DARESBURY INTERNATIONAL CRYOMODULE COUPLER PROGRESS

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Abstract

The Daresbury International Cryomodule Collaboration requires RF couplers capable of providing 30 kW CW RF power at 1.3 GHz that will fit into the footprint of the existing ALICE cryomodule, whilst maximising the capability for adjusting the coupling. For this a modified Cornell Injector coupler has been used. Modifications to the cold section were carried out. These couplers have now been assembled into a test cavity and conditioned to 30 kW pulsed, 10 kW CW. This paper describes the modifications required to fit inside the cryomodule and details of the tests that were carried out.

INTRODUCTION

The Daresbury International Cryomodule Collaboration [1] is developing a 100 mA CW class cryomodule based on a hybrid design of the Stanford/Rossendorf Cryomodule and the Cornell Injector Cryomodule. Due to the enhanced beam current, the cryomodule is required to manage the additional HOM power produced and increased input power demand. This report focuses on the status of the high power RF couplers, in particular the preparation and conditioning.

Due to power demands in excess of 30 kW CW and the requirement for adjustable coupling, it was decided to use the Cornell Injector Cryomodule Coupler [2]. To test the project with beam, this new Cryomodule will replace the existing linac in the ALICE accelerator [3], therefore to ease the exchange the same module size has been adopted. The footprint for the module was too narrow to fit the standard Cornell injector coupler into the cryomodule, therefore it was required to reduce the length of the cold coupler section. To allow this it was required to remove one of the 5K heat intercepts as well as 3 convolutions of the bellows. Since the required RF power is of the order of 30 kW, modelling was performed which suggested that this modified design was sufficient to maintain a low heat load to the 2K system.

Table 1: Input Coupler Requirements

Operating Parameters	Values	Units
Frequency	1.3	GHz
Qe Range	10^6 to 10^8	
RF Power Requirements	30	kW
Number of Couplers	2	
Phase control	0.3	°

Conditioning of the RF couplers is essential prior to installation into an RF cavity, to ensure that there are no manufacturing defects preventing high powers operation or inclusions in the metal surface that may be difficult or impossible to condition away. Thus conditioning of the RF couplers on a purpose built test stand is required to mitigate risk of installing a failed coupler onto a cavity string, since the assembly process of the cavity string is complex and the reworking cost very high. For this reason it was required to set up a test stand in order to evaluate the couplers at the desired operating powers. In their final configuration the couplers will be acting as a thermal intercept from the hostile 2K environment to room temperature as well as a pressure transition from UHV, to atmospheric pressure, therefore all these conditions need to be assessed. A decision was taken to evaluate both couplers together, thus the coupler test stand was designed, so that the couplers are critically coupled to the cavities thereby allowing the cavities to be placed back-to-back and for the RF power to be transferred from one coupler through the other, and then dumped into a suitable RF load.

Whilst it was not financially feasible to mimic the thermal transition from 2K to 300K, an appropriate test chamber was set-up to allow the conditioning of the couplers connected in series with evacuated sections, similar to the final operating regime. Figure 1 shows a schematic of the test stand configuration.

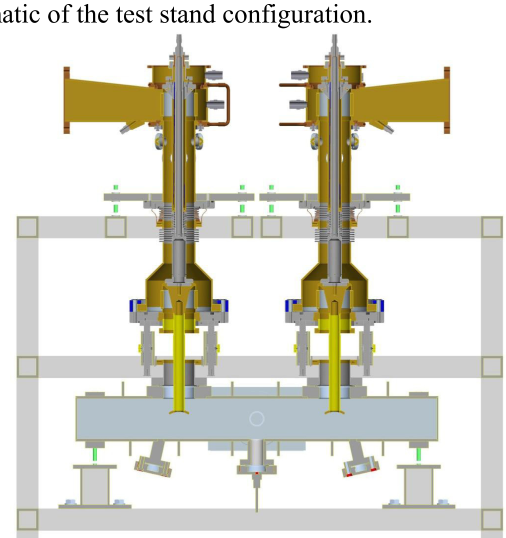

Figure 1: Coupler Test Stand

UHV PREPARATION

Prior to installation on the test stand the couplers needed to be cleaned to UHV standards, in order to maximise the vacuum conditions during the conditioning process. Each of the components were cleaned with alcohol then rinsed with ultra pure water under cleanroom conditions. The couplers were then mounted onto a test stand where they were baked to 120°C for 48 hours to ensure all water vapour was removed. During this baking operation temperatures were monitored and the gas species generated were analysed via a RGA. Ion pumps were used during bake-out, to ensure a maximum pressure of 10^{-9} mBar was never exceeded. To verify that the cleaning process had been successful, particle counting of the coupler components was carried out to ensure lowest possible levels of particulate levels was observed, thus reducing the likelihood of breakdown and damage to the inner coupler surfaces.

