HIGH POWER COUPLER TEST FOR TRIUMF E-linac SC CAVITIES

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Abstract

TRIUMF has been funded to build an electron linac with a final energy of 50 MeV and 500 kW beam power using TESLA type 9-cell superconducting cavities operating at 1.3 GHz at 2 K [1]. The e-linac consists of an electron gun, buncher cavity, injector cryomodule (ICM), and two accelerator cryomodules (ACMs). The ICM has one 9-cell cavity whereas each of the ACMs contains two 9-cell cavities. One ICM and one ACM are scheduled to be installed by 2014. Six power couplers, each rated for 60 kW CW, have been procured for three cavities. The ICM will be fed by a 30 kW CW Inductive Output Tube (IOT) and each ACM will be powered by a 290 kW CW klystron. Before installing the power couplers with the cavities, they are to be assembled and conditioned with a high power RF source. A power coupler test station has been built and tests of two power couplers have begun. A 30 kW IOT has been commissioned to full output power and it will be used for the power coupler tests. In this paper, test results of the RF conditioning of the power couplers in pulse and CW mode will be described.

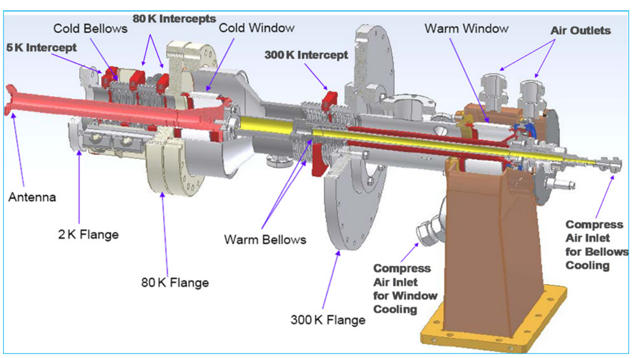

Figure 1: The CPI coupler is based on the Cornell 60 kW TTF-III coupler design.

INTRODUCTION

The power couplers that are being tested are manufactured by CPI, USA and have been adapted from the Cornell coupler shown in figure 1. The couplers, prior to installation with the accelerating cavities, are to be fully RF conditioned. A 30 kW IOT amplifier has been tested to full power and it will be used for RF conditioning of the couplers in both CW and pulse mode. Two couplers are mounted on to a waveguide box which has been designed such that RF power can be transmitted from the input coupler through the waveguide box and out through a second coupler to a 50 Ω waveguide load with minimum standing wave [2]. The coupler station is shown in figure 2. Each coupler has two ceramic windows, one cold and one warm. The cold window is the barrier for the ultra high vacuum pressure inside the SRF cavities which is on the order of 10^{-9} mbar and the warm window is a safeguard in the event of a failure of the cold window. Since the waveguide box and the couplers are at room temperature, the CW power applied to the couplers is kept to a level < 10 kW so as to limit the temperature of the inner conductor to 80 °C maximum. The couplers have Mega Industries WR650 coaxial to waveguide transitions which are at atmospheric pressure.

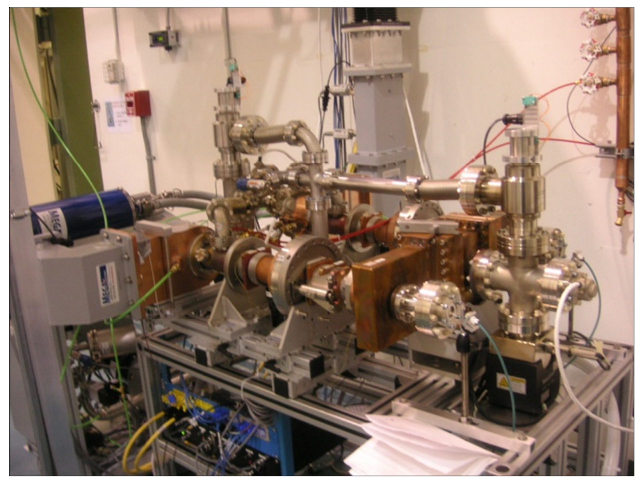

Figure 2: The power coupler test set up.

