20 KW CW POWER COUPLERS FOR THE APS-U HARMONIC CAVITY*

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Abstract

A pair of 20 kW CW adjustable RF power couplers optimized for 1.4 GHz has been designed and is being built as part of the APS-U bunch lengthening system. The system uses a single superconducting RF cavity to be installed into the APS Upgrade electron storage ring and will provide a tremendous practical benefit to the majority of users by increasing the beam lifetime by 2-3 times. The 80 mm diameter, 50 Ω coaxial couplers include 4 cm (~20 dB) of adjustability. This allows optimization of bunch lengthening for a range of storage ring beam currents and fill patterns while, simultaneously, maintaining the required 0.84 MV harmonic cavity voltage. To provide bunch lengthening, the cavity/coupler system must extract RF power (up to 32 kW) from the beam. Each coupler will transmit roughly half of the total extracted power to external water-cooled loads. The design extends upon on a well-tested ANL dual RF window concept, using a pair of simple rugged 80 mm diameter alumina disks. A new feature is the 'hourglass-shaped' inner conductor designed to maximize transmission at 1.4 GHz. Results of thermal simulations, as well as, prototyping and initial RF testing are presented.

INTRODUCTION

The APS-U storage ring [1] will have a relatively short beam lifetime due to Touschek scattering [2] and a bunch lengthening cavity is required to mitigate the effect. Harmonic cavities provide lengthening by modifying the longitudinal potential, reducing the slope near the bunch center [3]. Normal and superconducting RF (SRF) cavities are in use elsewhere for this purpose [4,5].

SRF cavities have advantages over normal conducting cavities in many high-current, high-power CW applications, including for the 6 GeV, 200 mA electron storage ring in the APS-U:

- One beam-driven single-cell harmonic cavity easily provides the required 0.84 MV potential
- Large-bore SRF cavities have no trapped monopole or dipole modes; HOM damping is, therefore, relatively less complex
- The high intrinsic quality factor, $Q_0>10^8$, combined with a variable coupler, permit adjustment of the loaded quality factor, Q_L, for near-optimal lengthening for various beam currents

The coupler/cavity design for the 4th harmonic system is shown in Figure 1. Some basic features are similar to the Cornell ERL injector couplers [6]. Two couplers reduces the time average power density and the symmetry reduces the transverse impedance presented to the beam.

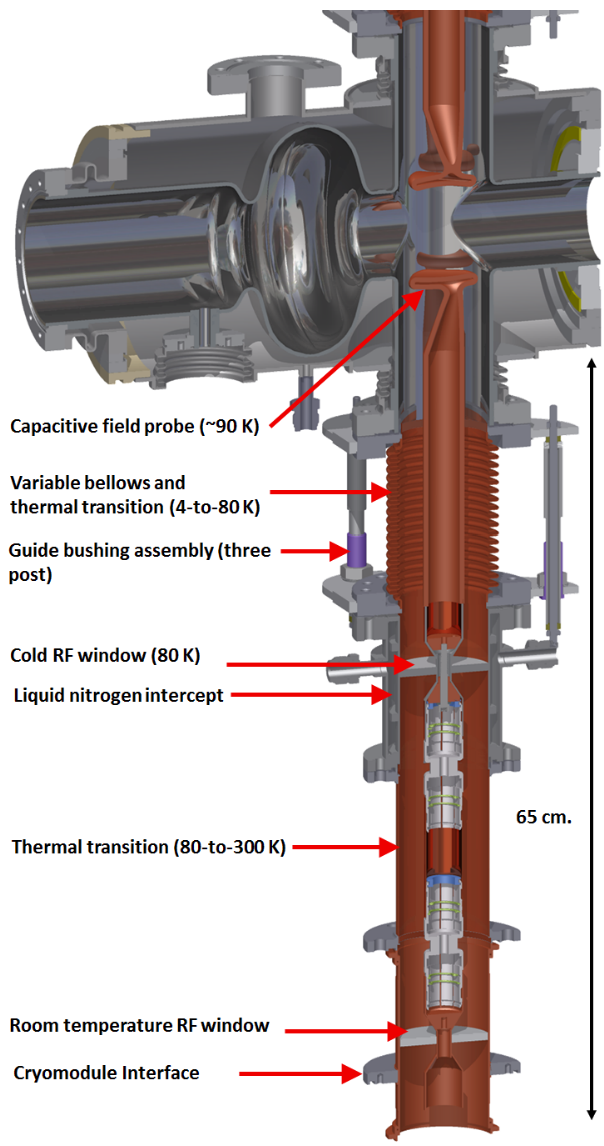

Figure 1: A pair of 80 mm diameter dual-window RF power couplers mounted to a 4th harmonic cavity

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REQUIREMENTS AND DESIGN

Important requirements and design features are summarized in Table 1. Each nominally identical coupler should be capable of stable CW operation with 20 kW RF power in the travelling wave mode. Losses into 4.5 K helium, 80 K nitrogen and room temperature should be reasonable, with good margin from 'thermal runaway'. The design should also be tolerant of other effects such as small reflections or power losses due to HOM's excited by the beam in the coupler near the beam aperture.

