VARIABLE CW RF POWER COUPLER FOR 345 MHZ SUPERCONDUCTING CAVITIES*

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Abstract

This paper reports the development of a cw variable coupler for 345 MHz spoke-loaded superconducting (SC) cavities. The coupler inserts an 80K copper loop into a 5 cm (2 inch) interior diameter coupling port on several types of spoke-loaded cavity operating at 2K or 4K. The coupling loop can be moved during operation to vary the coupling over a range of 50 dB. The coupler is designed to facilitate high-pressure water rinsing and low-particulate clean assembly. Design details and operating characteristics are discussed.

INTRODUCTION

Over the past decade, a class of superconducting cavities have been developed to accelerate ion beams for the production of rare isotopes [1,2]. The cavities range in frequency from 60 – 350 MHz, will operate cw, and will have beam loading on the order of 1 – 5 kW per cavity. This paper describes the ongoing development of an RF coupler intended for the entire class of cavities which have been developed for this application.

The initial design concept was initiated by two of us (KWS and AMP.) using simple, lumped-parameter approximations to model the electromagnetic losses and thermal properties.

The primary goals guiding the coupler development were:

- The same basic coupler design for all cavity types and frequencies.
- A single, room-temperature vacuum window.
- The cold end of the coupler transmission line (at 80K) inserts without touching into a 4 K coupling port on a SC cavity.
- The coupler is variable, with a slightly more than 3 inch range of motion, varying the degree of insertion of the coupling loop into the cavity coupling port.
- All parts of the coupler within the cavity vacuum are designed to facilitate high-pressure water rinsing and clean assembly.

The coupler has, to date, gone through two prototype iterations, the prototypes being used for TEM-class cavity development at 115, 172, and 345 MHz. This paper reports the current status of ongoing development of the coupler.

COUPLER DESIGN AND FABRICATION

The basic elements of the coupler (see Fig. 1) are:

1. An inductive loop terminating a 50 ohm coaxial line (which is at 80K) is inserted into the SC cavity coupling port 4K.
2. The physical connection between the 80K loop and line and the 4K cavity is a stainless-steel formed bellows of 2 inch ID and 3 inch travel.
3. A short, copper-plated stainless-steel section of coaxial line forms the thermal transition from 80K to room temperature.
4. A single vacuum window in the form of a ceramic coaxial feedthrough at room temperature
5. A double rack and pinion provides 3.1 inches of linear motion to vary the coupling over a large range (50 db)

The coaxial line is formed with an outer conductor machined from a bar of Glid-Cop and an inner conductor of pure copper. Near the mid-point of the coupler, the outer conductor is cooled by liquid nitrogen.

Just below the heat exchanger is the thermal transition to room temperature. The transition is a section of coaxial line a few cm in length formed of 20-mil wall stainless-steel tubing, with copper electroplated to a thickness of several microns on the outer surface of the center conductor and the inner surface of the outer conductor.

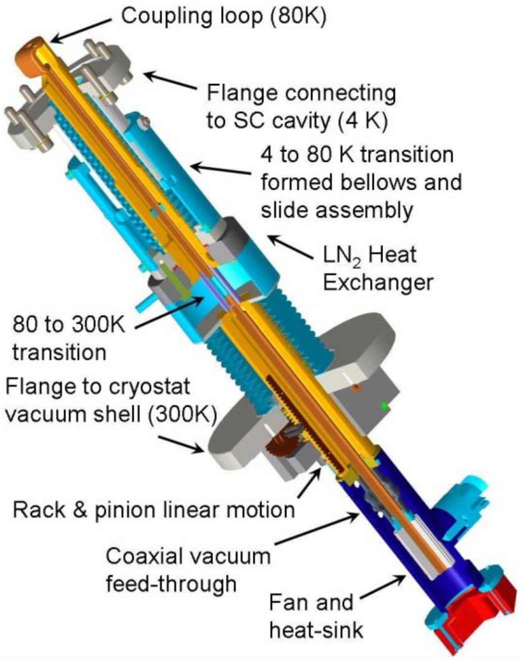

Figure 1: Quarter-section of the coupler. Overall length is approximately 40 cm.

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The center-conductor cools by conduction from the thermal transition up to the coupling loop and through the loop to the outer conductor, then through the outer conductor to the heat exchanger flange.

The coupler "window" is a kovar-ceramic vacuum isolator feedthrough at the room-temperature end of the coupler. The kovar elements were copper plated to a thickness of several microns.

MODELING

Simulations of the coupler were performed with HFSS using detailed CAD geometry files. The simulation model was used primarily to quantify losses throughout the coupler. As a result, detailed representations of the grooved heat sink, transitions, h-loop, feed-thru and ceramic were incorporated into the model. The ribbed bellows was constructed as a smooth cylinder with its conductivity modified to account for the reduced surface area in the model.

