POWER COUPLER AND TUNER DEVELOPMENT FOR SUPERCONDUCTING QUARTER-WAVE RESONATORS*

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Abstract

The construction of a re-accelerator for secondary ion beams is currently underway at the National Superconducting Cyclotron Laboratory (NSCL). The re-accelerator linac will use superconducting quarter-wave resonators (QWR) operating at 80.5 MHz with β = 0.041 and β = 0.085. A coaxial probe-type RF fundamental power coupler (FPC) will be used for both QWR types. The power coupler makes use of a commercially available feedthrough to minimize the cost. The FPC has been simulated and optimized for operation at 80.5 MHz using a finite element electromagnetics code. Prototype FPCs have been fabricated and conditioned with traveling wave and standing wave power using a 1 kW amplifier. A niobium tuning plate is incorporated into the bottom flange of the QWR. The tuner is actuated by a stepping motor for slow (coarse) tuning and a stacked piezoelectric element in series for fast (fine) tuning. A prototype tuner for the β = 0.041 QWR has been tested on the cavity at room temperature.

INTRODUCTION

NSCL is building a re-accelerator, currently titled ReA3, which will create rare isotope beams (RIBs) for experiments in nuclear science [1]. Stable ions will be produced in an ion source and accelerated by the NSCL Coupled Cyclotron Facility. Particle fragmentation will be used to create a secondary beam. The secondary beam will then be stopped and re-accelerated. This will allow measurements on the exotic beams to be done with higher precision than other techniques.

The first phase of the re-accelerator will accelerate the RIBs up to 3 MeV per nucleon. The superconducting linac will consist of three cryomodules, containing a total of 15 QWRs for either β = 0.041 or β = 0.085 [2-4]. Both QWR cavities will utilize similar methods for frequency tuning and RF coupling. Tuning will be done using a slotted tuning plate made from sheet niobium, similar to the designs used at TRIUMF and Legnaro [5,6]. One feature of the NSCL QWRs is the use of separate cavity and insulation vacuum, as opposed to common vacuum, which affects the design of the tuning plate assembly. This plate will provide approximately 20 kHz of tuning for the β = 0.041 cavities. A fixed probe-type power coupler will penetrate through the tuning plate to transmit power to the cavity. This differs from the adjustable loop-type couplers used at Legnaro and TRIUMF.

This paper will cover the design, prototyping, and testing of both the fundamental power coupler and the tuner for the ReA3 QWRs.

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COUPLER DESIGN

The FPCs for ReA3 will be coaxial, operating at 80.5 MHz, with fixed coupling and continuous wave (CW) power, with 400 to 800 watts of forward power, depending on the cavity type [7]. A key component of the power coupler is the RF power feedthrough, which will isolate the cavity vacuum and allow cavity pressures of less than 10^{-8} torr. The feedthrough is based on a power feedthrough readily available in industry, which helps reduce cost and production time.

A prototype low-β cryomodule [8] has been built and tested. The coupler used for the prototype cryomodule test has a small diameter inner conductor and a thin ceramic window [9]. This coupler was designed for lower forward power than needed for ReA3. The updated design incorporates a larger diameter center conductor, thicker alumina window, and less obtrusive air side geometry. These improvements increase the durability, especially during assembly, and power handling capacity of the coupler. The addition of diagnostic ports on the coupler allows the condition of the ceramic window to be monitored. The diagnostic devices consist of a vacuum gauge, current probe, and spark detector. Additionally, a sealed adapter flange is used on the air side, which will be filled with argon gas. In the event of a window failure, the cavity vacuum will be less vulnerable, and the increase in argon can be detected using a residual gas analyzer (RGA).

Several iterations of feedthrough configurations were modeled using Analyst[1], a finite element solver, until an acceptable geometry was found. The S-parameters were also modeled. The final design utilizes a semi-custom feedthrough to allow a more compact size.

After the feedthrough configuration was chosen, an analysis of the mechanical modes of the copper inner conductor was performed. Fundamental modes were found near 30 Hz, and were verified experimentally. Several inner conductors with various lengths of stainless steel liners were modeled, in an attempt to increase this frequency. With an 11 inch (279.4 mm) liner, the frequency was shifted up approximately 7 Hz. Other methods are being investigated to increase the fundamental frequency above 100 Hz.

