RF PROCESSING OF COUPLERS FOR THE SNS SUPERCONDUCTING CAVITIES*

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Abstract

The Spallation Neutron Source (SNS) in Oak Ridge National Laboratory (ORNL) employs 33 medium beta (β=0.61) and 48 high beta (β=0.81) superconducting cavities. Each cavity has a coaxial fundamental power coupler (FPC) to have 550 kW pulsed RF power in 1.3 msec, 60 Hz pulses. RF processing, 600 kW in forward traveling wave and 2.4 MW peak with full standing wave, of the couplers has been an important task. Before installing a coupler on a superconducting cavity, the vacuum components of the coupler were subjected to rigorous acceptance and conditioning procedure consists of quality assessments, cleaning and clean room assembly, vacuum leak checks, baking, and high power RF processing. Similar acceptance procedures except clean room assembly and baking were applied to the coupler airside components. 40 of total 81 SNS fundamental power couplers were RF processed at JLAB and the rest was processed at the SNS. This paper discusses details of coupler processing along with the high RF power test results.

1. INTRODUCTION

Superconducting RF section of the SNS linac uses 6-cell superconducting RF cavities operating at 805 MHz in fundamental TM_{010}-mode. Normal conducting section of the linac delivers H^- ions to the superconducting section that accelerates the ion beam from 185 MeV to the full final energy (840-1300 MeV) and then delivers the beam to accumulator ring [1]. Each 6-cell cavity is powered by a klystron amplifier that can deliver minimum 550kW peak pulsed power at 8% duty cycle through a FPC.

Table 1: Coupler RF power requirements

Parameter	Operation	Processing
Frequency	805 MHz	
Coaxial Impedance	50 Ω	
Peak power	550 kW	600kW/2.4 MW
Pulse length	1.3 ms	1.3 ms
Repetition rate	60 pps	60 pps
Average power	Max 53 kW	
DC Bias	± 2.5 kV	± 2.5 kV

The coaxial design of the coupler is based on the design developed for the KEK B-factory superconducting cavities [2][3]. To adapt to different RF operating frequency and constraints set by the cryomodule geometry and assembly procedures of the SNS superconducting RF cavities, a number of design modifications were made to the KEK design.

FPCs were qualified before integration to a cryomodule after passing RF high power processing and tests. The RF specifications of the couplers are shown in Table 1. RF power levels for operation and processing of the couplers were limited by the peak power capacity of the SNS klystrons that is rated to 550 kW minimum. For complete RF processing of the couplers, 600 kW forward traveling wave (2.4 MW peak with full standing wave) was needed in 1.3 msec 60 Hz pulses. This was done using a dedicated test cart with vacuum pumps and a connecting waveguide which allows simultaneous processing of a pair of FPCs [4].

2. PREPARATION

2.1 Construction

The SNS FPC consists of three 50-ohm coaxial line sections including a window section with a planar ceramic window and a waveguide to coaxial transition. On the vacuum side of the assembly, the outer conductor made of double wall copper-plated stainless steel is helium gas cooled and the inner conductor made of OFE copper is conduction cooled. The coaxial alumina ceramic window assembly has four instrumentation ports on the vacuum side: two for vacuum gauges, one for an electron pick-up antenna and one for an arc detector with sapphire optical view port.

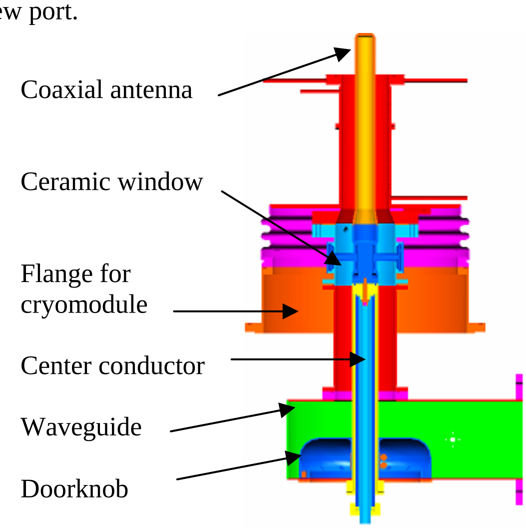

Figure 1.FPC for the SNS superconducting cavities.

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On the air side, the outer extension is also made of copper-plated stainless steel and the water cooled inner coaxial extension is made of OFE copper. The FPC is matched to a WR-975 rectangular waveguide transition with a waveguide doorknob [2][3][4]. The cross-sectional view of the FPC is shown in Figure 1. On the window section, modified Conflat® gaskets are used to provide good RF contact and UHV joints at the same time. A coaxial cylindrical capacitor using Kapton insulator is provided between the inner extension and doorknob for D.C. biasing for control of multipacting.

