HIGH POWER COUPLER TEST FOR ARIEL SC CAVITIES

Y.Y. Ma#, V. Zvyagintsev, R.E. Laxdal, B.S. Waraich, D. Lang, P. Harmer
TRIUMF, 4004 Wesbrook Mall, Vancouver, BC, Canada, V6T 2A3

Abstract

TRIUMF ARIEL [1] (The Advanced Rare Isotope Laboratory) project employs five 1.3 GHz 9-cell superconducting elliptical cavities [2] for acceleration of 10 mA electron beam up to energy of 50 MeV. 100 kW CW (continuing wave) RF power will be delivered into each cavity by means of pair of Power Couplers: 50 kW per each coupler. Before installing the power couplers with the cavities, they have to be assembled on Power Coupler Test Stand (PCTS) and conditioned with a 30 kW IOT. Six couplers have been conditioned at room temperature and four of them have been installed to the cavities and tested during beam commissioning. Test results of the power couplers will be described and discussed in this paper.

INTRODUCTION

E-Linac for ARIEL project [1] consists of three cryomodules with 5 superconducting 1.3 GHz 9-cell elliptical cavities [3]. 100 kW CW RF power will be delivered into each cavity by means of pair of Power Couplers: 50 kW per each coupler (Fig. 1).

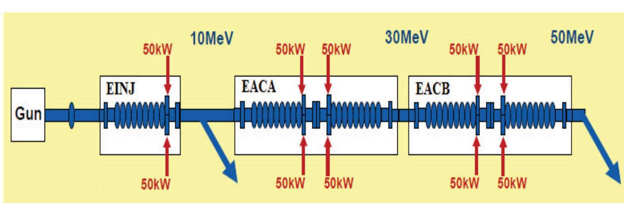

Figure 1: Schematic of the E-Linac.

We employ CPI [4] Power Coupler VWP 3032 [5] capable to deliver up to 75 kW CW RF power at 1.3 GHz to superconducting cavity operating at 2K temperature of liquid He. The coupler design is presented on Fig. 2, it consists of 2 assembly units: ‘cold’ assembly which has to be mounted to the superconducting cavity RF port and ‘warm’ assembly which to be connected to waveguide and operates like a warm-cold transition.

‘Cold’ assembly is a coaxial line loaded with antenna and terminated on other end by ‘cold’ window, which separates ‘cold’ cavity and ‘warm’ assembly vacuum volumes. ‘Warm’ assembly consists of a coaxial line between ‘cold’ and ‘warm’ windows and a coaxial-waveguide transformer at the ‘warm’ window side. Outer conductor of the ‘cold’ assembly, ‘warm’ assembly inner conductor and ‘warm’ assembly outer conductor have bellows to provide coupling antenna adjustment and reduce thermal flow to the cavity.

#mayanyun@triumf.ca

PCTS was developed at TRIUMF [6] for power couplers conditioning before installation to the cavity. The PCTS is designed for conditioning of two RF power couplers at the time which are installed in series with an RF waveguide box. The coupler which is connected to IOT through waveguide is an ‘input coupler’ and the coupler which is connected with RF dummy load or variable movable short plate is an ‘output coupler’. We are doing RF conditioning in travelling wave mode with water cooled RF dummy load and in standing wave mode with variable movable short plate with air cooling.

There are three valves for vacuum insulation. The turbo pump, three ion pumps and three ion gauges are installed to provide and monitor the vacuum in the PCTS. The warm assemblies of ‘input coupler’ and ‘out coupler’ have separated vacuum spaces. The ‘cold’ sections and waveguide box have a common vacuum.

One Hamamatsu H10722-01 PMT attached to each power coupler, it is sensitive to photons generated by multipacting in the region between the warm and cold RF windows. Ten thermocouples are attached in various points to the exterior of the couplers and the waveguide box. Two PT100 temperature sensors are built (by CPI) inside the inner conductor of the couplers near the inner conductor bellows. Two Raytek MI series IR sensors measure the temperature of the ‘cold’ window ceramics through view ports in the waveguide box.