The heat load to liquid helium from the coupler is a major concern. The total load of the coupler can be

[1] Simulation Technology & Applied Research, Inc., Mequon, Wisconsin, USA.

estimated from the sum of the conducted heat, radiated heat, and RF heating for both the inner and outer conductors. The design specifies that the static heat load should be less than 1 watt. Stainless steel has a much lower thermal conductivity than copper, so the outer conductor is made from 0.035 inch (0.89 mm) wall AISI 316 stainless steel tubing. In order to minimize RF heating, the interior surface of the outer conductor was plated with approximately 8 µm of copper. The location of the 77 K intercept was chosen to produce a total heat load of 1.8 watts and a static heat load of 1 watt to the helium bath.

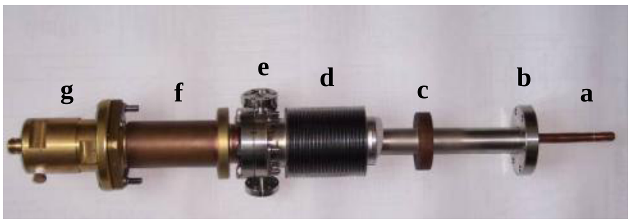

Figure 1: Assembled fundamental power coupler: (a) vacuum side inner conductor, (b) vacuum side outer conductor, (c) 77 K intercept, (d) bellows, (e) diagnostic ports, (f) air side outer conductor, (g) adapter to type N.

COUPLER TESTING

Four prototype coupler assemblies have been manufactured, as shown in Figure 1. Two of those couplers were assembled tip-to-tip, placed under vacuum, and conditioned using both standing and traveling wave power.

The vacuum components of the FPCs were ultrasonically cleaned and rinsed in class a 10,000 clean room. The feedthroughs were leak tested, and then ultrasonically cleaned and rinsed separately in a weaker cleaning solution. The components were assembled end-to-end with a copper barrel connecting the tips of the two inner conductors. This allowed two couplers to be conditioned simultaneously.

Once the assembly was under vacuum, it was removed from the clean room and baked out. The outer surface of the vacuum section was heated to a temperature of 200° C and baked for 36 hours, until the vacuum no longer showed much improvement. After baking, the vacuum inside the conditioning assembly improved by an order of magnitude.

Standing wave conditioning was done using two sliding shorts, for two reasons. First, this allowed the couplers to be conditioned at higher power than the amplifier could apply alone: the equivalent power in the standing wave was 20 dB higher than the forward power. Second, the moveable shorts allowed the entire surface of both couplers to be subjected to both high voltage and high current. Input power was slowly ramped up to 50 dBm. The system was then left for a period of time to condition. The shorts were then shifted 3 inches (76.2 mm) each, to maintain a frequency of 80.5 MHz, and the process was repeated until the entire length of both couplers was completely conditioned.

The conditioning set-up was next reconfigured for traveling wave to perform a high power endurance test. A power of 1 kW, the amplifier limit, was applied through the couplers and into a matched load for seven days. The temperature of one inner conductor was measured twice using thermal labels: it did not exceed 54° C. The outer conductors reached approximately 50° C.

The assembly was transferred back into the clean room, where it was backfilled with dry nitrogen and stored for future reconditioning tests. The reconditioning will determine how well the conditioning holds after venting.

TUNER DESIGN

Tuning of the QWRs is done using a thin niobium plate mounted at the base of the cavity. The cavity is tuned by mechanically adjusting the distance between the bottom plate and the tip of the inner conductor. Mechanical actuators apply force to the center of the tuning plate to adjust the position. The plate's outer edge is beveled and pinched between a Nb45-Ti flange (electron beam welded to the outer conductor) and the stainless steel plate which provides the RF contact; an indium seal is used for vacuum, placed just outside the bevel.

Initially, the tuning plate was a flat sheet of niobium. This design was very stiff and limited the tuning range. Two new tuning plates were made from 1.25 mm thick sheet niobium. Concentric convolutions are stamped into the plates and up to 20 slots are EDM cut to reduce the tuning force. The final design is shown in Figure 2. This configuration gives the tuning plates a ± 3 mm range of motion. Modeling was performed on the two slotted designs using ANSYS[2] in order to locate the high stress areas and estimate the forces necessary to actuate the tuner, as shown in Figure 3.