2.2 Component Inspection, Cleaning, Assembling, and Vacuum Tests

For production and high power RF processing of the 81 FPCs, two test carts and eight UHV stainless steel connecting waveguides were custom made for medium and high beta couplers. The connecting waveguides were designed for S_{11} < -25 dB at 805 MHz [4]. No copper plating was provided on the inner surface of the connecting waveguides.

All coupler components have undergone incoming inspection: visual examination of the inner surface finish, integrity of vacuum sealing and surface finish, accuracy of dimensions using a coordinate measuring machine, and UHV cleaning for vacuum leak checks. The quality of the copper plating on the outer coaxial conductors were checked by high pressure water rinsing with 100 Bar for 30 minutes and by firing under vacuum for 3 hours at 300°C. All coupler components were carefully cleaned again before final assembly started. The outer conductors and all the stainless steel components were cleaned by 15 minutes of immersion in an ultrasonic bath filled with a 10% solution of Micro-clean® detergent, followed by rinsing with de-ionized (DI) water and drying with dust-free antistatic nitrogen gas. The transfer from the cleaning area to the class 100 clean room was done in double-all plastic bags filled with dry nitrogen [5].

The window assemblies were inserted into the pre-assembled outer conductors and connecting waveguide. Al-Mg gaskets were used as vacuum seals between the outer conductor and the connecting waveguide ports. The instrumentation ports on the outer conductors were equipped with MKS® cold cathode gauges and the window assembly with an electron pick up antenna and one sapphire optical view port. Vacuum leak test were performed on the assembled couplers using a Stanford® RGA. Helium leak detector sensitivity of the system was better than $2\text{x}10^{-10}$ Torr l/sec.

2.3 Baking

The assembled FPCs and connecting waveguide were baked under vacuum, using a heating box with hot air blower operated with a computer and PLC controller. The baking procedure was: ramping up the temperature at 10°C/hour to 200°C, staying at 200°C for 24 hours, and a controlled cool down to room temperature at 10°C/hour. During baking, an Argon atmosphere was locally provided to avoid oxidization of the RF contacts and the temperature, vacuum and residual gas were continuously monitored and recorded. After baking, vacuum in the system was better than $5\text{x } 10^{-10}$ mbar.

3. RF PROCESSING

3.1 Low RF Power Measurements

After baking, the air side components of the couplers were assembled with the outer conductor extensions and two waveguide/doorknob transitions. Figure 2 shows the processing setup for the FPCs; two couplers are connected back to back in the test stand. For each set of couplers, after complete assembling, low power RF S-parameter measurements were made to make sure the assembling was done right and to obtain predicts of local peak power readings in the waveguide transmission line during RF processing and high power testing.

3.2 High power RF setup

RF processing and power tests on all medium beta couplers and several pairs of high beta couplers 1 MW 805 MHz pulsed RF power stand [5] was used at JLAB. For the rest of the high beta couplers, the test setups for baking and RF processing were moved, commissioned and used at the SNS site in ORNL. One of the 550 kW SNS klystrons was used for the RF processing in ORNL.

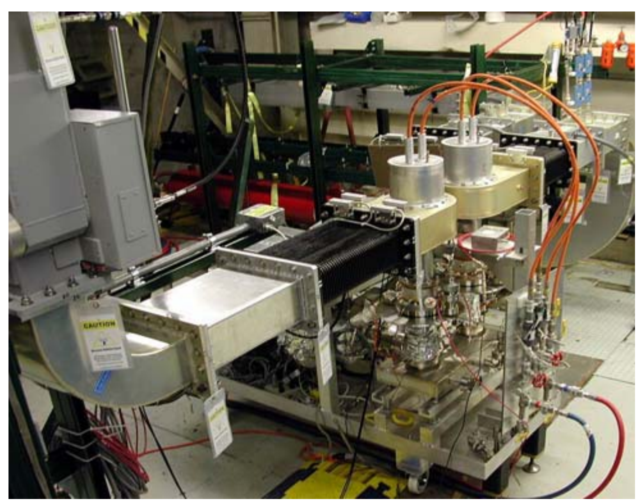

Figure 2. RF test stands for processing of FPCs

RF power delivered by the klystron is transmitted through the waveguide circuit with two FPCs via the connecting waveguide that is terminated with either a 600 kW matched water load for traveling wave or a variable short circuit for standing wave. Three sets of directional couplers were used to independently monitor the transmitted RF forward and reflected power levels at various locations in the waveguide. Each ceramic window had a fast photodiode arc detector for hard interlock that turns off RF if arcing occurred on the vacuum side or on the air side of the coupler. The RF conditioning was assisted by a fast RF feedback control, which controls the RF pulse amplitude if vacuum events exceed a defined threshold as shown in Figure 3. Real time LabView® software provides the operator interface with data acquisition system that allows to change and control the RF conditioning or testing parameters [6]. A fast interlock on the vacuum controller's analog outputs shut off RF if the coupler vacuum was worse than $5x10^{-7}$ mbar. The RF transmission restarts after the vacuum pressure was better than $2x10^{-7}$ mbar. The signals from the vacuum controllers and the current monitors that measure electron activities near the ceramic windows were archived during the RF processing.

