DEVELOPMENTS FOR PERFORMANCE IMPROVEMENT OF SNS H- ION SOURCE RF SYSTEMS*

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Abstract

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory is ramping up the accelerated proton beam power to 1.4 MW after achieving 1.1 MW. The RF-driven multicusp ion source employing internal RF antenna originally developed by LBNL has been used to deliver up to ~38 mA H^- beam current in 1 msec pulses at 60 Hz with limited availability. To improve availability, an RF-driven external antenna multicusp ion source with a water-cooled, ceramic aluminum nitride (AlN) plasma chamber has been developed. Computer simulations were done to analyze and optimize the RF performance of the new design. Plasma ignition system using a separate 13 MHz antenna is under development. To improve the RF power system for easier maintenance, a 70-kV isolation transformer for the 80-kW, 6% duty cycle 2-MHz amplifier was developed and used to power the ion source from a grounded power amplifier.

INTRODUCTION

The RF driven pulsed H^- ion source in SNS has been performing well after the initial commissioning. The system has been operational for many years delivering the beam with the steadily increasing duty cycle following the power ramp up schedule [1]. However, as the RF duty cycle increased to near maximum, the failure of the internal RF antenna became a critical problem. When operating at high duty cycle within the plasma, the antenna had damage on the ceramic insulation. As a solution to the problem, an ion source with an external antenna was designed, built, and tested in the SNS test stand [2]. The development of the external antenna ion source required optimizations to eliminate various problems such as breakdown in antenna insulation and RF heating of multicusp magnet holder.

Other performance problems that needed to be resolved for robust operation of the ion source system were the reliability of the 2 MHz vacuum tube power amplifier, the 13.56 MHz plasma igniter, the RF impedance matching network, and the limited accessibility of the 2 MHz amplifier operating on -65 kV floating platform. The unreliable vacuum tube amplifier was planned to be replaced with a solid-state amplifier along with the addition of a high voltage isolation transformer. In this paper, we discuss the new external antenna development with computer simulations, the plasma ignition system, and powering the ion source from a grounded RF power amplifier through an isolation transformer.

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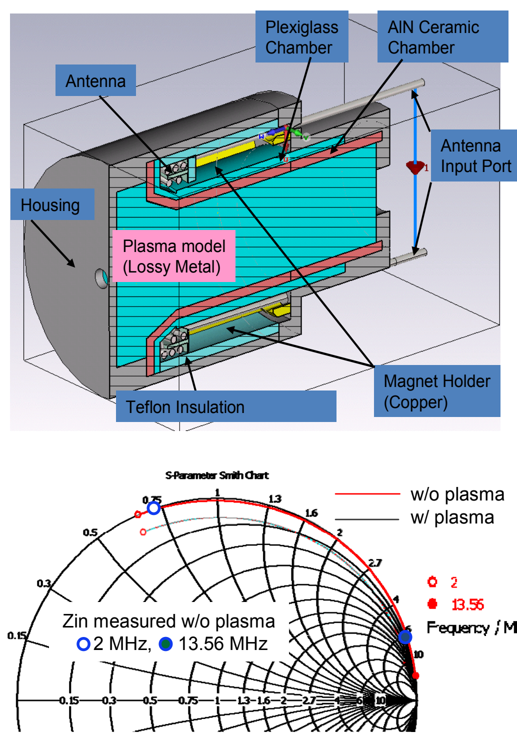
ION SOURCE RF

Antenna Design

For design optimization for improvement of the ion source, computer modeling of RF operation was done using CST MWS, a 3-D FDTD code package. Figure 1(a) shows the cross secion of the new external antenna design that employs an aluminum nitride (AlN) plasma chamber. Figure 1(b) shows the measured and the calculated antenna terminal impedances. The simulated result was considered a reasonable estimate of antenna impedance that can allow initial design of the impedance matching networks. The RF heating and the voltage breakdown in the ion source could be estimated with the modeling. The



(a) (b)

Figure 1: (a) External antenna ion source, (b) computed input impedance of the external antenna.

plasma was modeled as a lossy metal by finding the equivalent conductivity σ from the measured antenna impedance. The conductivity could be found by comparing the real parts (resistivity) of the measured and simulated antenna impedances. The data provided by Raizer [3] helps to estimate the rough conductance that can update through the above comparison process. The effective σ varies roughly 100 – 1,000 S/m depending on the details of the source design. The modeling was done to determine field strengths, impedance, and power deposition on the parts inside the ion source structure. In this external antenna model, σ = 600 S/m was used to roughly agree with the measured RF input impedance of the antenna and used in power deposition analysis.

