UPGRADE OF INPUT POWER COUPLING SYSTEM FOR THE SNS RFQ *

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Abstract

A RF input power coupler system has been developed and installed as an upgrade of input RF coupling to the RFQ in the SNS linac front-end. The design employs two coaxial loop couplers for 402.5 MHz operation. Two couplers are used in parallel to power the accelerating structure, with up to 800 kW total peak power at 8% duty cycle. Each coupler loop has a coaxial ceramic window that is connected to each output of a magic-T waveguide hybrid splitter through a coaxial-to-waveguide transition. The coaxial loop couplers have been designed, manufactured, and high-power processed. This paper presents the following: RF and mechanical designs of the couplers and system, procedure and result of high power RF conditioning, and test and operation results of the upgraded system.

INTRODUCTION

The SNS has been successfully commissioned and is producing neutrons for advanced scientific research and development. The beam power of the accelerator has reached 500 kW as planned on the way to 1.4 MW full power in a couple of years. A RFQ structure is being used at the lowest energy section of the linac right after the H$^-$ ion source. A power coupling system for 402.5 MHz RFQ has been developed at SNS for full power operation in the future. [1][2]. This replaces the 8-coupler system originally installed by LBNL. Figure 1 shows the connection, using a waveguide magic-T to deliver equal power to the two loops with good isolation between the ports. The coaxial alumina ceramic window employed in this design is identical to the 81 coupler windows being used on the SNS superconducting RF (SRF) cavities operating at 805 MHz. [3]. The electrically-coupling SRF couplers were successfully conditioned and tested for forward power of 650 kW peak, 8% duty cycle at 805 MHz. Operation of the windows in the SNS linac has shown excellent RF power handling capability and mechanical reliability.

Simulation and preliminary measurements showed that the window design can work well at around 400 MHz. The plan was to use the existing RFQ accelerating structure with no modification and using the same loop coupler. A tapered coaxial transmission line section in the vacuum side of the coupler assembly is used between the 10 cm diameter coaxial ceramic window and the 4 cm diameter coupling port. The RFQ in the SNS linac operates at 402.5 MHz with about 800 kW peak, 6% duty cycle pulsed RF power. For reliable and uninterrupted operation of the high power RF accelerating structures, good RF conditioning of the coupler windows was essential. In the following sections, design, manufacturing, and RF power conditioning of the couplers are described.

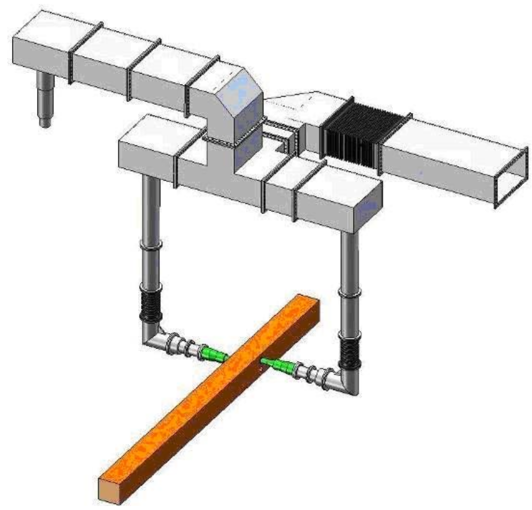

Figure 1: RF power coupling with two coaxial loop couplers to an RFQ structure with a Magic-T waveguide power splitter.

DESIGN AND MANUFACTURING

The new coaxial coupler consists of an inner conductor integrated with a ceramic window and outer conductor that are joined by two vacuum flanges.

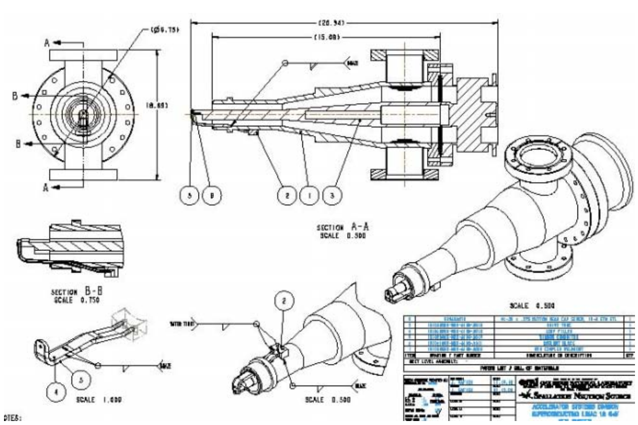

Figure 2: Coaxial loop coupler assembly.

