805 MHz HIGH POWER INPUT COUPLER FOR SRF CAVITY IN A RIA CRYOMODULE*

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Abstract

The Rare Isotope Accelerator uses 805 MHz superconducting rf cavities in the linac. Power is transmitted capacitively into the cavities via a high power input coupler. The coupler was designed for greater than 10 kW cw with a VSWR less than 1.05. The design load to the 2 K liquid helium is less than 2 W. The external Q of the coupler is about $2x10^7$. The couplers were conditioned off-line to over 200 kW pulsed before installation into a prototype cryomodule. The cryomodule was tested at 2 K to full accelerating gradients. Multipacting barriers in the coupler were quickly conditioned, and no arcs or discharges were observed during testing. Details of the power couplers performance will be presented.

Index Terms—Accelerator RF system, high RF power coupler, superconducting accelerator, superconducting cavity resonators.

I INTRODUCTION

THE RIA HIGH RF power coupler was designed by AMAC to meet the specification requirements for the RIA accelerator cryomodule of Michigan State University (MSU). MSU provided the RF specification, and performed the calculations to match the coupler to the SRF cavity. Communications & Power Industries (CPI) performed the manufacturing optimization, and fabricated two prototype couplers. The prototypes have been high RF power tested by Jefferson Lab and met or exceeded the requirements of the RIA technical specifications. The RF tests and conditioning are described in another paper at SRF-2003. The couplers were installed with superconducting cavity in a cryomodule by MSU and high power tested at cryogenic temperature of 2 K. Performances of couplers with cavities meet the RIA specifications.

The RF window problem has grown as the power required for waveguide and coaxial operating systems has exceeded prior design margins. Failures of windows generally occur in three categories: (1) excessive heating, (2) arcing, and (3) weak mechanical designs. In the first case, power lost in transmission through the window has not been adequately removed and the resulting stress build-up within the window exceeds the ultimate tensile strength of the material. In the second case, failure is a result of charges building up on one side of the window developing an electrical gradient, which exceeds the dielectric strength of the window material. The resulting breakdown arc causes a puncture through the window and a loss of vacuum. The third case is due to mechanical design. AMAC was awarded by the US Department of Energy an innovative research grant to develop the high RF power input coupler to take up some of these challenges.

II DESIGN CONSIDERATION

The RIA technical requirement are briefly listed in the following[1]–[3]:

VSWR: 1.05 or lower at 805 MHz

Maximum radiative heat loss to 2.1 K circuit: 1 W

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Maximum CW power: 10 kW
External Q of coupler: 2×10^{7}
Operating pressure: $< 5\times10^{-9}$ torr
Radiation resistance at tip of antenna: 4×10^{8} rads

Fig. 1 is the coupler with a MSU 805 MHz low bate superconducting cavity assembled for external Q measurement. It is a coaxial type of coupler with a planar ceramic window separating the vacuum side from the air side. In HFSS simulation, the loss tangent is taken as 0.0002, and the permittivity value is 9.6.

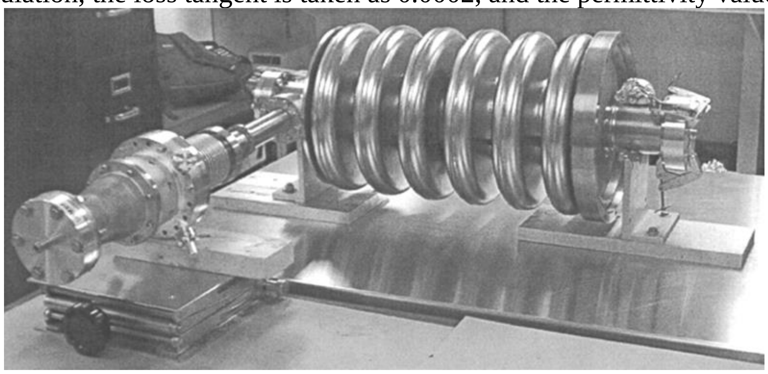


Fig. 1. The RIA coupler with a MSU RF cavity for external Q measurement

The RIA accelerating cavity geometry requires a coaxial 805 MHz coupler design with a transition to a standard 3-1/8″ transmission line. The window geometry incorporates chokes at the inner and outer conductor. The dissipated power at the window and the antenna are transferred conductively through the material and removed by air cooling. The vacuum side of the ceramic window is coated with 20–25 Angstrom Titanium Nitride.

The RF calculations performed for the MSU RIA coupler window, using MAFIA and HFSS programs, and analyzed for their multipacting behavior with a program from the University of Helsinki and are identical for this coupler. We carried out a series of simulations using different parameters to optimize the performance of the AMAC window. The following figures show the simulations results.