Coupler field probes shown in Figure 1 are in the 'full in' condition and are retractable back into the cavity port by up to 4 cm. Center conductors are conduction cooled via a pair of ceramic windows (one warm, one cold). The temperature profile during 20 kW CW operation is expected to vary smoothly from ~90 K at the coupler tip to room temperature near the cryomodule interface, as predicted using coupled electromagnetic and thermal simulations in ANSYS [7]. The cold and warm windows, respectively, also provide the vacuum break between the (clean) cavity and the cryomodule, and the cryomodule and the outside environment.

The direction of power flow is from the cavity out through the couplers and into external loads, as shown graphically on the inset in Figure 2. The portion of the field probe inside the cavity port is carefully shaped with consideration of peak fields, coupling strength and 'coupler HOMs' which could be excited by the beam [8].

The design avoids the known multipacting bands for coaxial lines. Figure 2 shows CST Particle Studio calculations of the number of emitted secondary electrons in copper and ceramic materials for various power levels up to 50 kW CW (travelling wave). The secondary electron yield (SEY) scale factor for alumina was assumed to be 6. The inset in Figure 2 shows a separate Eigenmode solution for the electric field and the resulting travelling wave produced in the power couplers. Resonant growth in emitted electrons is not predicted at any power level and multipacting is not expected to be a significant issue for 1.4 GHz operation.

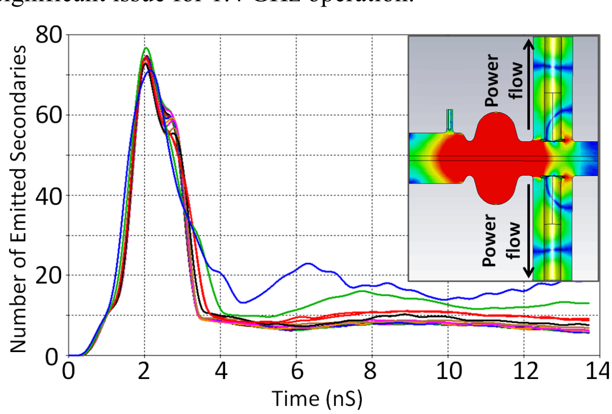

Figure 2: Main figure – CST multipacting simulations for several coupler RF power levels up to 50 kW CW (travelling wave). Inset – travelling wave due to coupling to the cavity electric field (red).

Table 1: Main Coupler Parameters

Parameter	Value
Type	Two window co-axial
Characteristic impedance, Ω	50
Design frequency, MHz	1408
Operating temperature, K	4.5 - 300
Max. design power @ 1.4 GHz*, kW	20
Axial stroke, cm	4
External quality factor	2×10^5 - 2×10^7
Return loss S11, dB	< -20
RF power loss to 300 K*, W	74
RF power loss to 80 K*, W	94
RF power loss to 4.5 K*, W	2

*at 20 kW CW travelling wave, ceramic tanδ = 0.0027

Optimization for 1.4 GHz

For this relatively high frequency, a new version of the ANL dual alumina disk window (see Figure 1) has been design and fabricated. The purpose is to reduce the ~10% of reflected power that would occur at each window using straight cylinders and a 6 mm thick alumina disk. Instead, the center conductor diameter is reduced from 3.3 cm down to 1.3 cm in the vicinity of the alumina. The effect is to produce a dip in the reflected power near 1.4 GHz, reducing the reflection coefficient, S_{11} to less than negative 20 dB per RF window. Measured data using a network analyzer are shown in Figure 3 for a pair of recently fabricated RF windows and confirm the calculations.

Heat Flow and Power Management

Conductive cooling of the coupler inner conductor is outward through the alumina disks and into either the room temperature or nitrogen-cooled outer conductors. The ceramic is WESGO AL300 97.6% alumina. In addition, dissipated RF power must flow across the

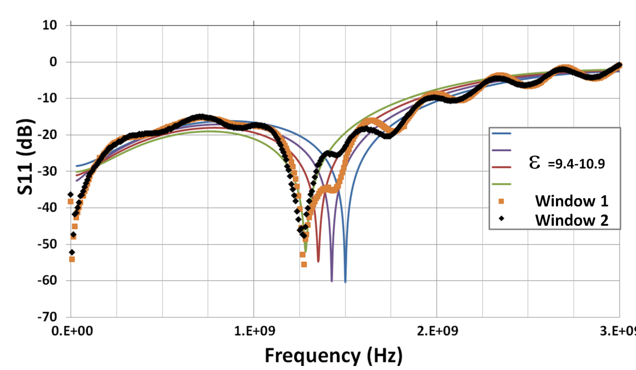

Figure 3: Measured (black and orange dots) and calculated reflection coefficients for two RF windows with the 'hourglass-shaped' central conductor

