamic tuning is a feed forward correction, which is perfect for the SNS application since the repetition rate of the machine is 60 Hz, and the beam intensity doesn't change from cycle to cycle. Tuning current will be changing at 60 Hz (or a multiple of it) by +/-450 amperes peak around the dc component needed to tune the cavity without the beam loading.

The results were great, and a full power tuning supply was built to test on the final cavity.

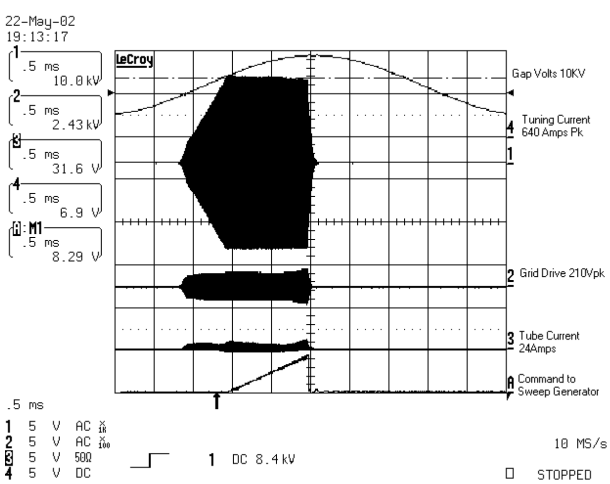

Figure 3

Fig. 3 shows a dynamically tuned cavity at 10 kV on the gap with the tube current less than 30 amperes. The tube current and the grid drive are drastically reduced.

5 POWER SUPPLIES

The beam accumulation in SNS lasts mS, and if we add mS for pre tuning the cavities to the nominal voltage, the duty cycle of the HLRF system does not exceed 12%. A pair of 12 kV, 3.5 amp charging power supplies in parallel, charging a 70uF capacitor bank was chosen for the anode supply. To switch the tube on and off we used fast (1 MHz) grid bias power supply that switches the bias between the shut-off (-700 volts) and 20 amperes of quiescent current.

Anode, screen, grid and 3 out 4 tuning power supplies are at BNL being tested. 500 watt drivers were successfully tested and being ready to ship to ORNL.

6 CONCLUSIONS

Two cavities, two power amplifiers and a set of power supplies were rigorously tested and operated at BNL at the gap voltages exceeding the design values and are being packaged for shipment to ORNL

The system was designed conservatively with an eye on reliability, ease of operation and troubleshooting in a high radiation environment. All the components used were rated with comfortable safety margins.

7 REFERENCES

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