Figure 2: Niobium tuning plate with convolutions, slots, and RF ports.

TUNER MEASUREMENTS

Room temperature measurements were performed on the new tuning plates, and cold tests were performed on the initial flat tuning plate. The forces necessary to actuate through the full tuning range and the

[2] ANSYS, Inc., Canonsburg, Pennsylvania, USA

corresponding frequency shift were measured. An S-beam load cell was used to measure the force. Some hysteresis was found, as shown in Figure 4, however more analysis will be needed to find the cause. Actuation of the tuner the full ±3 mm range provides approximately 28 kHz of tuning with a maximum force of 600 N. This experimental data agrees with the simulated results.

Actuation of the tuning plate will be provided via a linear stepper motor for coarse tuning and a stacked piezoelectric (PZT) element for fine tuning. Both actuators are at room temperature and feed into the vacuum vessel via bellows. The force is transmitted through concentric tubes, producing a push-pull action between the tuner plate and the cavity flange. Both tubes are 77 K intercepted to reduce the cavity heat load to 0.13 W. The stepper motor has a range of ± 25 mm, and a maximum force of ± 900 N. It has a resolution of nearly 0.04 mm, which equates to approximately 13 Hz per step. The PZT actuator has a range of 0.09 mm and can apply forces of +3000 N to –700 N. The PZT has a closed-loop resolution of 1.8 nm and can shift the frequency approximately 300 Hz total.

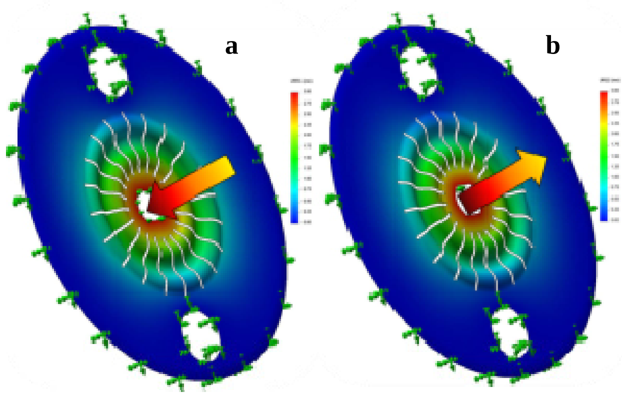

Figure 3: Simulations for a 3 mm displacement (red) of the final tuning plate, (a) pulling and (b) pushing.

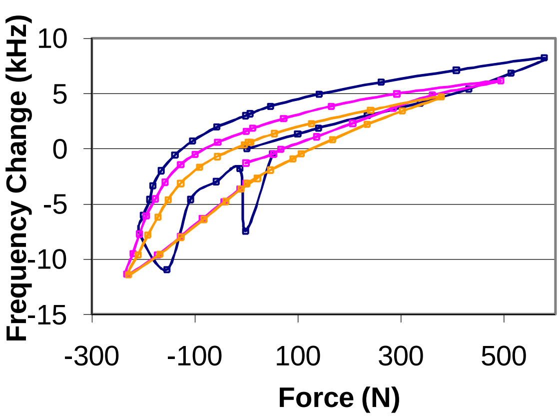

Figure 4: Measured frequency change versus force for the full ±3 mm actuation of the final tuner design.

CONCLUSION

Prototype tuners and power couplers have been designed and individually tested for the re-accelerator at NSCL. The results show that both components meet their respective design goals. The construction of the cryomodules for ReA3 is underway. The first module will contain a single β = 0.041 QWR. This will allow the components to be assembled as shown in Figure 5, and tested together in an operational environment.

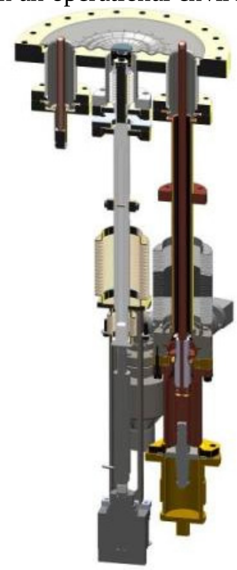

Figure 5: Power coupler and tuner assembly.

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