Figure 2 shows the design of the coupler assembly. The inner conductor of the loop antenna is built as a single piece with the center conductor of the ceramic window. A

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small 1/8” cooling tube circuit connects the inner and the outer conductors at the end of the reduced diameter coaxial section to form a complete loop antenna. Computer simulation resulted in return loss > 30 dB and insertion loss < 0.05 dB at 402.5 MHz. The RF heating on the inner and outer conductors were estimated to be 0.37 W and 0.15 W for 1kW average input power, respectively. This requires light cooling, since the outer conductor is connected to the temperature-controlled cavity body. The loop cooling tube carries a 1 gpm water flow to cool the center conductor and is connected to the water source through the outer conductor.

Two vacuum ports with 2-3/4” flanges are placed in front of the vacuum side of the ceramic window, with RF shielding axial slots on the outer conductor of the coaxial transmission line. A coaxial transmission system needs to be used for connecting the couplers between the klystron output waveguide and the RFQ. The coaxial loop antenna has coupling area enough to have 40% more than critical coupling to the cavity. A 4-1/16” to 6-1/8” EIA coaxial transition and a waveguide to coaxial transformer with a 6-1/8” EIA coaxial port are used to connect to the atmosphere-side coaxial flange of the window. A short 4-1/16” coaxial section is modified for precise matching to the 100 mm ceramic window flange.

RF CONDITIONING

Figure 3 shows the coupler conditioning setup with two couplers connected back to back through a bridge waveguide. WR-2100 waveguide run is transformed to a 6-1/8” coaxial system to feed the two couplers on the bridge waveguide and then transformed back to rectangular waveguide that is terminated with a matched water load. Hardware identical to that originally used for installation to cavity is used for the couplers connecting to the bridge waveguide. The complete processing setup was also simulated with two couplers on a bridge waveguide.

Maintaining a good vacuum around the vacuum side of the window is critical for reliable operation of the coupler system. Two vacuum ports are placed in front of the ceramic window for efficient vacuum pumping, for protection of the windows. Either one or both of the ports can be used for efficient vacuum pumping. For conditioning, only one port is used for pumping, and the other port is used for vacuum monitoring with a cold cathode gauge (CCG).

Three couplers have been successfully manufactured and delivered. The bridge waveguide made of stainless steel was successfully manufactured and prepared. After cleaning and assembling the parts to construct a complete setup, before starting the high power testing and RF conditioning, the couplers mounted on the bridge waveguide were baked at 200°C. The RF responses of the bridge waveguide with two couplers connected back to back as shown in Figure 3 were measured with vector network analyzer to make sure the good RF transmission can be made through the couplers.

The bridge waveguide has an additional tuning mechanism that can deliver ± 2 MHz tuning range. The initial resonant frequency was high, but the frequency was corrected by adjusting the gap between the ridge and the waveguide bottom along with the vacuum pumping that added additional shift in the frequency.

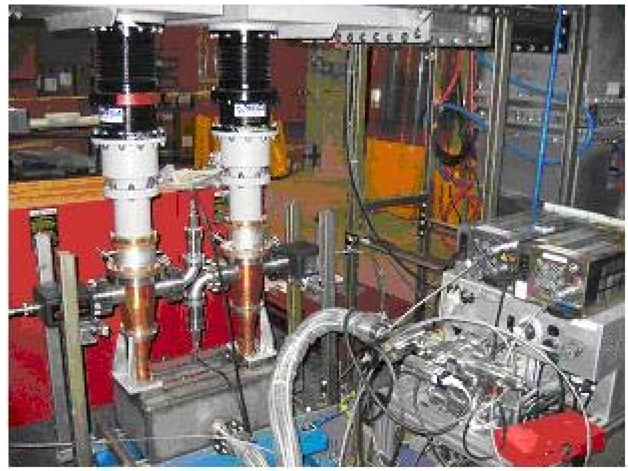

Figure 3: Couplers mounted on the bridge waveguide for RF processing. Two couplers connected back to back through the bridge waveguide.

