DESIGN AND CONSTRUCTION OF A HIGH-POWER RF COUPLER FOR PXIE*

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Abstract

A power coupler has been designed and built at Argonne National Laboratory for use with the Project X Injector Experiment (PXIE) 162.5 MHz superconducting (SC) half-wave cavities. The 50 Ohm coaxial capacitive couplers will be used to operate 8 cavities CW with up to 10 kW of forward power under any condition for the reflected power. A key feature is a moveable copper plated stainless steel bellows. The bellows permits up to 3 cm of axial stroke and adjustment of Qext by two orders of magnitude in the range of 10^{-5} - 10^{-7}. The mechanical and vacuum design includes two ceramic windows, one at room temperature and another at 70 Kelvin. The two window design permits a compact, low particulate assembly inside the clean room. We present other design features including thermal intercepts to provide a large margin for RF heating and a mechanical guide assembly for low-friction motion while cold and under vacuum.

INTRODUCTION

The front-end of the proposed Project-X SC H- linac at Fermilab has been re-designed to include a single cryomodule of eight SC half-wave resonators (HWR's) operating with β=0.11 and f_0=162.5 MHz [1], replacing the previous linac section of 24 β=0.1 325 MHz spoke cavities. The 162.5 MHz HWR cryomodule along with, the LEBT, MEBT and one cryomodule of spoke cavities for β=0.2 comprise PXIE, the Project X Injector Experiment. The compact, lower part count, re-design does, however, reduce redundancy and increase power handling for each cavity/power coupler system. The specification, fundamentally, now requires a very reliable coupler for 10 kW CW operation under all conditions of reflected power.

DESIGN APPROACH

Requirements for the coupler are that it deliver to the cavity the required CW rf power for operating modes with low beam-power up to 5 mA and also that it be suitable for cavity rf (pulse) conditioning. The coupler should not adversely impact cleanliness of the high-gradient SC cavities. Considerations for the already demonstrated ANL 4 kW, 72 MHz coupler are similar [2], and the 4 kW design serves as the starting point for the new coupler, parameterized in Table 1.

Table 1: Coupler Design Parameters

Parameter	Value
Max. design power (kW)	15
Type	Coaxial capacitive
Outer diameter (cm)	5
Length (cm)	37
Impedance, nominal (Ω)	50
S11 @ 162.5 MHz (dB)	-30
Static load to 2K (W)	0.06
Static load to 5K (W)	1.6
Static load to 70K (W)	2.6

The modular design has four separate components. These are a cold bellows, a cold rf window, a 70-to-300 K transition and a 300 K rf window. Windows each use an alumina disc with a hole for the center conductor. The disc is brazed between the inner and outer conductors.

Adjustability of the center conductor by 3 cm into and out of the cavity is performed by compressing the cold bellows, formed from thin-walled stainless steel with 20 μm of copper on the inner (rf) surface. The cold window is anchored to 70 K by circulating cold He or N_2 gas, as shown in Figure 1, and also divides cavity and cryomodule vacuum spaces. The window conductively cools the center conductor, so that it operates near 70 K for all operating modes. The cold bellows and rf window are readily cleanable for assembly onto the clean SC cavity. The warm window, located near the bottom wall of the cryomodule, separates the cryomodule vacuum from atmosphere.

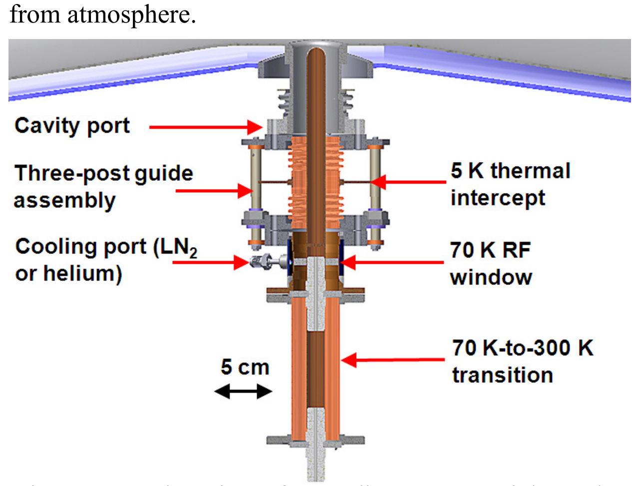

Figure 1: Section view of 5 cm diameter co-axial coupler.