HIGH POWER TEST OF COUPLERS

The waveguide box was baked and found to be leak tight. The cold windows and the waveguide box were assembled in a clean room environment and leak checked. The warm window and waveguide to coaxial transition were assembled on the coupler test stand and all monitoring and instrumentation were attached.

Signal Level Measurement

The strength of the coupling to the waveguide box can be varied by moving the inner conductors of the couplers. Both couplers are adjusted for best matching (minimum VSWR). Measured values of S11 and S21 are 1.065:1 and 0.166 dB respectively. From the S21 measurement, the power loss in the two couplers and the waveguide box in total will be 39 W for an input power of 1 kW. Hence no cooling is required. However for 10 kW input power, the power loss increases to 390 W which requires cooling if run for a long time.

Interlocks and Monitoring

The vacuum system for the coupler test stand uses two systems; one vacuum common to the cold windows of the couplers and the waveguide box and the second system common to both of the warm windows of the couplers.

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A hardware interlock system was built to protect the power couplers during RF conditioning, figure 3. A sample of the IOT output power is derived from a 60 dB directional coupler and a four way splitter. This signal is brought to the protection electronics ZX47-40LN-S+ logarithmic power detector module using Andrew Heliax cable. The log detector output and a reference level set by a potentiometer drive a comparator to generate a trip. When a trip occurs, the 1.3 GHz drive signal to the linear IOT RF power amplifier is cutoff by a Mini-Circuits ZASWA-2-50DR+GaAs switch with ~65 dB of isolation. This switch has no latching problems and it is designed in fail-safe mode. The response time of the system, a few µs, is fast compared to the RF pulse widths used for conditioning and thus trips on peak rather than on average power. It has been found to be very stable and not to cause false trips when operating just below the trip level.

The fast trip system includes vacuum cold cathode gauges and photomultiplier (PMT) arc detectors. A trip is generated if the pressure in the warm space exceeds $5 \cdot 10^{-6}$ Torr or the pressure in the cold space exceeds $5 \cdot 10^{-7}$ Torr [3]. One Hamamatsu H10722-01 PMT attached to each power coupler is sensitive to light generated by multipacting in the region between the warm and cold RF windows. Ten thermocouples are attached at various points to the exterior of the couplers and the waveguide box. PT100 temperature sensors are attached inside the inner conductor of the couplers near the warm window bellows. Two Raytek MI series IR sensors measure the temperature of the cold window ceramics through viewing windows in the waveguide box. The ion pump current for both cold and warm sections, air cooling of the coupler inner conductors and water cooling of the external parts of the waveguide to coaxial transitions are monitored.

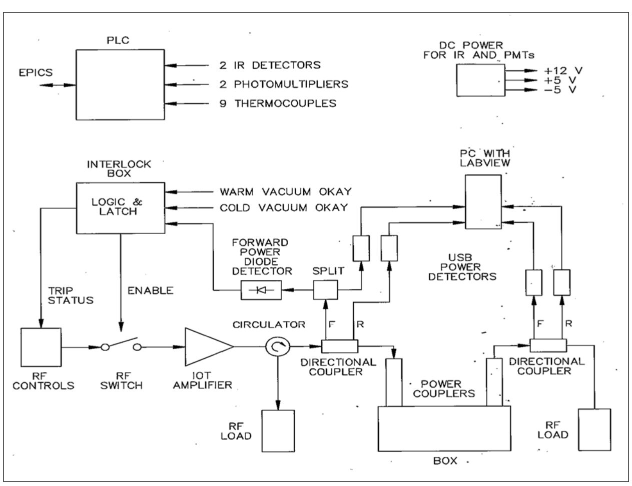

Figure 3: A block diagram of the RF set up.

RF Power Measurements

The couplers will be RF conditioned both in travelling wave mode and standing wave mode. The 30 kW IOT transmitter will be used for these tests. RF power will be initially pulsed with low duty cycle to allow high voltage conditioning of the coupler inner surfaces. Once no evidence of multipacting is observed and low pressure is established, $< 1.0 \cdot 10^{-7}$ Torr, it will be driven in CW mode.