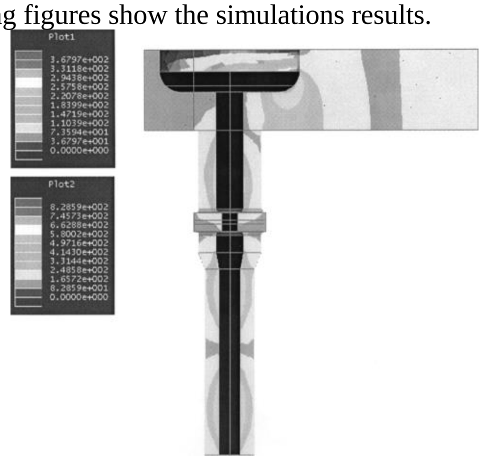
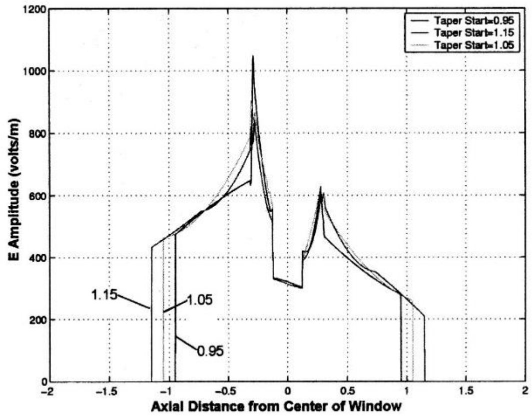


Fig. 2. Coupler electric fields in V/m for 1 W average input power



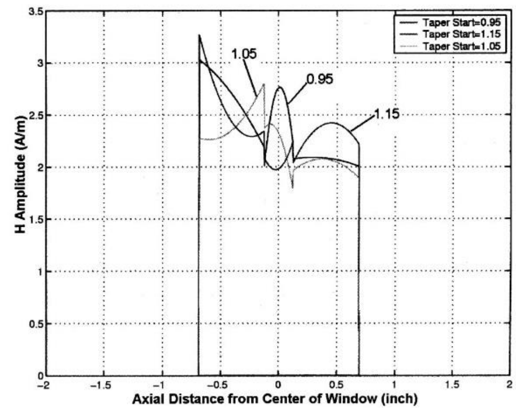


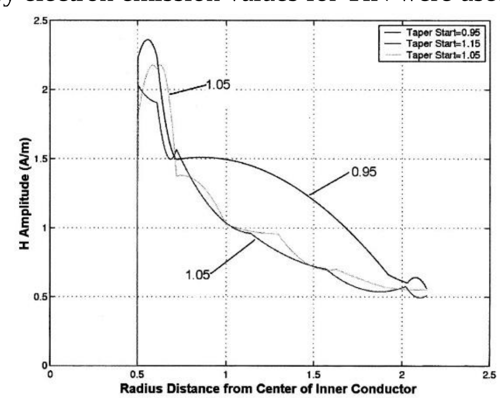
Fig. 3. Electric field amplitude along inner conductor surface

Fig. 4. Magnetic field amplitude along the inner conductor surface.

Figs. 2, 3, 4 and 5 show the results of the HFSS calculations for the E and H field distribution for the window design for 1 KW input power. In Figs. 3, 4 and 5, the negative side is the air side of the window. Dimensions of the coupler were optimized by lowering the electric and magnetic fields.

Figs. 6 and 7 show the MAFIA calculation results for the electric and magnetic fields for 0.5 W incident power. Fig. 8 is a contour plot of the dielectric loss in the ceramic. Figs. 9 (a) and (b) show the dielectric loss distribution, and the electric fields at the center plane of the ceramic for 1 W incident power.

Secondary electron emission data for copper extended to 50 eV on the lower energy side was used in the calculations for all copper and copper plated surfaces for the SNS design and apply also to the RIA coupler. The secondary electron emission values for TiN were used for the ceramic window surface.



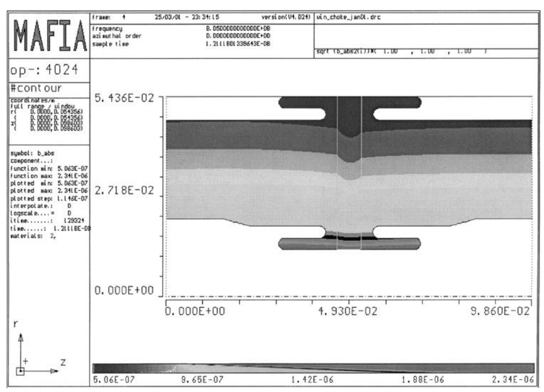
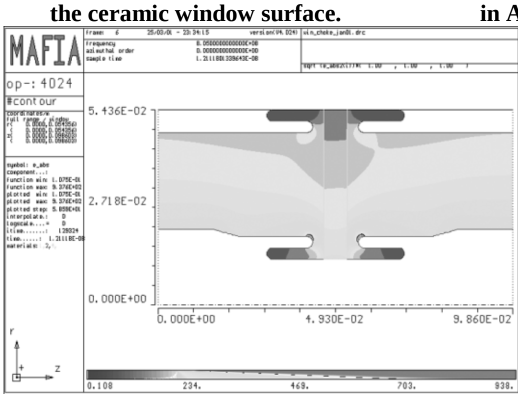


Fig. 5. Magnetic field amplitude along the ceramic window surface.

