RETROSPECTIVE ON FUNDAMENTAL POWER COUPLERS FOR THE SPALLATION NEUTRON SOURCE AT OAK RIDGE^{*}

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Abstract

As of September 2009 a sustainable 1 MW in beam power was achieved at Oak Ridge, continuing to make SNS the highest energy-pulsed neutron source available for scientific research worldwide.

This paper evaluates the FPCs designed and built at JLAB for the SNS project, emphasizing their performance and related issues addressed during prototyping, qualification on the RF power test stand at room temperature, superconducting cavity commissioning and successful but challenging operation with beam for more than 5 years.

INTRODUCTION

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

Eighty one niobium cavities were installed in the SNS tunnel: 11 medium beta (.61) cryomodules each containing 3 cavities and 12 high beta (.81) cryomodules each with 4 cavities. The niobium cavities and cryomodules were designed and assembled at Jefferson Lab to operate at 2.1 K. Each cavity is powered by a coaxial coupler [2] with parameters specified in Table1.

Qualification for cavity assembly involves performing RF high power tests on each fundamental power coupler.

This was done using a dedicated test cart [3], [4] 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

Parameter	Operation	Processing
Impedance	50 Ω	
Peak power	550 kW	2.4 MW
Pulse length	1.3 msec	1.3 msec
Repetition rate	60 pps	60 pps
Average power	Max 53 kW	Klystron limit
DC bias	± 2.5 kV	± 2.5 kV

Table 1: Coupler Requirements

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tapered 50-ohm coaxial line with a planar ceramic window. The design is based on the coupler developed for the KEK B-factory superconducting cavities [2], [6]. To adapt that design to the SNS power coupler requirements, a number of significant 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. Al-



Figure 1: Fundamental Power Coupler for the SNS Project.

Mg on the cavity side of the outer conductor and modified Conflat[®] seals on the window side have been used.

The outer conductor has two instrumentation ports for vacuum gauges. A large stainless steel bellows integrates the window assembly and instrumentation with cryomodule space frame. The window assembly has two instrumentation ports: one for electron pick-up antenna, and a sapphire optical view port for arc detector.

On the air side, the outer conductor extension is made from copper-plated stainless steel and the water-cooled inner conductor extension is made of OFE copper. The FPC is matched to a rectangular WR975 waveguide via a waveguide doorknob transition. A capacitor for DC bias was inserted between the inner and outer conductors of the coaxial line. The final FPC design for SNS cryomodules is shown in Figure 1 and has been described in previous publications [2], [5], [6] and [7].

To ensure fluent FPC RF high power testing production style, two test carts and custom made UHV connecting waveguides for medium and high beta couplers have been built [4]. All components used to assemble the FPCs 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 UHV cleaning and vacuum leak checks of vacuum volumes and circuits for

He gas cooling, static pressure tests on inner extensions.

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. Baking procedure 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.

After bake, at room temperature, vacuum in the system was better than 5 10^{-10} mbar.

CONDITIONING AND POWER TESTS

The 1 MW 805 MHz pulsed RF power stand [3], [5] and [7] has been used to perform RF conditioning and power tests on all medium beta couplers and several pairs of high beta couplers (Figure 2) at JLAB. In April 2004, the bake and RF test stands had to be moved, commissioned and used at SNS – Oak Ridge [7].

With the two couplers assembled on the cart, the RF power delivered by the klystron was transferred from the input coupler to the output coupler via the connecting waveguide and dumped into a water load or to a variable short circuit.

The RF conditioning was assisted by a fast vacuum-RF feedback loop, which modulates the RF pulse amplitude if vacuum events exceed a predetermined threshold (Fig 3).

A fast interlock system based on vacuum controller's analog output, switched RF OFF if the coupler vacuum was worse than 5×10^{-7} mbar (this threshold could be adjusted as a function of coupler response). The RF



Figure 2: Test stand and cart for FPCs RF power qualification at room temperature.



Figure 3: RF modulation as a function of vacuum.



Figure 4: Typical RF processing of FPCs assembled on Medium Beta SNS cavity at JLAB.

permit was obtained and RF processing continued after the vacuum pressure was better than 2×10^{-7} mbar.

Real time LabView[®] software provided the operator with data acquisition and control interface that allowed to change the RF conditioning or testing parameters [5], [7].

The efficiency of DC bias in controlling multipacting events in coaxial line has been tested while cycling the pulse amplitude up to 650 kW.

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

After RF conditioning and power testing on room temperature test cart, measured vacuum in the system was usually in the 10^{-10} mbar range.

Once the cavity string was inserted in the cryomodule the air side of each FPC was re-assembled for RF qualification in Cryomodule Test Facility (CMTF) at JLAB, before cryomodule shipment to SNS Oak Ridge.

On cryomodules, in addition to instrumentation used on the room temperature test stand, each coupler had gas cooling circuits on the outer conductor, Si diodes for temperature measurements on outer conductor and a temperature controlled resistor to prevent ice ball formation near the ceramic window.

The first task was to process the coupler (vacuum-RF feedback loop assisted) and define the cavity maximum gradient (Emax). This was accomplished by gradually raising the gradient while allowing time for the coupler vacuum to improve (Figure 4).

On several occasions, DC bias has been successfully tested on FPCs during cryomodule qualification.

The RF testing of the cavities in the SNS tunnel at Oak Ridge was performed initially at 4.2K, then at 2 K, mostly in open loop at 10 pulses per second and at a full pulse length of 1.3 msec, via EPICS control system and by using the Low Level RF (LLRF) interface both for protection and measurements.

During SNS linac commissioning, some heating of beam pipe and coupler flange were reported [9], and later that some sub-components exhibited peculiar behaviors [10], [11]. The cold cathode gauges, which provide hard interlock protection to the fundamental power coupler

window, behaved erratically, with response often not correlated with other independent measurements of gas



Figure 5: Vacuum and arcing events recorded on fundamental power coupler at SNS Oak Ridge.

pressure at the window [9], [10]. As illustrated in Fig 5, explosive vacuum and numerous associated arcing events were recorded.

These embarrassing events (usually reported on unconditioned cold surfaces of waveguides or coaxial lines, exposed to ultra-high vacuum and RF, can be tamed by vacuum-RF feedback loop assisted conditioning and then, by applying DC bias) have plagued several power couplers.

With DC bias applied on these couplers, smooth and reliable linac operation with beam has been successfully established [10], [11], [12] and [13].

SUMMARIES AND CONCLUSIONS

The FPC design adopted for SNS superconducting cavities as well as testing facilities and procedures established proved to be adequate. We have demonstrated initially at LANL, then at JLAB and Oak Ridge, that the SNS fundamental power couplers can sustain RF power levels in excess of machine specifications.

Since the initial commissioning of the accelerator complex at Oak Ridge in 2006, none of the 84 fundamental power couplers have failed. The superconducting linac is now one of the most flexible and robust system installed in the machine [12], [13].

The design goal of the SNS project was demonstrated in September 2009 continuing to make SNS the highest energy-pulsed neutron source available for scientific research worldwide [13] and [14].

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