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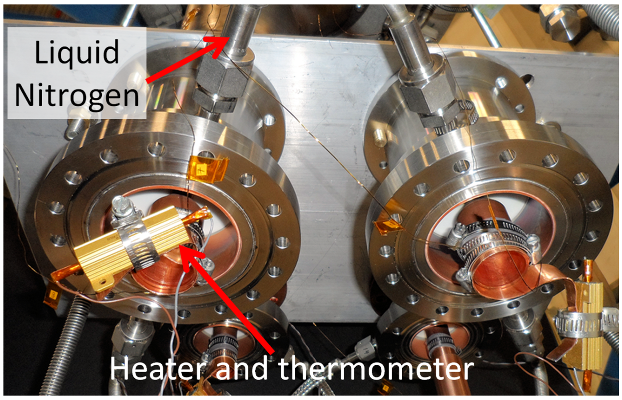

Figure 4: Calorimetry hardware for heat transfer measurements in RF windows at 80 K and 300 K

copper-gold braze joint interface at both the inner diameter and outer diameters of each disk. For example, the analytically estimated RF loss on the field probe (center conductor) between the coupler tip and the cold window is 5 Watts for 20 kW transmitted power. This heat, along with losses in the ceramic itself, must flow through the 80 K disk and braze joints and into the liquid nitrogen cooled outer conductor. Uninterrupted heat transfer is clearly critical to stable high power operation, so the conductivity have been experimentally measured in two recently fabricated cold windows from MPF Inc. Room temperature and 80 K calorimetry was performed

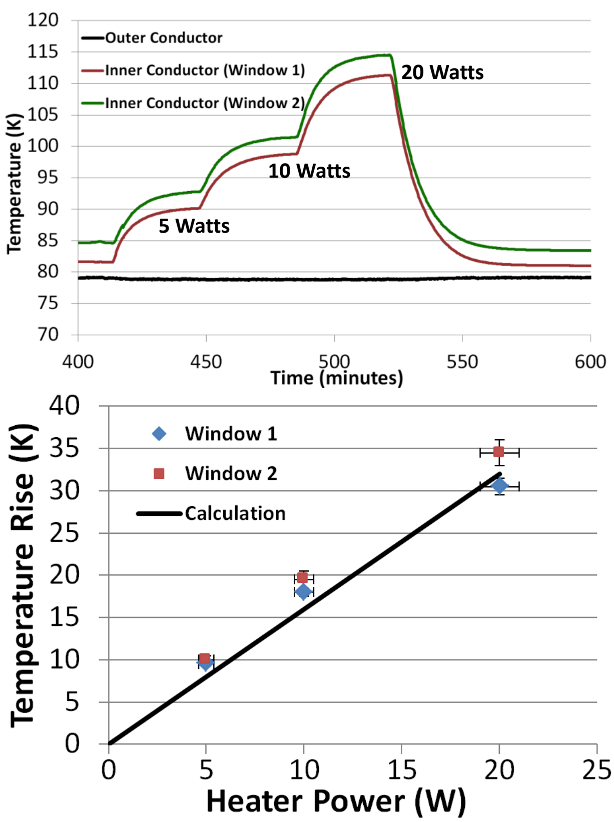

Figure 5: Top – temperature rise due to conduction in alumina and copper, bottom – analytically calculated versus measured termperature increase.

using the setup shown in Figure 5. Hardware in Figure 5 were tested in a vacuum cryostat to eliminate convective losses to air.

The plots in Figure 6 show measured and calculated temperature rise on the central conductor assuming conductive heat transfer through the (Tellurium) copper antenna and the alumina disk. Note, the first data point for 5 Watts of heater power corresponds roughly to the anticipated RF loss in copper for 20 kW CW operation. Temperature rises are consistent with the 80 K thermal conductivity values of 360 W/m-K and 100 W/m-K for (Te)-copper and alumina respectively. Notably, there is no measureable ΔT due to the braze interfaces. Dielectric losses in the ceramics will also be measured when the couplers are initially tested, separately from the cavity, using a 20 kW 1.3 GHz CW RF power amplifier which is under assembly at ANL.

SUMMARY

The combination of moveable

couplers with an SRF cavity provide the flexibility to adjust for a range of APS-U storage ring beam currents and fill patterns, a capability that is not available with copper cavities. A 4 cm adjustable 20 kW CW power coupler optimized for the 1.4 GHz has been studied and designed at ANL. A pair of these couplers is under fabrication and will initially be tested with a 20 kW 1.3 GHz source.

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