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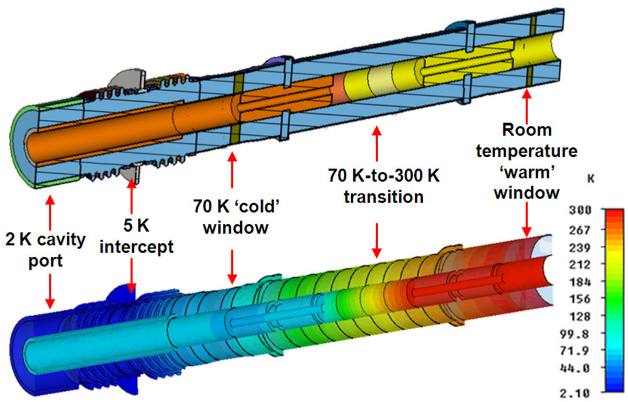

Figure 2: Coupler electromagnetic/thermal model in CST Studio for 15 kW forward power.

ELECTROMAGNETIC AND THERMAL MODELS

To provide operating margin even at the highest power levels of 10 kW, the electromagnetic and thermal analysis has been performed in CST studio for an incident power level of 15 kW. The new CST thermal simulation capability has also been checked analytically, in many cases, to establish confidence in the simulations. Multipacting, predicted for lower incident power levels of 500 W to 2.5 kW, can be suppressed, if need be, by the straightforward application of a 300 V bias to the center conductor [3].

Temperature dependent physical properties of the materials (e.g., copper, stainless steel), which include thermal conductivities, resistivities, and heat capacities are modelled by breaking the CST model into many discrete pieces since code does not do this explicitly. Results in Figure 2 (bottom) shows no localized heating for the case of 15 kW forward power (full reflection, overcoupled) and indicate that the coupler is far from thermal runaway.

The low-conductivity thin-wall thermal transitions are the most susceptible to overheating since the thin wall reduces heat dissipation from rf losses. Figure 3 shows a detailed view of the CST model for the cold bellows, including an accurate model for the 20 μm copper plating onto 150 μm of stainless steel. No significant heating is observed. The 5 K intercept also reduces losses into 2 K helium to 60 mW (see Table 1).

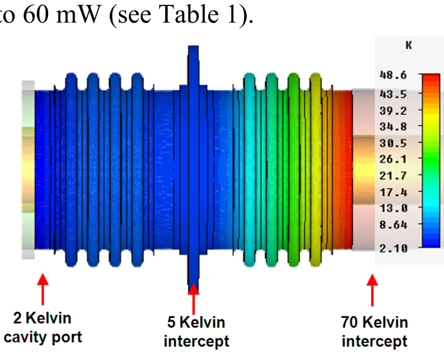

Figure 3: Detailed T-map of moveable bellows.

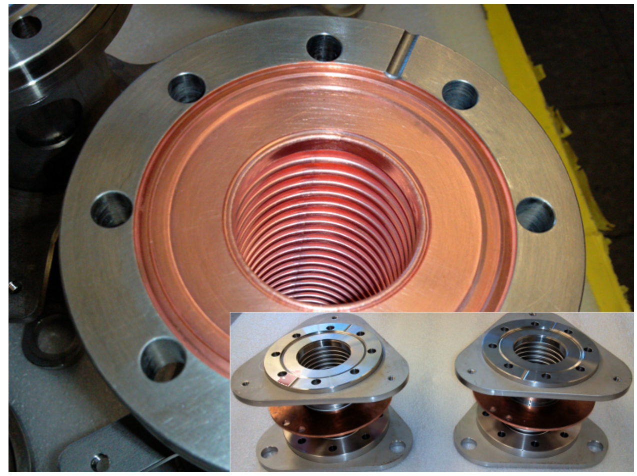

Figure 4: Two prototype bellows assemblies (inset) and a 20 μm of copper plating deposited onto a thin-walled stainless steel bellows.

FABRICATION

A pair of prototype couplers are being built and will be ready for testing ahead of two 162.5 MHz HWR prototypes. Fabrication borrows heavily from techniques used for the smaller ANL 72 MHz, 4 kW coupler.

Warm and cold rf windows have been designed at ANL and are being fabricated by MPF Products Inc. Each window consists of a 96-97% pure 5-cm outer diameter alumina 'donut' brazed with copper-gold alloy to copper inner and outer conductors. A vacuum tight stainless cylinder surrounds the outer conductor and is used to cool the assembly using circulating He or LN_2.

The cold bellows assembly is made by welding a thin-wall (150 μm) formed 321 stainless steel bellows into a pair of modified CF flanges (see Figure 4). A three post and bushing guide assembly located just outside the flanges has Dicronite coatings to maintain clean, low friction linear sliding under vacuum and at cryogenic temperatures. Critically, the 20 μm of copper plating is deposited as the last fabrication step by Saporito Finishing. This is necessary to support the current density in the compact 5 cm diameter line. Preliminary testing is planned for summer 2012.

ACKNOWLEDGEMENTS

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