Various operating conditions of the coupler were modeled including off-resonance, fully retracted and inserted, and matched conditions with beam loading. The coupler was centrally located on the periphery of a superconducting pillbox cavity and coupled to the cavity TM_{010} mode. Its position was established in order to approximate the magnetic field flux at the coupler port to that of a typical triple spoke resonator, as well as to fix its location at an electric field null.

Analysis of the warm section of the coupler showed excessive rf losses in the stainless steel feed-thru and initiated a redesign of the sapphire inner conductor support and a relocation to a lower field region. Coupler self-fields in the fully-retracted position were found to create RF losses in the stainless steel bellows, while the fully-inserted position produced somewhat higher losses than expected on the coupler h-loop during matched operation.

RF TESTS

The coupler has been used for cold testing of numerous SC cavities. A single test has been focused on coupler development, in which thermometers (and heaters for calibration) were attached to the 4K flange and the LN_2 heat exchanger flange. The coupler was attached to the power-coupling port of a 345 MHz, $\beta = 0.5$ triple-spoke cavity [2], which was then cooled to 4K for the RF tests.

This configuration enabled the simultaneous measurement of the heat deposited in the liquid nitrogen heat exchanger and the heat leak to the cryogenic system. The modeling of the electromagnetic losses on the coaxial copper line and the thermometric measurements were in reasonably good agreement, but the interaction between the electromagnetic field and the bellows is still not entirely understood.

When the coupler extended 3.3" into the cavity coupling port and the coupler was driven slightly off the cavity resonance at 345 MHz, (with 1000 W of forward power) the numerical modeling predicted 1.9 W heating into the liquid nitrogen heat exchanger. The thermometric measurements under these conditions indicated the heating to be 1.1±0.9 W, which we consider to be good agreement, given the uncertainties of the calorimetric method employed.

In order to separately measure the RF heating effects of both the cavity-produced electromagnetic field and also the self-fields of the coupler, the following procedure was used:

1. The coupler was weakly coupled to the cavity by positioning the coupling loop so that it extended only 0.2" into the coupling port.
2. Measurements were done at three different forward power levels. At each power level the heat flowing into both the cavity cryogenic system and the liquid nitrogen heat exchanger were calorimetrically measured.
3. These measurements were done under two different conditions: first, the cavity was excited to 9 MV/m and then secondly, for the same forward power, the frequency was slightly detuned so the cavity was not excited.

A summary of the analysis done with the coupler calorimeters is shown in table 1. Notice the increased heating due to the cavity fields, this is still not understood.

Cavity Gradient	**0 MV/m**			**9 MV/m**		
Forward Power	1000 W	800 W	600 W	1000 W	800 W	600 W
LN_2 Flange	6 W	4 W	3 W	5 W	3 W	2 W
4K Flange	3 W	2.5 W	2 W	19 W	19 W	13 W

Table 1: Coupler thermometric measurements (accurate to ±1W) for the coupler extending 0.2" into the coupling port, weakly coupled to the cavity, and for several levels of forward power.

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DISCUSSION AND CONCLUSIONS

The present coupler design has functioned well at modest power levels in numerous cold tests of several types of TEM-class superconducting cavities varying in frequency from 109 to 345 MHz. In these tests the RF power was limited to a maximum of 1 kW cw.

Thermometric measurements have shown that, in the present design, RF losses in the cold, formed SS bellows are larger than tolerable for cw high-power operation. The losses are larger than appeared in the model results, possibly because the magnetic field symmetry of the model did not couple to TEM modes in the secondary coaxial line formed by the copper coupler structure extending through the stainless-steel formed bellows and into the niobium cavity coupling port (2 inch ID).

Further work will initially expand the model to include such modes, and subsequently modify the formed bellows assembly, and possibly the coupling port itself, to reduce the RF power coupled into the bellows.

Additionally, plating a few microns of copper on the bellows interior would substantially reduce the RF loss into the bellows.

While some development work remains, the coupler design presented here has worked very reliably and smoothly in numerous cold tests of several types of SC cavity. The flexibility of the variable coupler has proven sufficiently valuable that we believe the additional development that will be required for cw operation in the 5 – 10 kW region to be entirely warranted.

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REFERENCES

[1] K. W. Shepard, P. N. Ostroumov, and J. R. Delayen, Phys. Rev. ST – AB **6**, 080101 (2003)

[2] K. W. Shepard, M. P. Kelly, J. Fuerst, M. Kedzie, Z. A. Conway, Physica C **441**, Pp 205- 208 (2006)