Travelling Wave Test

The RF drive power was pulse modulated, with a 200 ms period and pulse width varying from 100 µs to 10 ms. The duty ratio will eventually be changed to 10%, 20%, 50% and 100% and RF power reduced accordingly to stay within temperature and pressure limits.

Table 1: Travelling Wave Test in Pulse Mode

Width (ms)	Period (ms)	Duty Ratio (%)	Peak Power (kW)	Cold Vac (Torr)	Warm Vac (Torr)
0.1	200	0.05	7.50	1.19E-08	1.00E-07
0.2	200	0.10	10.00	1.70E-08	2.30E-07
1	200	0.50	9.00	2.30E-08	3.30E-07
2	200	1.00	7.60	2.50E-08	5.00E-08
10	200	5.00	7.20	1.48E-08	2.60E-08

Table 1 shows the vacuum pressure in the cold and warm sections for varying duty ratio and peak power ranging from 7 to 10 kW. There was no noticeable increase in temperature in the couplers or in the waveguide box. The results of a CW RF test are shown in figure 4 where the RF power was increased slowly from 0 to 9 kW over 2 hours. The pressure in the cold section remained unchanged whereas the pressure in the warm section deteriorated as the power was increased. The temperature increased from 22.6 to 29 °C for TCM-1 TC7 (the outer conductor of the coupler) and from 23.6 to 33.8 °C in TCM-2 TC3 (the inner conductor of the coupler). At 10 kW CW, the vacuum tripped and since then it has been difficult to condition at more than 1 kW CW. Both low level (<1 kW) pulse and CW RF conditioning were undertaken and severe multipacting was observed in the input coupler.

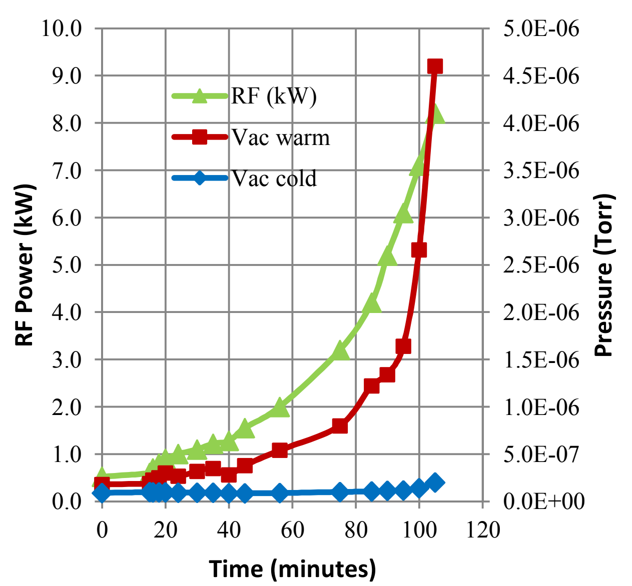

Figure 4: A travelling wave test in CW mode

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Standing Wave Test

Standing wave mode will be used to establish higher peak power in the couplers using a movable waveguide short instead of the 50 Ω waveguide termination. The waveguide box is made in-house, figure 5. A variation of a half guide-wave length can be achieved by moving the shorting plunger by 180 mm. High standing wave was established near the vacuum side of the input coupler's warm window by observing the vacuum bursts as the shorting plunger was moved.