Fig. 6. Contour plot of magnetic field in AMAC-1 at 1/2 W incident power



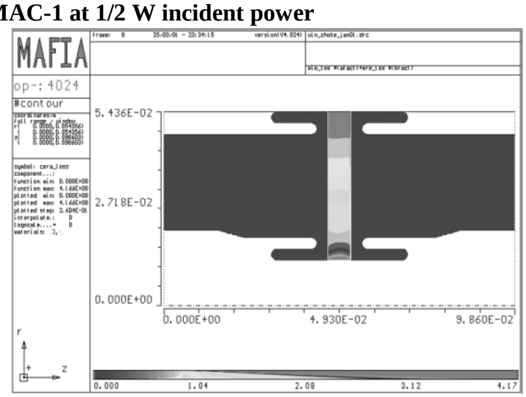
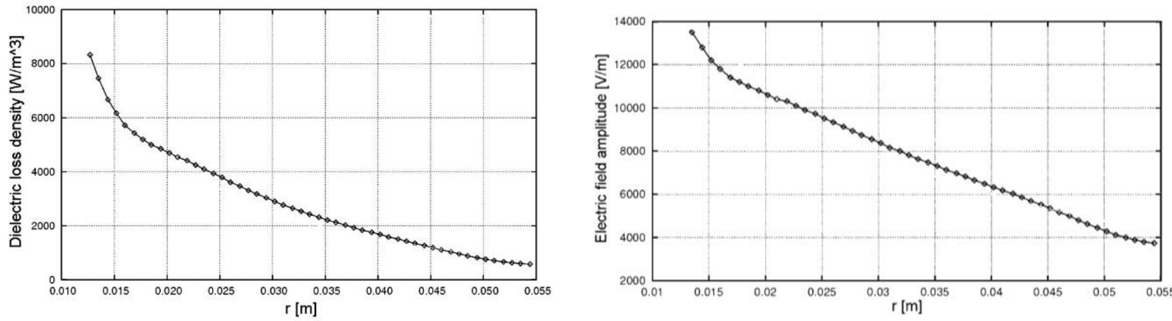


Fig. 7. Contour plot of electric field in AMAC-1 at 1/2 W incident power.

Fig. 8. Contour plot of dielectric losses in the ceramic at 1/2 W incident power.

