CRYOGENIC TESTING OF THE RF INPUT WAVEGUIDE FOR THE CEBAF UPGRADE CRYOMODULE*

T. Hiatt†, M. Breth, M. Drury, R. Getz, L. Phillips, J. Preble, J. Takacs, W. Schneider, H. Whitehead, M. Wiseman and G. Wu
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

Abstract

In order to support the planned CEBAF upgrade at the Jefferson Lab a new cryomodule has been designed. A key component of the new cryomodule is the upgraded RF input waveguide, which may couple as much as 10 kW of Radio Frequency (RF) power to Superconducting Radio Frequency (SRF) cavities contained in a bath of superfluid helium. The coupler consists of a straight copper plated stainless steel waveguide as a thermal transition between 2 K and 300 K and one ceramic window at the warm end of the waveguide. The waveguide interior shares a common vacuum with the cavity. Initial testing of the upgraded coupler has been conducted at Jefferson Lab in a representative cryomodule. During testing, data was obtained regarding waveguide temperature profiles as well as coupler arcing and multipacting. Predicted temperature profiles were used to determine the optimum location of the 60 K heat intercept on the waveguide, and were found to be comparable to the actual measured profiles. The coupler was found to be free of multipacting up to 1.7 kW. No arcing occurred during multiple eight-hour runs in heavy field emission with typical radiation levels of 0.5 to 1.0 R/hr outside the cryostat.

1 INTRODUCTION

An upgraded prototype waveguide coupler has been developed and tested in a representative cryomodule at the Jefferson Lab. The prototype waveguide was built from two original CEBAF waveguides. A series of tests were performed on the waveguide to include temperature profiles, multipacting and arcing. This paper describes the results of the testing as well as the physical and performance characteristics of the waveguide.

2 WAVEGUIDE DESCRIPTION

The typical production, upgraded waveguide is a copper plated, stainless steel rectangular tube with end flanges that has a set of three-convolution bellows near each flange. The waveguide is 21.59 cm (8.50 in) in length. The thickness of the copper plating inside the waveguide tube is nominally 1.5 µm (60 µin) and should uniformly coat the interior of the waveguide from the cold to the warm flange.

Stiffening ribs were welded to the waveguide tube in order to support atmospheric load during cryomodule and beamline assembly. Mounting tabs for temperature diodes were added to the ribs for testing purposes. A heat intercept was positioned 6.99 cm (2.75 in) from the cold flange to act as a thermal heat sink, in order to maintain a constant 60 K temperature at that position. The inside of the waveguide is subjected to the cavity vacuum and is separated from the outside world by a ceramic window at the warm end of the waveguide.

3 WAVEGUIDE OPTIMIZATION

Analysis was done to determine a waveguide configuration and optimize heat loads to the 2 K helium bath and 60 K heat station. In order to accomplish heat load optimizations and predict temperature profiles, a one dimensional finite difference model was developed. This model calculates temperature profiles, as well as static and dynamic heat loads to the 2K helium bath and 60K heat station. Radiation is not included in this model. Temperature assumptions include a fixed 2 K temperature at the end of the cold flange, a fixed heat intercept temperature of 60 K, 6.99 cm away from the cold flange, and a fixed 300 K temperature at the end of the warm flange. A heat station temperature of 60 K has been assumed in order to provide a 15 K ΔT across the thermal straps between the heat station and the thermal shield that was assumed to be at 45 K.

In this optimization, the static heat load is inversely proportional to waveguide length, while the dynamic heat load is directly proportional to waveguide length. The dynamic heat load is also directly proportional to RF input power, which for purposes of this optimization is fixed at 6 kW supporting a cavity gradient of 15 MV/m at a Q_{ext} of $2x10^7$.

3.1 Optimization Results

An optimization using a 6 kW RF input yielded a heat intercept location 6.99 cm (2.75 in) from the cold flange, approximately 1/3 of the length of the waveguide. Investigation of RF input powers as high as 10 kW reveal that the waveguide is slightly longer than optimum and could be shortened by as much as 10 cm (4 in). Shortening the waveguide would not be advantageous however, because a longer waveguide is better able to translate almost 8 mm (0.3 in) when adjusting to thermal contraction of the beamline during cool down and cavity tuning [1]. Overall heat load summaries are provided in Table 1.

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† hiatt@jlab.org

Operating Power (kW)	Heat Load (W)		
	2 K	60 K	300 K
4	0.49	3.37	0
6	0.87	7.60	2.50
8	1.26	12.97	5.49
10	1.81	19.11	9.16

Table 1: Waveguide Heat Loads

4 WAVEGUIDE MEASUREMENTS

Several tests were conducted on the waveguide to investigate its mechanical and electrical performance. Thermal profiles, arcing and multipacting were three areas of concern.