The forward and reverse power measurement is provided with power meter connected to directional couplers. In order to protect couplers during RF conditioning, the PMT signals, ion gauge signal are using to fast trip of RF drive with Mini-Circuits ZASWA-2-50DR+GaAs RF switch.

As PCTS works under room temperature we use water loops which installed in the middle of bellows and external fans which set beside the bellows for cooling as shown in Fig.3. In cryomodule, the ‘cold’ bellows are equipped with 4 K Siphon loop at antenna side, an 80K heat link in the middle of cold bellows and an 80K Nitrogen cryogenic cooling loop at the cold window side. In cryomodule, the ‘warm’ bellows are equipped with a thermal link connected to the 80K thermal shield.

During 2013-2014 six RF power couplers have been conditioned at TRIUMF with PCTS. Four conditioned couplers have been installed to EINJ and EACA; EACA presently equipped with one single 9-cell cavity and a ‘dummy’ cavity. During the 1st stage of ARIEL E-Linac commissioning EINJ and EACA cryomodules in the present configuration produced a final energy of 23MeV [7]. Another two pre-conditioned power couplers will be installed to VECC Injector cryomodule [8].

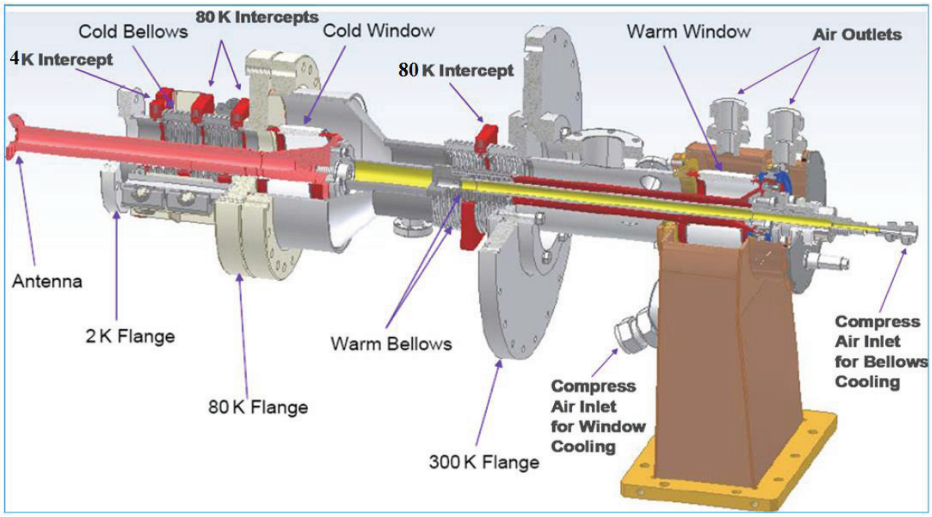

Figure 2: The CPI VWP 3032 Coupler.

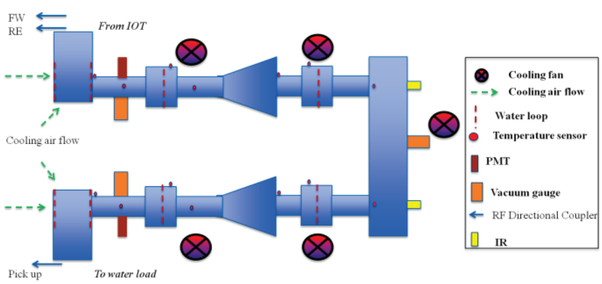

Figure 3: PCTS simplified schematic.

PREPARATION

The RF power couplers are operating in superconducting cavities in ultra high vacuum environment and to avoid contamination with dust, all the inspection, assembling and dissembling operations to be done in clean room (Fig. 4).

Before assemble all parts were inspected in class 100 clean room. Then all parts are sealed with bags with filtered Nitrogen gas and stored in class 100 clean room in order to avoid coupler parts exposed long time to atmosphere and contamination with dust.