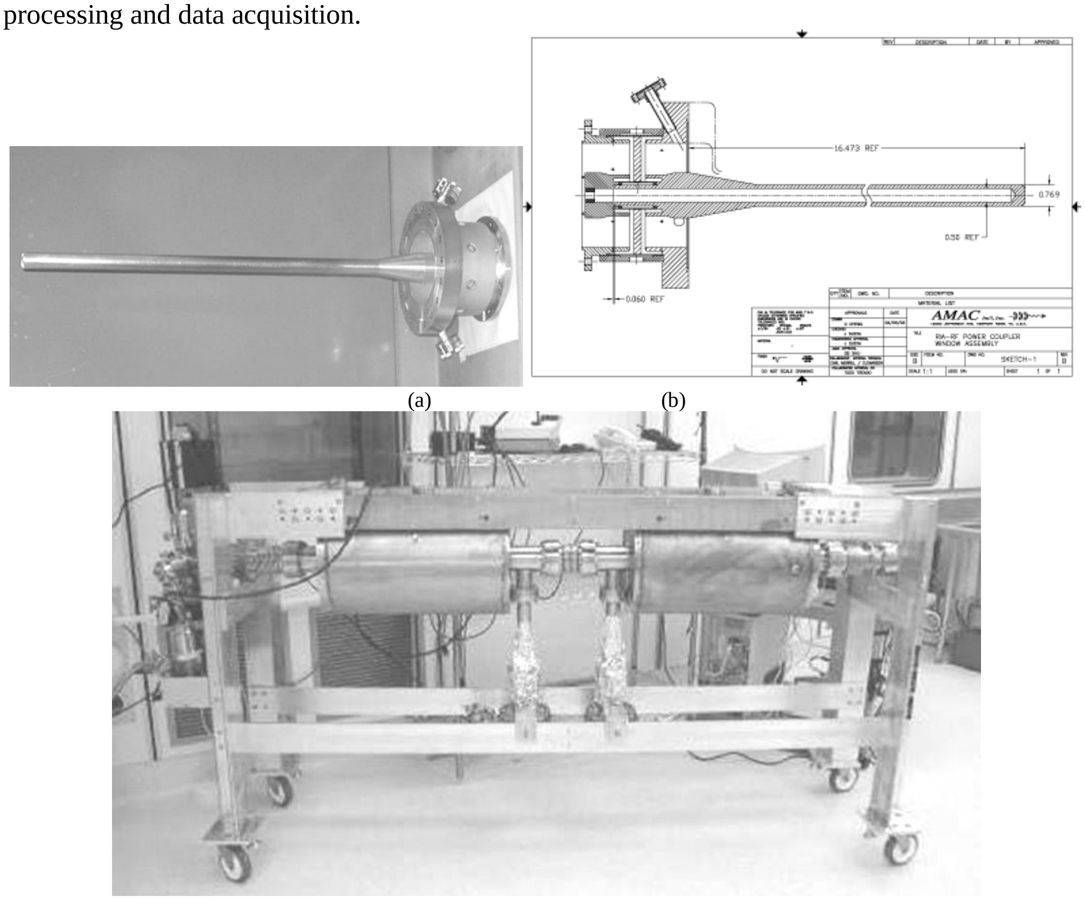


(a) (b)

Fig. 9. (a) Radius dependence of dielectric loss at 1000 W incident power.
(b) Radius dependence of electric field at the ceramic center plane at 1000 W incident power.

III CRYOGENIC AND RF TEST

Figs. 10(a) and 10(b) show the coupler's photo and design structure [4], [5]. RF conditioning on the test stand at room temperature was performed at DOE Jefferson Lab (JLab) using the 1 MW RF system consisting of a klystron, waveguide distribution system, terminating load or variable short circuit, directional couplers and associated RF power meters, electronic racks for klystron controls, coupler instrumentations, interlocks, software for RF processing and data acquisition.



(a) (b)

(c)

Fig. 10. (a) Photo of RIA coupler window. (b) RIA coupler window assembly. (c) Two couplers connected to the cavities with the LHe vessel attached with the Ti rail.

Two couplers were installed to SMU RIA cavity in the cryomodule to be tested [1]. Fig. 10(c) [1] is the cold mass of the cryomodule. The 2 K LHe vessel is mounted on the Ti rail and couplers are installed from down to up in the center. The thermal shield and μ metal magnetic field are not shown in the Fig. 10(c).

The measured input coupling strengths were:

$$Qext=1.4\times10^{7} \text{ for Cavity \#1 and } Qext=1.3\times10^{7} \text{ for Cavity \#2,}$$

both a bit lower than the design value($Qext=2\times10^{7}$) .

Multipacting barriers were encountered at low field (Ea<0.1MV/m) with both cavities after they were cooled to 4.2 K. In both cases, we punched through the barriers after less than 1 hour of RF conditioning. Current was detected on the center conductor during the conditioning, which suggests that the multipacting was in the coupler, not in the cavity. Since the input antennae cannot be moved, sliding shorts were installed on the coaxial lines to adjust the input coupling (see Fig. 1).

Loop antennae on the sliding shorts were used to couple power in and excite a standing wave in the coupler. For high field measurements, the short was moved to the detuned position to maximize the field in the cavity and minimize the field in the coupler.

For low-field microphonics studies with a wide band-width, the short was moved to the tuned position. The range of measured Q_{ext} values was 6×10^{4} to 6×10^{9}.

IV CONCLUSION & FUTURE DEVELOPMENT

(1) After extensive RF calculations, using MAFIA, HFSS and ANSYS programs, the design was further analyzed for multipacting secondary field emissions with a program implemented at the University of Helsinki. These calculation results support the selection of the design parameters of MSU RIA coupler. The cryogenic and RF test results support the design consideration and parameter choices.

(2) For further commercialization of the innovative technologies, the frequency and cryomodule dimensions are chosen to develop the high RF power couplers: a coaxial 805 MHz, 50 Ohm coupler design with a waveguide transition, an inner conductor bias voltage of 2.5 kV, and the installation of water cooling is used to remove the dissipated power at the window and the antenna. An innovative feature consisting of a compression ring was incorporated to reduce the tensile forces on the ceramic by pre-stressing the ceramic and increase the reliability of the ceramic window. The RF ceramic window in a -30° standing wave phase angle position is used. The coupler windows have been conditiond and RF qualified at the Jefferson Laboratory as part of a CRADA collaboration agreement. The development will be published in a separate paper.

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