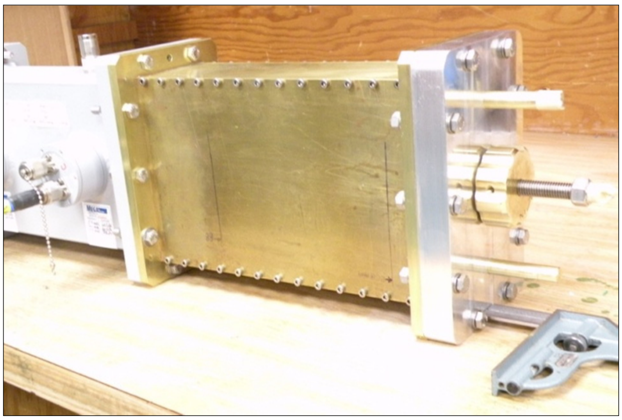

Figure 5: Movable WR650 waveguide short

A 500 W solid state amplifier was used in CW and pulse mode under standing wave conditions to locate the region of multipacting. Figure 6 shows the vacuum bursts as the waveguide shorting plate is adjusted to get high standing wave in the warm window region. The RF drive and the waveguide short were interchanged and the same cw and pulse tests were carried out. It was found out that coupler 2 vacuum settled to a steady, low value as shown in figure 7. It was concluded that the coupler 1 warm window shows signs of multipacting. Further investigation is to be carried out with higher power and higher duty ratio.

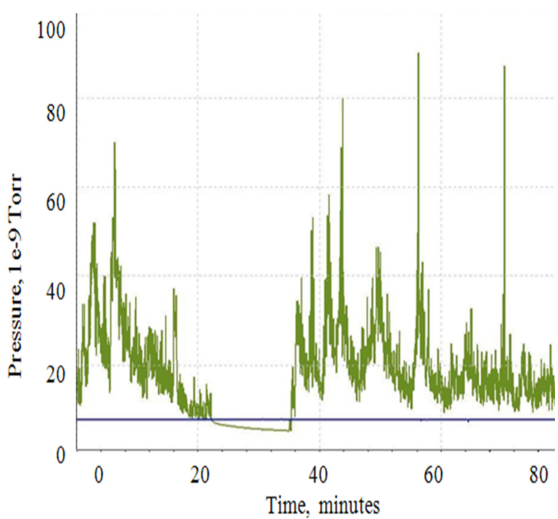

Figure 6: RF power applied to coupler 2 with the waveguide short at coupler 1.

CONCLUSION

The CW and pulse coupler tests were successful to a power level of 8 kW. However, after a vacuum trip at the warm window of the input coupler (coupler 1) at 8 kW, multipacting was observed at the 1 kW CW level. Afterwards, a solid state amplifier with 500 W output and a variable waveguide short were used to carry out coupler conditioning in standing wave mode in order to find the reason and location of the multipacting inside the coupler. The IOT transmitter will be used (it's going through some high voltage issues at present) again for conditioning after the low power test is concluded. It was observed that the warm window reacts to pulse conditioning much more than the cold window, hence another turbo pump and ion gauge will be installed so that the pressure at both of the warm windows can be observed simultaneously. The IR sensors which look at the cold windows are very helpful but their alignment is sensitive since their 20° field of view is partially obstructed and covers a small fraction of the ceramic. With improved cooling of the inner conductor of the coupler, possibly at liquid nitrogen temperature, it is envisaged to reach the final target of RF conditioned to 30 kW CW and 60 kW pulse. The RF conditioning of the coupler test is vital for the e-linac project since two such couplers are required to be installed with the ICM by mid 2013.

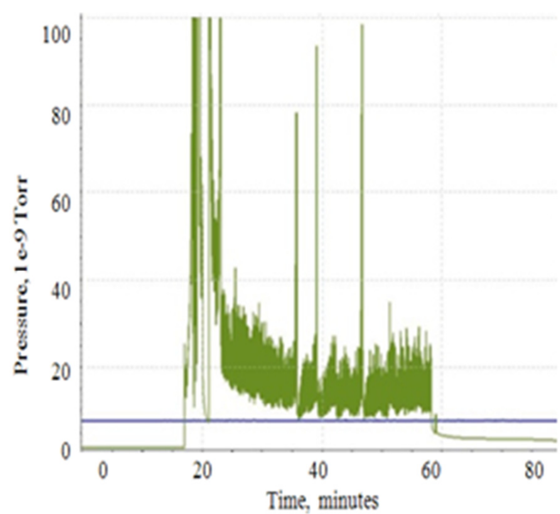

Figure 7: RF power applied to coupler 1 with the waveguide short at coupler 2.

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