RF CONDITIONING AND TESTING OF FUNDAMENTAL POWER COUPLERS FOR SNS SUPERCONDUCTING CAVITY PRODUCTION*

M. Stirbet#, K. M. Wilson, M. Wiseman, J. Henry, M. Drury, G.K. Davis, C. Grenoble, T. Powers and G. Myneni, Jefferson Laboratory, Newport News, VA 23606
I.E. Campisi, Y. Kang, D. Stout, SNS Project, Oak Ridge National Laboratory, TN 37831.

Abstract

The Spallation Neutron Source (SNS) makes use of 33 medium beta (0.61) and 48 high beta (0.81) superconducting cavities. Each cavity is equipped with a fundamental power coupler, which should withstand the full klystron power of 550 kW in full reflection for the duration of an RF pulse of 1.3 msec at 60 Hz repetition rate. Before assembly to a superconducting cavity, the vacuum components of the coupler are submitted to acceptance procedures consisting of preliminary quality assessments, cleaning and clean room assembly, vacuum leak checks and baking under vacuum, followed by conditioning and RF high power testing.

Similar acceptance procedures (except clean room assembly and baking) were applied for the airside components of the coupler. All 81 fundamental power couplers for SNS superconducting cavity production have been RF power tested at JLAB Newport News and, beginning in April 2004 at SNS Oak Ridge.

This paper gives details of coupler processing and RF high power-assessed performances.

INTRODUCTION

The SNS makes use of superconducting RF cavities resonating at 805 MHz in the fundamental TM_{010}-π mode to accelerate H^- ions in the main linac from 185 MeV to 1.0 GeV, the initial goal of final energy (the energy range can be 840-1300 MeV with the upgrade) [1].

In order to power the cavities, coaxial couplers were chosen. The couplers must be able to withstand at least the peak power delivered by the SNS klystrons (shown in Table 1), 550 kW for a 1.3-msec pulse length at a repetition rate of 60 pulses per seconds (pps).

Table 1: Coupler requirements.

Parameter	Operation	Processing
Impedance	50 Ω	
Peak power	550 kW	2.4 MW
Pulse length	1.3 ms	1.3 ms
Repetition rate	60 pps	60 pps
Average power	Max 53 kW	Kly. limit
Bias	2.5 kV	± 2.5 kV

Qualification for cavity assembly involves performing RF high power tests on each fundamental power coupler. This was done using a dedicated test cart using a connecting waveguide which allows for simultaneous processing of two fundamental power couplers.

PREPARATION OF THE SNS FPCs FOR RF CONDITIONING

The fundamental power coupler (FPC) consists of a tapered 50-ohm coaxial line with a planar ceramic window (Figure 1). The design is based on the coupler developed for the KEK B-factory superconducting cavities [2] [3]. To adapt that design to the SNS frequency and to the constraints imposed by the cryomodule geometry and assembly procedures, a number of significant design modifications were implemented. On the vacuum side of the assembly, the outer conductor is double walled, helium gas cooled copper-plated stainless steel and the inner conductor is OFE copper. The coaxial alumina window assembly has four instrumentation ports on the vacuum side: two for vacuum gauges, one for an electron pick-up antenna and one for a sapphire optical view port for an arc detector.

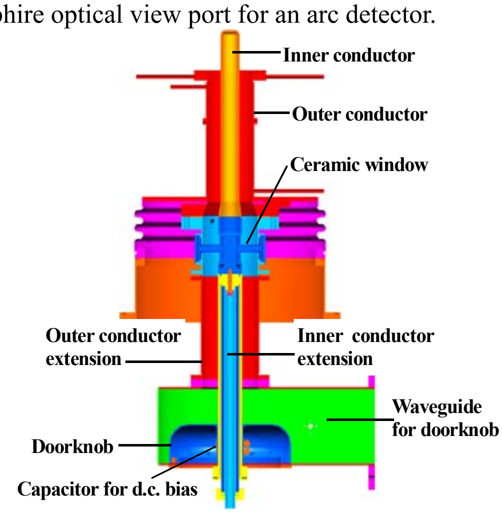

Figure 1: Fundamental Power Coupler for the SNS Project.

On the air side, the outer extension is made from copper-plated stainless steel and the water–cooled inner extension is made of OFE copper. The FPC is matched to a rectangular WR975 waveguide via a waveguide doorknob transition [2][3][5]. Modified Conflat® gaskets are used on the window side to provide good RF contact and at the same time a UHV joint. A capacitor for DC bias is provided between the inner and outer conductors of the coaxial line.

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#Mircea.Stirbet@jlab.org

Test Carts and Connecting Waveguides

To ensure fluent FPC RF high power testing production style, two test carts and eight custom made UHV connecting waveguides for medium and high beta couplers (dimensioned for 805 MHz resonance with S11 parameter better than -25 dB) have been built [4].

No copper plating was provided on connecting waveguide's surfaces exposed to UHV and RF.

Incoming Inspection

All components have undergone incoming inspection including full check of dimensions on a coordinate measuring machine; visual examination of the RF exposed surface finish, integrity of vacuum sealing surfaces, followed by cleaning for vacuum leak checks.

The adherence of the copper plating on the outer conductors have been checked by high pressure water rinsing (100 Bar for 30 minutes) and by firing under vacuum for 3 hours at 300°C. Both methods have proved to efficiently identify copper plating issues (blisters, non-adherent copper).