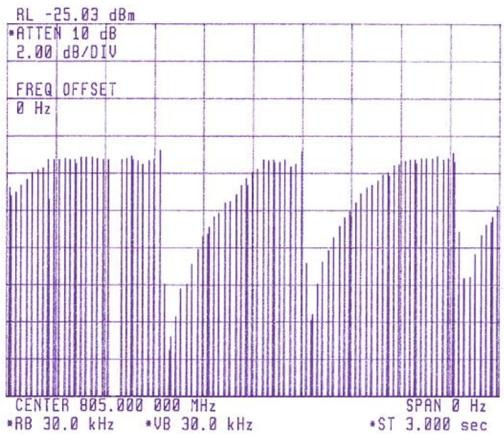

Figure 3. RF pulse amplitude as a function of vacuum.

3.3 Results of RF processing

RF conditioning was performed by slowly increasing the RF power through the couplers while maintaining good vacuum in the couplers. The RF conditioning started in traveling wave mode up to the desired maximum (650 kW pulse amplitude at the SNS and up to 1 MW at JLAB.) The RF power level reached the maximum available from the klystron usually after 8-12 hours of processing. Then, cycling the RF power from none to the maximum of the RF power was performed for about 12 hours. Next step was cycling, keeping constant and cycling again the RF amplitude with and without the D.C. bias voltage; effectiveness of D.C. biasing in controlling multipacting was tested during this step. Last step in traveling wave mode was done with constant pulse amplitude in 1 msec at 600~650 kW for at least 12 hours. Processing with standing wave was done by increasing the forward RF power up to 600 kW in steps of 100 kW while moving the short circuit over a distance greater than a half wavelength for 30 min at each power level; local peak power along the coaxial line can be up to 2.4 MW during this step. Air side components were assembled and RF power tested at room temperature prior to assembling on the cryomodules. Two fundamental power couplers were baked, RF processed and then used as a test stand of the many airside sets. Processing was done in standing wave mode like the last step for the couplers: ramping the forward RF in steps of 100 kW up to 600 kW in 1 msec, 60 Hz.

4. CONCLUSION

All 81 SNS FPCs have been successfully processed with high power RF and qualified for use in the SNS linac. The FPCs were assembled to the cavities after the RF tests and processing. About 50 hours of computer controlled RF processing was needed to completely process a pair of couplers. The RF processing also verified the RF performances of the FPCs in each set. During RF processing, measurements of RF leakage around the couplers were performed for checking the integrity of the assembly as well as verification of personnel radiation safety.

It has been demonstrated that the FPCs of the SNS can perform satisfactorily at the specified RF power level. Also shown was that operating was successful even at the power level higher than the specification in room temperature. All couplers installed on the superconducting cavities in the SNS linac cryomodules have been successfully RF power tested [7]. The couplers are now used for test and operation with beam in the SNS linac toward full commissioning of the SNS. The RF test facilities at the SNS/ORNL and at JLAB both performed well and showed the procedures and the equipment setups were effective in successful processing of the couplers.

5. ACKNOWLDGEMENTS

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6. REFERENCES

[1] T. E. Mason, "The Spallation Neutron Source: A Powerful Tool for Materials Research," PAC2001, Chicago, IL, June 2001.

[2] Y. Kang et. al., "Electromagnetic Simulations and Properties of the Fundamental Power Couplers for the SNS Superconducting Cavities," PAC2001, Chicago, IL, June 2001.

[3] K.M. Wilson et. al., "The Prototype Fundamental Power Coupler for the Spallation Neutron Source Superconducting Cavities: Design and Initial Test Results." 10th Workshop on RF Superconductivity 2001 Tsukuba, Japan 6-11 Sept 2001

[4] M. Stirbet et. al., "Processing Test Stand for the Fundamental Power Couplers of the Spallation Neutron Source (SNS) Superconducting Cavities," PAC2001, Chicago, IL, June 2001.

[5] M. Stirbet et. al., "Testing Procedures and Results of the Prototype Fundamental Power Coupler for the Spallation Neutron Source," PAC2001, Chicago, IL, June 2001.

[6] M. A. Drury et al., "Overview of SNS Cryomodule Performance" PAC2005, Knoxville, TN, May 2005

[7] I. E. Campisi et al., "Testing of the SNS Superconducting Cavities and Cryomodules" PAC2005, Knoxville, TN, May 2005