RF Impedance Matching

The calculated antenna impedance obtained by the modeling was used to design the impedance matching network. The schematic of the current SNS ion source RF system with the internal antenna is shown in Fig. 2. The 2 MHz and the 13.56 MHz systems are tied together in parallel through separate impedance matching networks. The 2 MHz system uses a ferrite RF power transformer and a variable vacuum capacitor, which can tune out the inductance formed by the antenna and a series inductor that is used to move the impedance to the range of the variable tuning capacitance. The internal antenna uses a ~1 μH inductor (1) to resonate with ~2.2 nF capacitor. The new external antenna source does not require the series inductance since its antenna inductance is about 4 μH. For the external antenna ion source, the matching network used for the internal antenna is modified by adding a 50 pF fixed capacitor (2).

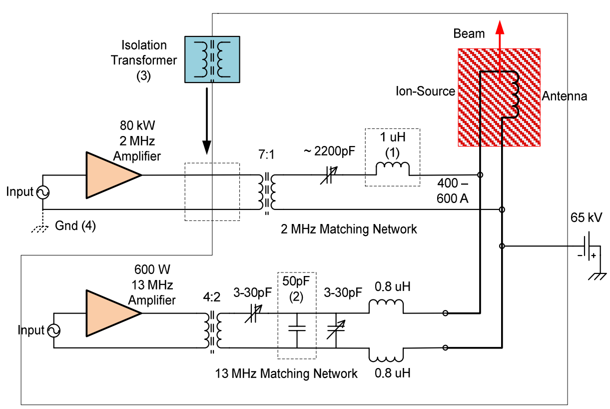
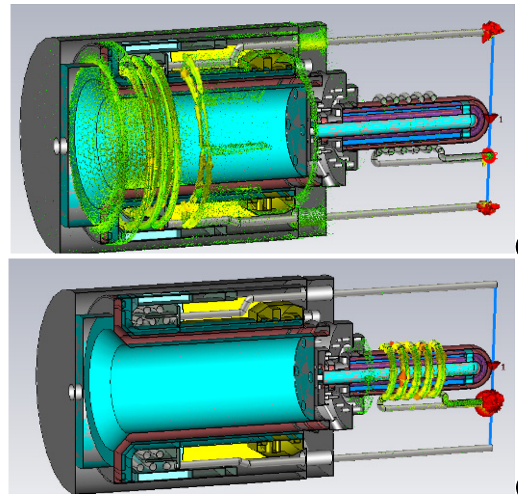


Figure 2: SNS ion source RF system. An isolation transformer (3) is inserted between the 2 MHz amplifier and the impedance matching transformer.

RF Plasma Ignition

If a single RF generator is used for ignition and production of the plasma, it requires a fast acting variable matching network since the antenna impedance changes significantly with the plasma density. Consequently an igniter for maintaining quality plasma is needed. The present system uses a 13.56 MHz ignition amplifier that supplies RF to the common antenna. A DC plasma gun was developed and tested. The system exhibited electrode erosion problems, which may have poisoned the Cs layer [4] in the plasma chamber. A Plasma RF gun with a separate 13.56 MHz antenna is shown in Fig. 3 with the RF simulation result [5]. This approach can deliver more isolation between the two power amplifiers, easier RF impedance matching, and lower 13 MHz power. A smaller 1.375” diameter alumina ceramic chamber with a 5-turn antenna is used behind the main plasma chamber.



(a)

(b)

Figure 3: RF modeling of external antenna ion source with separate 13.56 MH antenna: (a) Surface current at 2 MHz, (b) Surface current at 13.56 MHz.

Another approach being tested is using only the 2 MHz power. The plasma can be ignited and maintained if the antenna is continuously impedance matched at 2 MHz. The approach uses sequential frequency shifting that matches antenna with no plasma at the beginning of the pulse and with antenna with fully ignited plasma later during the main part of the RF pulse.

RF POWER SYSTEM

The system operates with a 1 msec pulse width at a 60 Hz repetition rate. Present operation is with an 80 kW grid driven tetrode 2 MHz power amplifier that requires continuous effort to keep the amplifier tuned. Lately the grid bias on this PA was changed from -275 V to -300 V which reduced plate current and tube heating. The PA output coupling and bypass mica capacitors frequently failed and were replaced with ceramic capacitors of a higher voltage rating.

A narrow band tunable 200 W custom 2 MHz driver amplifier that was conjugate matched to the PA was replaced with a broadband commercial 500 W solid-state amplifier using a single short-circuited stub tuner to match to the PA input. A custom 2 MHz pulse generator chassis has been replaced with a commercial two channel function generator, which has also allowed us to do frequency shifting to follow resonance changes which occur during plasma ignition.