Component Cleaning and Clean Room Assembly

Before final assembly, all coupler components were once more carefully cleaned. 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 water (DI) and drying with dust-free antistatic nitrogen gas. The transfer from the cleaning area to the class 100 clean room was done in double plastic bags filled with dry nitrogen [5].

Mechanical Assembly and Vacuum Tests

The window assemblies were inserted into the pre-assembled outer conductors and connecting waveguide.

Aluminum-Magnesium 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 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 2×10^{-10} Torr l/s.

Baking

The assembled FPCs and connecting waveguide were baked on the test stand under vacuum, using a heating box with hot air blower operated via a computer and PLC controller (Figure 2). Our usual baking procedure was applied: ramping up the temperature with a gradient of 10°C/h, soaking for 24 hours at 200°C then cooling down to room temperature with a controlled gradient of 10°C/h. During bake, to avoid oxidization of the RF contacts, an Argon atmosphere was locally provided. Temperature, vacuum and residual gases were continuously monitored and recorded. After bake, at room temperature, vacuum in the system was better than $5 \ 10^{-10}$ mbar. Use of the heating box with hot air has proved to be very efficient during coupler production.

Low RF Power Measurements

The air side of the couplers was assembled after baking, using the inner and outer conductor extensions and waveguide/doorknob transitions. Low RF power measurements for S parameters were performed and used as an estimate for local peak power in the transmission line during RF conditioning and high power testing.

CONDITIONING AND POWER TESTS

High Power RF Setup

The 1 MW 805 MHz pulsed RF power stand at JLAB [6] was used to perform RF conditioning and power tests on all medium beta couplers and a several pairs of high beta couplers. From April 2004, the bake and RF test stands had to be moved, re-commissioned and used at SNS – Oak Ridge (Figure 2) [7].

Figure 2: Bake and RF test stands for FPCs processing.

With the two couplers assembled in the test stand, the RF power delivered by the klystron is transferred from the input coupler to the output coupler via the connecting waveguide and dumped into a water load rated for 600kW peak power at 8 % duty factor or to a variable short circuit. Three sets of directional couplers (two sets between klystron and test cart and one between the test cart and the terminating load (or variable short circuit) were used to independently monitor the transmitted RF power levels. The RF conditioning was assisted by a fast RF feedback loop, which modulates the RF pulse amplitude as function of FPC vacuum (Figure 3).

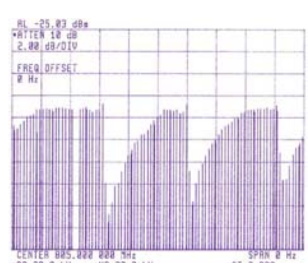

Figure 3: RF pulse amplitude modulation as a function of vacuum.

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A fast interlock system on the vacuum controller's analog output switched RF off if the coupler vacuum was worse than $5x10^{-7}$ mbar. The RF permit was obtained after the vacuum pressure was better than $2x10^{-7}$ mbar. Real time LabView® software provides the operator interface with data acquisition system that allows to adjust and control the RF conditioning or testing parameters [5] [6]. During RF tests, in addition to the vacuum signals, information regarding the electron activity near to the ceramic window is obtained with electrometric instrumentation. A fast photodiode based arc detector was hard interlocked to switch RF off if arcing events occurred on the vacuum side or on the air side (doorknob region) of the coupler.

RF Testing Results

All 81 SNS FPCs have been qualified for cavity assembly after RF power tests. About 50 hours of RF processing was necessary to assess FPCs RF power performance. During these tests, RF leak measurements were performed and faulty instrumentation identified (vacuum gauges) to be later replaced. After RF processing the FPCs have been transported and stored under dry particulates free nitrogen.

RF Tests on FPCs Vacuum Components

RF conditioning as a function of vacuum has been done after baking each pair of couplers. The RF conditioning was started in traveling wave (TW) mode up to 650 kW pulse amplitude at SNS Oak Ridge (1 MW at JLAB). Usually, after 9–12 hours of RF conditioning the maximum power delivered by the klystron was reached.

RF conditioning was continued by cycling the pulse amplitude up to the maximum of the RF power delivered by the klystron for at least 12 hours. High RF power tests were then performed by cycling, keeping constant and cycling again the RF amplitude between 10 and 650 kW. The efficiency of d.c. bias in controlling multipacting has been tested while cycling the pulse amplitude up to 650 kW. Last test in TW mode was done with constant pulse amplitude run (1 msec, 650 kW) for at least 12 hours (at Oak Ridge this test was done over night).

Tests in standing wave SW mode were performed in steps of forward RF power of 100 kW up to 600 kW, moving the short circuit over of distance greater than $\lambda/2$ for at least 30 min (maximum local peak power along the coaxial line 2.4 MW with 1 ms pulse duration at 60 Hz).

RF Tests on Air Side Components of FPC

The air side components have been assembled and RF power tested on the room temperature test stand before being assembled on the cryomodule. Two fundamental power couplers have been baked, RF conditioned and then used for testing airside kits in SW mode, ramping the RF in steps of 100 kW up to 600 kW 1 ms 60 Hz. During these qualification tests RF leak measurements were performed and d.c. bias efficiency assessed.

SUMMARIES AND CONCLUSIONS

Testing facilities and procedures established during FPC prototyping at LANL proved to be efficient throughout production. We have demonstrated at JLAB and Oak Ridge that the SNS fundamental power couplers can sustain, on the room temperature test stand, RF power levels in excess of machine specifications. To date, almost all couplers assembled on cavities have been successfully RF powered on the SNS cryomodules at JLAB and SNS [8] [9] and similar results are expected with beam operation in the near future.

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