It is noted that the tested prototype waveguide differs from the typical production waveguide that will be used in the upgraded CEBAF cryomodule in three ways. First the tested prototype waveguide is 1.27 cm (0.50 in.) longer between the thermal intercept and the warm window than the typical production waveguide. Second, the thickness of the copper plating on the prototype waveguide is twice as thick, 3 µm (120 µin), as the copper plating on the typical production waveguide. Finally, the tested prototype waveguide uses the same heat intercept as the 4 GeV waveguide currently used in the CEBAF machine. The typical production waveguide has a redesigned heat intercept that allows thermal strapping to the narrow sides of the waveguide. Thermal profiles were predicted using the tested prototype geometry and a thermal intercept temperature of 51 K. This intercept temperature is the average of the measured inlet and outlet temperatures of the thermal shield.

4.1 Thermal Measurements

Waveguide temperatures were recorded under static conditions (no RF power input) as well as at various RF power levels. Nine silicon temperature diodes were attached to mounting tabs on the waveguide stiffening ribs. The temperature diodes were held in place using Delta Bond 152, with an additional tenth diode bonded to the niobium fundamental power coupler (FPC). Table 2 shows diode numbers and their corresponding longitudinal position with respect to the FPC interface, as well as measured and predicted static temperatures. The niobium to stainless steel flange interface is at x = 0 cm. Figure 1 shows the waveguide and the diode tabs attached to a cavity string prior to insertion into the representative cryomodule. Figure 2 shows the reverse view of the waveguide with the copper heat station located approximately 1/3 of the waveguide length from the cold flange.

It should be pointed out that diode number 1 reveals a static temperature of 7.97 K and a dynamic temperature of 10 K with an input of 1,680 W of reflected RF power. This reading is thought to be inaccurate however, as a temperature of 9 K would cause the FPC to become normal conducting. Since cryogenic monitoring systems did not detect an excessive draw of cryogenics during waveguide testing, it is believed that heat leak from the diode leads, contact resistance, improper mounting or some combination contributed to the higher than likely temperature reading. Figure 3 and 4 show cold and warm side temperature measurements and predictions for static loading. Figure 5 and 6 show cold and warm side temperature measurements and predictions for 1,680 W of reflected (3,360 W total) RF power, which is the operational limit of the RF input power supply. Figures 4 and 6 show only the waveguide region, 7 cm to 19 cm, which was outfitted with temperature diodes.