The vacuum tube PA output circuit variable inductors are adjusted for optimum load matching to achieve clean and stable output power waveforms. A high voltage probe was installed in the output circuit of the PA to monitor transients transfered back to the PA from ion source -65 kV spark events.

Solid-state Amplifier

A 120 kW 2 MHz solid-state amplifier has been purchased to replace the existing unreliable vacuum tube amplifier. The amplifier is being tested for the upgrade of the PA system with the isolation transformer. Table 1 shows the key specifications of the new solid-state amplifier.

Table 1: Specifications of the New Solid-state 2 MHz Amplifier

Rated Pulsed Power	120 kW minimum RMS
Frequency Range	1.8-2.2 MHz
P1dB	120 kW minimum
Maximum pulse width	1300 µs
Maximum duty-cycle	8%
RF Pulse droop	0.5 dB maximum
Load SWR	2:1 minimum at full power

Isolation Transformer

The previous 2 MHz power amplifier floated at 65 kV. Having a grounded amplifier can significantly reduce downtime during operation by enabling easier maintenance. It allows better monitoring and control and much quicker diagnosis, repair and facilitates routine servicing of the amplifier. The isolation transformer is placed between the amplifier and the matching network in the 2 MHz circuit shown in Fig. 2. The grounded 2 MHz RF system and isolation transformer has been installed and tested on both the ion source test stand and the production ion source. The transformer consists of 1:1 impedance ratio ferrite transmission line transformer. The isolation transformer is being used to power the production ion source from a grounded 2 MHz power amplifier successfully.

Figure 4: Isolation transformer.

During operation of the SNS ion source, 65 kV arcs occasionally trip the 2 MHz amplifier requiring physical access to the HV box. The transformer allows 2 MHz ion source amplifier to be located outside the 65 kV enclosure. Figure 4 shows the second-generation isolation transformer that was developed for improved bandwidth, reduced RF loss, smaller size while still providing required high voltage isolation and high RF power transfer. The isolation transformer was tested to maximum 120 kW pulsed RF with 6% duty cycle at 2 MHz with minimum 90 kV DC isolation.

CONCLUSION

It was identified that the 2 MHz RF system had to be improved for availability in beam production through operational statistics and test runs up to 56 mA MEBT beam current. A RF driven multicusp external antenna ion source with a water-cooled, AlN plasma chamber has been developed and being optimized for performance improvement.

Reliable and efficient plasma ignition remains a major concern with a single antenna ion source system. We are in the process of developing a 13 MHz plasma ignition system to replace the DC plasma gun, which is suspected of poisoning the Cs converter surface. A sliding frequency system for igniting and sustaining the plasma with only a single 2 MHz amplifier is being developed to dynamically compensate the RF antenna resistance that changes with increasing plasma power. This should eliminate the need for separate plasma starters. A new solid-state 2 MHz power amplifier has been purchased to replace the vacuum tube amplifier.

Computer modeling and simulations have been made to help design, analysis, and optimizations of the new developments. Using an equivalent conductance for the plasma modeling seems useful for estimation of RF power deposition and field breakdowns in the ion source. The isolation transformer has been successfully integrated to the production ion source and has been in operation. Further tests of the solid-state amplifier with the isolation transformer in beam production are being made.

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REFERENCES

[1] M.P. Stockli, B.X. Han, S.N. Murray, D. Newland, T.R. Pennisi, M. Santana, and R.F. Welton, "Ramping up the SNS Beam Power with the LBNL Baseline H⁻ Source", AIP Conf. Proc. CP1097, pp. 223-235, 2009.

[2] R.F. Welton, N. J. Desai, J. Carmichael, B. Han, Y. W. Kang, S. N. Murray, T. Pennisi, M. Santana, and M. P. Stockli, "The Continued Development of the SNS external antenna H- Ion Source," International Conference on Ion Sources, 2009.

[3] Y. P. Raizer, Gas Discharge Physics, Springer-Verlag, 1991.

[4] M.P. Stockli, B. Han, S.N. Murray, T.R. Pennisi, M. Santana, and R.F. Welton, "Ramping up the SNS Beam Power with the H⁻ Source using 0 mg Cs/day", International Conference on Ion Sources, 2009.

[5] S. W. Lee, R. H. Goulding, Y. W. Kang, K. Shin, and R. F. Welton, "Computer Simulations for the RF Design of SNS External Antenna H⁻ Ion Source," International Conference on Ion Sources, 2009.