The couplers were then assembled in ISO 4 conditions onto the coupler test stand, so as to ensure that the contamination effects prior to the high power RF conditioning was minimised, as this would extend the conditioning time or in the worst case result in coupler failure.

COUPLER TEST LAYOUT

The couplers were driven from a high power RF amplifier system, which consists of a CPI IOT (CHK51320W) that is capable of delivering 30 kW CW power at 1.3 GHz, a 200 W solid state amplifier (Microwave Amps Ltd, model AM83), and an in house built 30 kV, 1 A, high voltage capacitor charger power supply. Due to the limitations of the high voltage power supply the power from the IOT was limited to 10 kW CW and 30 kW pulsed. The output transition and waveguide distribution system to the couplers are all in WR650 and the RF power transferred to the coupler via a door knob transition. For protection of the IOT a circulator was situated after the IOT, with directional coupler monitoring positioned before and after, to provide RF power measurements for the IOT and for the couplers. Additionally, a further set of directional couplers were located after the couplers, so as to monitor for any RF power being lost in transmission. Finally the RF power is absorbed in a water-cooled load. The layout of the test stand is visualised in Figure 2 below.

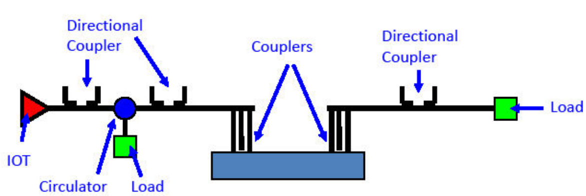

Figure 2: Schematic of the test stand.

At cryogenic temperatures the thermal and electrical conductivity of the ceramic improves reducing the losses in the ceramic and also reducing the temperature gradient across the ceramic, therefore reducing the thermal stress. This also provides additional heat transfer for the inner conductor, therefore allowing high average RF powers to be evaluated.

The test stand was designed without cryogenic cooling, therefore reducing the highest average power that was considered safe to operate. Due to the fact that the high power amplifier system was only capable of providing 10 kW CW and since the purpose of the conditioning was to ensure the inner surface could withstand the high voltages, it was not deemed necessary to condition up to the final 30 kW average powers anticipated.

MONITORING AND DIAGNOSTICS

During the operation of conditioning the couplers, it was essential to monitor the performance of the couplers. Thermocouples were located along the length of the couplers and two infrared (IR) sensors were positioned to provide temperature monitoring for both ceramic windows. Additionally photomultiplier tubes were installed to provide protection from arcing. A full list of monitoring and control systems is provided in Table 2, along with the numbers used and the output type. Monitoring of the vacuum levels within the couplers and the section of waveguide between the couplers is provided by three ion pump gauges and 3 inverted magnetron cold cathode ionization gauges (IMG).

Table 2: Monitoring and diagnostics devices

Device	Monitor	No.	Output
IR Sensor: – Raytek, Thermalert MID infrared pyrometer	Ceramic window temperature	2	0-10 V, or 4-20 mA
Photo Multiplier Tube:- Raytek, Thermalert MID infrared pyrometer	Arcing voltage breakdown	3	0-10 V analogue signal
Temperature sensors :– T & K Type Thermo-couples	Temperature	20	Read-back to Lakeshore device
RF Detectors: – Mini-circuits	RF FWD and REF power	6	0-10 V analogue signal

The data from all of these instruments and the RF power signals from the directional couplers were monitored by a control PC using a LabVIEW system and a National Instruments [3] interface control board. The PC control system was designed to monitor and store all the conditioning data as well as provide interlock protection to both the IOT and couplers.

TEST RESULTS

CW and pulsed conditioning of the couplers has been undertaken and to date power levels of 5 kW have been achieved under CW conditions and 10 kW under pulsed conditions. Further conditioning work is on-going at present.

Initially CW conditioning tests were performed up to 3 kW, raising the power level in steps of 1 kW. The vacuum levels as measured on the ion pumps remained constant throughout the tests at 1 x 10^{-8} mBar or better. For all CW conditioning runs additional air cooling was provided to the ceramic window. The ceramic temperatures as monitored by the IR sensors were seen to mimic one another, and rose steadily from 6°C to a peak of around 16°C, for 2 kW. For 3 kW of RF power the temperature rose to 17°C, however a slight increase in the rate of rise was seen for this level, so the RF power was removed. Similar temperature results were seen with the thermocouples. These tests were repeated, this time allowing the monitored temperatures to stabilise at the 3 kW level, and showed a 10°C rise in the ceramic window temperatures and a maximum 13°C rise on the thermocouples. Once again there were no vacuum events seen throughout the conditioning run.