All the 'cold' assembly operations were done in class 10 clean room as the 'cold' assembly will be installed to cavity directly after conditioning. Before the 'cold' section parts were mounted to PCTS, the 'cold' section parts were cleaned and checked on particles with filtered Nitrogen gas flow and particle counter (Met One, Laser particle counter 0.3uM size, 0.1CFM flow). The gas flow was stopped when the particle counter shows acceptable particle number. Vacuum leak check has been done at few mTorr back ground vacuum. The pumping rate is controlled and to be less than 1Torr per second to avoid the dust migration along to the 'cold' section. After leak check the 'cold' section should be pumping for one day to a high vacuum. The 'warm' sections have been installed and leak checked in class 1000 clean room.

Figure 4: 'cold' section assemble in class 10 clean room.

BAKING

The baking process is very important as it can significantly improve the back ground vacuum and reduce the RF conditioning time. A special procedure has been developed in TRIUMF.

As the Indium gaskets for rectangular waveguide RF box in 'cold' section are very sensitive for temperature and could get vacuum leak at high temperature, we are baking the 'warm' assembly only.

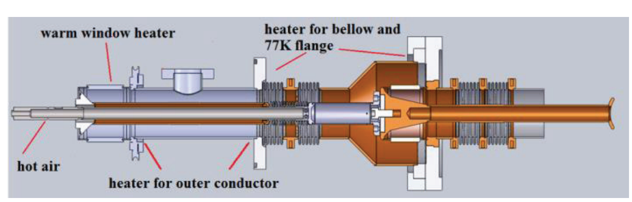

Figure 5: The heaters installation for baking.

The warm windows and outer conductors have been baked with heaters and the inner conductors are baked with hot filtered air (Fig. 5). The baking temperature is 100 C° and the process takes 7 days. In order to protect the ceramic windows from crack the temperature ramping rate to be less than 10C/hour for heating up and cooling

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down. All the heaters are controlled and monitored with programmable heater controllers. The outer conductor bellows of 'cold' section to be covered for protection with Aluminium foil during baking and heated to about 60 C from thermal conducting.

During baking the 'warm' window is covered by means of shroud with filtered N2 gas to avoid oxidation and damage of coupler parts (ceramic window, RF contact surfaces) as shown in Fig. 6. In the shroud the 1st layer is Aluminium foil to avoid the heater direct contact with ceramic and all copper RF surfaces. The 2nd layer is heater with temperature sensor. The 3rd layer is an Aluminium foil covering the heater. All the layers are covered with shrouds filtered Nitrogen gas flow to protect 'warm' windows from oxidation during baking. The shrouds are very efficient for oxidation protection as shown in Fig. 7.

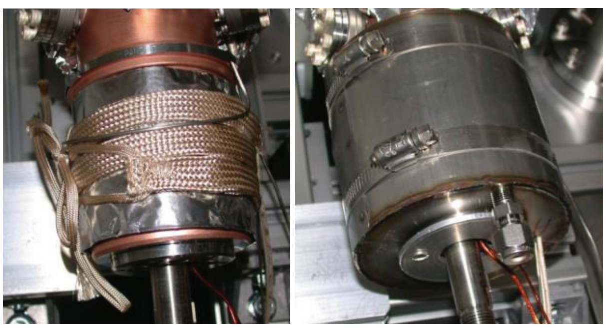

Figure 6: warm window protecting shrouds.

(a) (b)

Figure 7: The surface near warm window after baking: (a) without Nitrogen protection; (b) with Nitrogen protection.

The warm window temperature is controlled by OMEGA 7600 programmable temperature controller during the baking in closed loop with temperature sensor. During the baking we keep the ion pumps running and monitor the vacuum (Fig. 8).

The inner and outer conductor temperatures are regulated with OMEGALUX CBC991-550 programmable temperature controllers.