Figure 3 shows the setup for RF processing in the RF test facility with a complete vacuum circuit. Waveguide to coaxial transitions are used to connect to the klystron at the input and the water load at the output.

RF processing started with low duty cycle short pulses at around 0.1 msec, 10 Hz to reach 400 kW peak power, the intended maximum peak power, then pulse width and repetition rate were slowly increased to 1.0 msec and 60 Hz, respectively, to reach full design power. The power was cycled between near zero and peak after full processing level was reached with constant power [4]. After the above process, the couplers were powered up to 450 kW peak power for several hours to ensure flawless operation at the design power level.

INSTALLATION AND OPERATION

A magic-T hybrid coupler was added to the waveguide circuit of the RFQ cavity structure in the front-end area of the SNS. The fully conditioned coaxial couplers were integrated to the waveguide circuit around the RFQ through 6-1/8” EIA coaxial sections. The couplers were installed on the third row downstream of the four-row original coupler positions. This location can make the windows more resilient to possible contamination from the ion-source that can contribute to system reliability. The other six original coupler ports have been plugged with slug tuners that were machined to match the original field distribution through adjustments. Each coupler arm of the hybrid waveguide output has a coaxial directional coupler that can enable monitoring of the forward and reflected powers delivered through the arm. A special coaxial transition design is used between the ceramic window and the 6-1/8" coaxial transmission-lines.

Figure 4 – Upgraded coupling system of the RFQ.

Figure 4 shows the installed coupler system. Each ceramic window has two 20 liter/sec ion-pumps. The testing and conditioning of the RFQ system after the upgrade went flawlessly. The field distribution was measured through 46 field probes spread over the cavity structure.

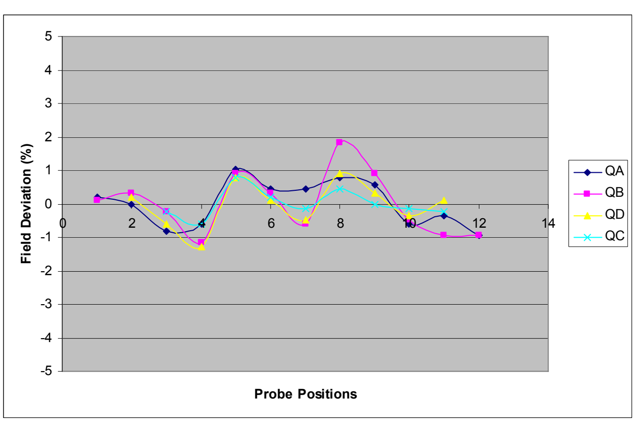

Figure 5 – Comparison of field distribution in four quadrants of the RFQ. Fields at Pin = 760 kW with beam normalized to the original fields.

Figure 5 shows the measured field distribution after the modification, normalized to the original field distribution. The field distribution data measured before the work was used to show the field distribution after the upgrade. The two power inputs to the cavity are well-balanced within 0.1 dB in amplitude and 2-degrees in phase. The system was RF conditioned to 900 kW peak power at full 8% duty-cycle and has been in operation for several months.

CONCLUSION

Moving the couplers further downstream with better vacuum pumping can improve the cavity vacuum and protection of the coupler windows. High power RF processing of the system has been performed successfully in the RF test facility at the SNS using a 2.5 MW, 402.5 MHz klystron system that can run up to 8% duty cycle.

Using bridge waveguide two couplers were conditioned at the same time. Vacuum levels and electron currents in both couplers were monitored with CCGs and electron probe antennas, respectively. An arc detector and an electron probe were used near each window for monitoring and interlocking the RF. The vacuum pressure limit was set for interlocking the RF power input to the klystron to protect the ceramic windows.

The goal of this work was to manufacture and completely process new couplers that are simpler and more robust than the original RF coupling system for upcoming full beam power operation. One constraint was to complete the job during a maintenance period without moving the RFQ cavity out from the linac. The cavity fields were measured with the field probes and tuned with slug tuners by comparing to the previously recorded fields data. The coupling system has been successfully manufactured, conditioned, and installed on the existing RFQ accelerating cavity structure as planned. Full power operation along with the beam transmission was done with complete success.

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