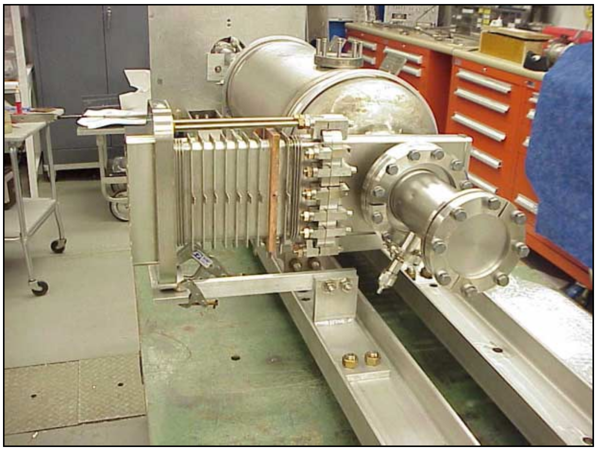

Figure 1: Waveguide on Cavity String

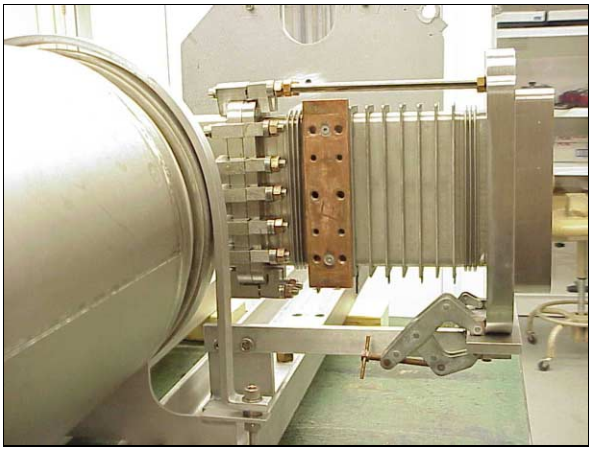

Figure 2: Reverse View Waveguide on Cavity String

4.2 Waveguide Arcing

The original CEBAF coupler suffered from "arcing" at the cold ceramic window [2] in the presence of field emission in the cavity. This has been and still remains a significant nuisance in the operation of CEBAF. Several features have been incorporated in the current waveguide design to eliminate this problem. The cold window of the original design has been eliminated and the warm window is about 22 cm from the beamline as opposed to 8 cm as in the original CEBAF coupler design. The ceramic thereby views a much smaller solid angle of the beampipe. A second feature of this coupler, which substantially reduces the electron flux from the cavity impinging on the window, is the increased distance between the waveguide and the last cavity iris, which is now 9 cm as opposed to 1 cm in the old design. This increase resulted from changing the waveguide stub length beyond the beamline from 1/2 to 1/4 wavelength to improve field symmetry across the beam aperture. The cavity iris which was in direct view of the window in the old design is now completely out of sight [3,4]. The cavity was run for several shifts, the longest being 8 hours, with heavy field emission producing 0.5 to 1.0 R/hr without arcing.

Table 2: Waveguide Diode Positions and Static Temperatures

Diode Number	Position (cm)	Measured Temp (K)	Predicted Temp (K)
1	-1.9	7.97	N/P
2	3.3	11.21	21.0
3	5.8	55.46	49.3
4	9.3	72.22	65.5
5	10.8	87.96	78.8
6	12.2	103.04	91.2
7	13.6	118.81	103.0
8	15.1	132.78	115.7
9	16.5	146.97	126.7
10	18.0	160.40	137.4

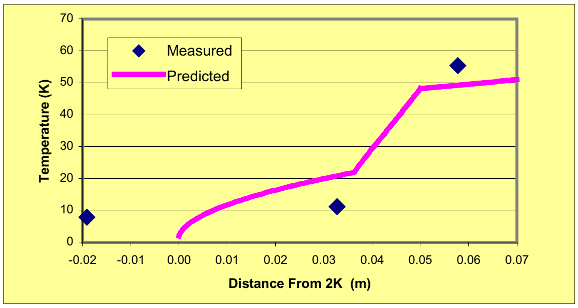

Figure 3: Cold Side Static Temperature Profile

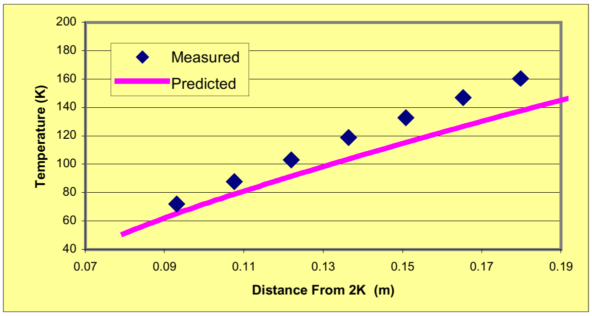

Figure 4: Warm Side Static Temperature Profile

4.3 Waveguide Multipacting

No multipacting was detected during any of the tests performed. This is consistent with past experience with this window configuration. It has been operated both in standing wave resonators and in a resonant ring with traveling wave power up to 50 kW without multipacting.

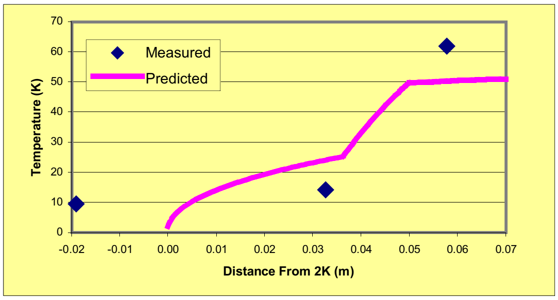

Figure 5: Cold Side Temperature Profile 1,680 W Reflected

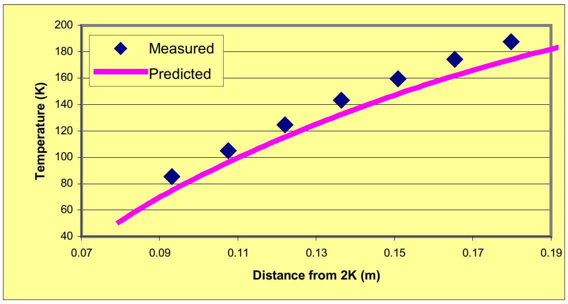

Figure 6: Warm Side Temperature Profile 1,680 W Reflected

5 STATUS

Testing of the RF input waveguide was successful up to input powers of 1,680 W reflected. Production waveguides are on order and the first shipment of 17 waveguides is due to Jefferson Lab in mid July 2001. Of particular concern is the uniformity and thickness of the copper plating. It is advantageous cryogenically to reduce the thickness of the copper plating to minimize static heat loss, but thin, uneven patches of copper could cause excessive resistance, hot spots and even thermal run away in the waveguide. Methods are being devised to measure the thickness of the copper plating.

6 REFERENCES

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