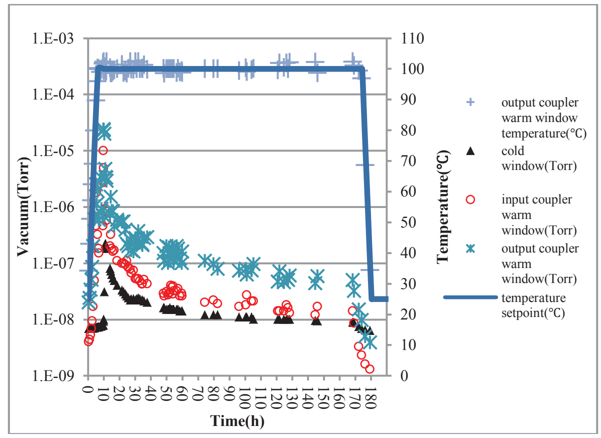

Figure 8: The warm window temperature and coupler vacuum.

PREPARATION FOR RF CONDITIONING

After baking the waveguide transformers were installed to the couplers and RF matching was adjusted by means of coupler antennas for reflection S11<-26 dB (which corresponds VSWR is about 1.1).

During the conditioning we use filtered air flow for 'warm' window and inner conductor cooling with flow rate about 110L/min. The waveguide transformer and the bellows are cooled by means of water cooling loop. For cooling of outer conductor and waveguide box we are using external fans.

In order to monitor the outer conductor temperature some temperature sensors are installed on the 300K flange, 77K flange, waveguide box and waveguide transformer as shown in Fig. 3. One PMT is installed on each warm section for monitoring of Multipacting. Two bi-directional couplers has been used for forward and reflection power monitoring. One is installed between IOT and PCTS and the other is installed between PCTS and RF load. PMT, vacuum and forward/reflection power signals are integrated into a fast trip box for coupler protection purpose.

RF CONDITIONING

There are two regimes of RF conditioning: pulsing in SW (standing wave) regime and CW (continuing wave) in TW (travelling wave) regime.

Pulse RF conditioning has been Standing Wave (SW) mode RF conditioning mode is corresponding to full reflection from variable reactance of shorted waveguide connected to 'output' coupler. The reactance cooling is limited, it is just external fan, and we are using this mode in pulse regime. Variable Short Plate was adjusted for 3 positions based HFSS simulation results to overlap phase of SW from 0 to 90deg: 0, 45 and 90 deg. Such a way we are moving SW along the coupler structure. Because of full reflection the SW in provides field amplitude in the coupler parts corresponding to 4 times more power than to TW regime. We have limit of forward RF power in pulse regime for IOT of 9 kW due to operational restrictions from IOT Power Supply; it is equivalent of 36 kW of TW. Power Supply vibration in pulse mode made impossible to get higher RF power for this test; 0.5ms pulse at period of 100 ms. During RF conditioning we are slowly ramping RF forward power watching vacuum and Multipacting sensors; it takes about 6 hours for the range of forward power 0.5~9 kW. For the three pairs of couplers, pulse test showed absence of Multipacting problems in the range of forward power up to 9kW in SW mode after baking.

CW RF conditioning regime has been done in TW mode with water cooled RF load for 3 pairs of couplers with maximum forward power 12.5kW, 17.5kW and 19.5kW. Ramping RF power slowly and monitoring the vacuum, temperature and PMT signals at each power level and hold few hours at the highest power level (Fig. 9).

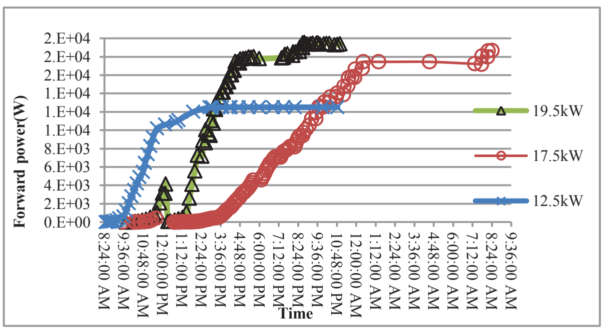

Figure 9: CW conditioning results.