On the third conditioning run the final power level was increased to 5 kW. The vacuum levels once again remained constant and the ceramic window temperatures reached 30°C, although they had not reached equilibrium. Figures 3 and 4 show the RF power levels and thermocouple temperatures during this run.

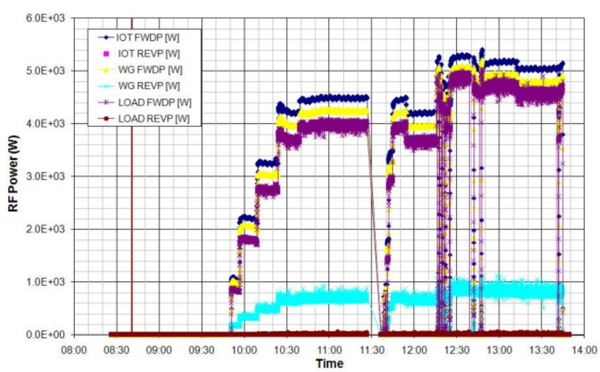

Figure 3: RF Power Levels for CW Conditioning Run.

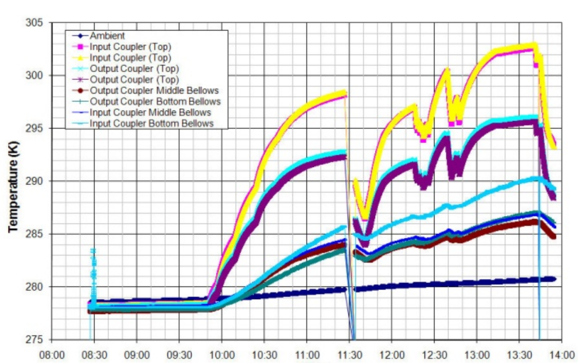

Figure 4: Thermocouple Temperatures for CW Conditioning Run.

The tests were then repeated for pulsed conditions (1 ms at 10 Hz). The RF power levels were raised in 1 kW steps to 10 kW (Figure 5). The equivalent thermocouple temperatures are shown in Figure 6.

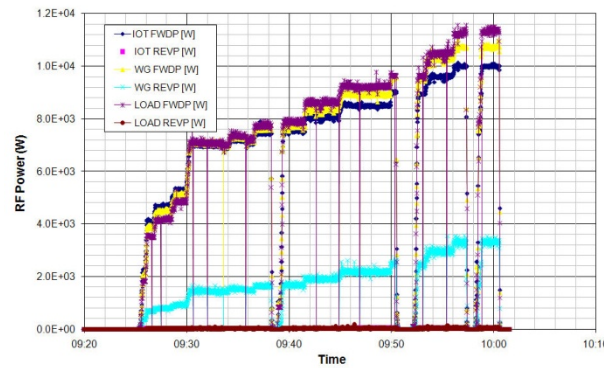

Figure 5: RF Power Levels for Pulsed Conditioning Run.

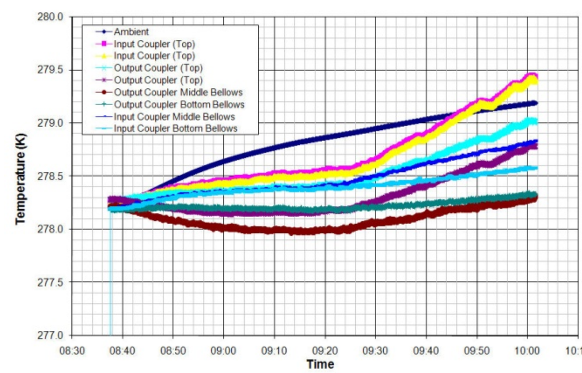

Figure 6: Thermocouple Temperatures for Pulsed Conditioning Run.

SUMMARY

Conditioning of the couplers has now been achieved to 5 kW CW and 10 kW pulsed with no real vacuum activity during the process. Further conditioning is being progressed at the present with an aim of reaching the required final peak RF power of 30 kW in readiness for assembling the couplers onto the cavity string.

REFERENCES

[1] P.A. McIntosh et al, "Assembly Preperations for the International ERL Cryomodule at Daresbury Laboratory", SRF'09, Berlin, September 2009, p.864.
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[3] S.L. Smith et al, "Progress on the Commissioning of ALICE, the Energy Recovery Linac Based Light Source at Daresbury Laboratory", PAC'09, Vancouver, May 2009, TU5RFP083.
[4] National Instruments; www.ni.com/labview.