The hottest part during conditioning was the inner conductor (Fig. 10). For the 1st pair of couplers, a combined air flow of both centre conductors and windows were about 180 L/min. Under this condition the air flow rate for each inner conductor was about 70 L/min. The inner conductor temperature raise was about 12 Celsius at 12.5kW forward power. For 2nd and 3 rd pairs of couplers, the air flow rate for each inner conductor was bout 110 L/min with about 10 Celsius temperature increase at 19.5kW forward power.

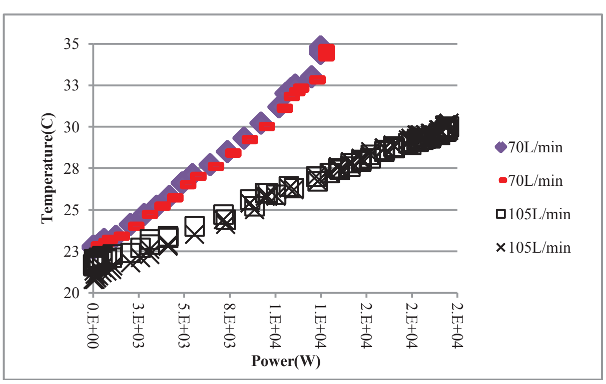

Figure 10: Inner conductor temperature during CW conditioning.

The 1st and 2nd pair of couplers have been installed into EINJ and EACA. The 'cold' assemblies were installed on the cavities in class 10 clean room. The 'warm' assemblies were installed in the vault of ARIEL E-Linac.. During the beam commissioning, there few Multipacting events on both warm assemble side. That might be caused by the external dust during assembling operations, especially the 'warm' assemblies which have been installed in dirty area. The Multipacting has been conditioned through pulse regime under cryogenic temperature with few MHz higher than cavity π mode. Finally 10kW CW forward RF power was achieved in each coupler in SW (full reflection) mode during the EINJ and EACA commissioning.

CONCLUSION

Six power RF couplers have been conditioned at PCTS at room temperature. Four of them have been installed on the cavities in ARIEL EINJ and EACA cryomodules and used for beam commissioning at TRIUMF. 10kw CW power in SW mode was achieved in each coupler. Multipacting conditioning was done in situ in pulse regime. The other two couplers are ready for installation in VECC cryomodule at TRIUMF.

REFERENCES

[1] S. Koscielniak, "An electron linac photo-fission driver for the rare isotope program at TRIUMF," SRF09, Berlin, Germany, September 2009.

[2] V. Zvyagintsev et al., "NINE-CELL ELLIPTICAL CAVITY DEVELOPMENT AT TRIUMF," MOPO020, Proceedings of SRF2011, Chicago, IL USA(2011).

[3] R.E Laxdal et al., "STATUS OF SUPERCONDUCTING ELECTRON LINAC DRIVER FOR RARE ION BEAM PRODUCTION AT TRIUMF," MOIOC01, Proceedings of LINAC2014, Geneva, Switzerland(2014).

[4] http://www.cpii.com/

[5] http://www.cpii.com/docs/datasheets/132/VWP3032.pdf

[6] A.K. Mitra et al., "HIGH POWER COUPLER TEST FOR TRIUMF E-linac SC CAVITIES," MOPB033, Proceedings of LINAC2012, Tel-Aviv, Israel (2012).

[7] M.Marchetto et al., "COMMISSIONING AND OPERATION OF THE ARIEL ELECTRON LINAC AT TRIUMF," WEYC3, Proceedings of IPAC2015, Richmond, VA, USA(2015).

[8] R.E. Laxdal et al., "THE INJECTOR CRYOMODULE FOR THE ARIEL E-LINAC AT TRIUMF," MOPB091, Proceedings of LINAC2012, Tel-Aviv, Israel (2012).

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