ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF004

THE SACLAY TEST STAND FOR CONDITIONING THE ESS RFQ POWER COUPLERS AT HIGH RF POWER

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Abstract

The RF power coupler system for the RFQ of the ESS LINAC will feed 1.6 MW peak power through two coaxial loop couplers for a 352.21 MHz operation at the expected duty cycle. A specific test stand has been designed to condition the power couplers, and test the different auxiliary components in the nominal conditions of the RFQ. The power couplers were successfully assembled, installed and instrumented on the test cavity. This paper presents the general layout of the test stand, the installation and preparation of the power couplers for their conditioning at high RF power up to the ESS nominal conditions.

INTRODUCTION

Involved in the ESS Project, CEA/DRF/IRFU is in charge of the Radio-Frequency Quadrupole (RFQ) [1] design, manufacturing, conditioning and installation at ESS (Lund) [2]. It is also in charge of the RFQ subcomponents, such as the two power couplers, that will feed the RFQ with a maximum of 1.6 MW peak power. Power couplers were successfully manufactured, assembled and installed on a dedicated test stand [3]. This last aims to submit the power couplers to ramped RF power runs up to 1 MW at 14 Hz during 3.6 ms, until the requested pressure is reached into the system. This imposes to overpass several outgassing barriers due to multipacting occurring at different levels of power.

TEST STAND

The following figure presents the diagram of the RF power and distribution, and the test stand.

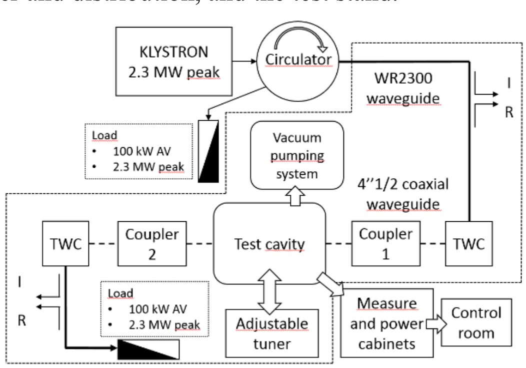

Figure 1: RF power and distribution, test stand.

A 2.3 MW peak power klystron, protected by a circulator, produces the necessary RF power. Any reflected power is directed into a load designed to withstand 100 kW of averaged power or 2.3 MW peak power. RF signal is carried out through WR2300 waveguides into the test stand of the high power test. TWC (Transition Waveguide-Coaxial) are installed at the inlet and outlet RF power of the test cavity. Bidirectional couplers are positioned before and after the TWC on WR2300 waveguide to measure the FP (Forward Power) and RP (Reflected Power) by the whole test stand. Additionally, electron probes are used to measure the RF power through the couplers and the voltage inside the test cavity. The test cavity, made mostly of OFE copper, as well as the couplers, is a resonator that can be adjusted to the same resonance frequency as the RFQ with the adjustable tuner. The different critical auxiliary systems of the RFQ are gathered and tested on the cavity (couplers, adjustable tuner,) in the nominal conditions of operation. The following figure presents the diagram of the test cavity.

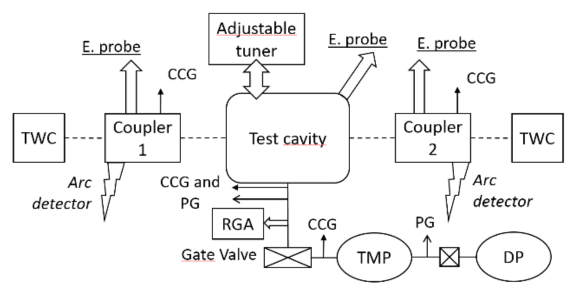

Figure 2: High power test cavity.

POWER COUPLERS

Two coaxial looped power couplers are necessary to critically couple the input RF signal to the resonant field of the test cavity (and finally the RFQ) with 1.6 MW maximum peak power (225 kW beam power and a maximum of 1375 kW RFQ power dissipation). The couplers are located at midpoint (z=2.425 m) of the RFQ. The coupler can be rotated along its axis in order to couple the power fed into the RFQ. The length of the loop is set to 16 mm, its external diameter is Ø 15.2 mm with a 14.4 mm bending radius. As the power dissipated in each coupler at 800 kW coupled power [4], reaches roughly 1.7 kW between the loop, the internal and external conductors, and the ceramic window, two cooling circuits were implemented near the highest power dissipation area. First, a concentric cooling circuit travels back and forth through the loop, using a 3.5 l/min ($5.9\text{x}10^{-5}$ $m^3.s^{-1}$) volumetric flow of water. The external tube of the loop is obtained by brazing multiple copper parts. The internal tube is a bent stainless steel tube, positioned inside the external tube, prior to its brazing, as presented on Figure 3.

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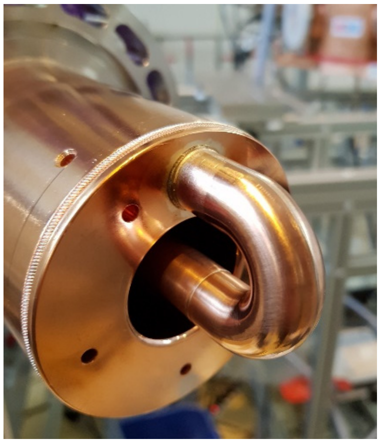

Figure 3: Cooling loop on the coupler body.

The second cooling circuit is implemented on the external diameter of the ceramic window, around a thin copper tube. Up to 5 l/min (8.33x10^{-5} m^{3}.s^{-1}) volumetric flow of water dissipate the approximate 420 W dissipated around the window. This last is made of 97,6% pure alumina (AL300), 6 mm thick for 4½" coaxial line. On the vacuum side of the window, a 10 nm thick coating of titanium nitride (TiN) is deposited, in order to moderate the SEY (Secondary Electron Yield) of the alumina. As the AL300 presents a dielectric constant (ε) of 9.5 (at 25°C) and a dissipation factor (tanδ) of 3.0x10^{-4} (at 25°C), it was estimated that 58 W are lost in the window for an input power of 800 kW. In order to monitor the temperature variation during the conditioning, several PT100 temperature probes, are positioned on both couplers (Figure 4).

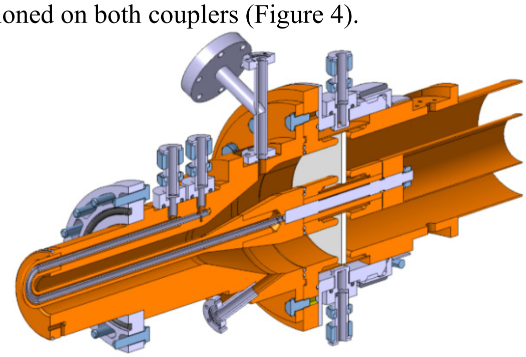

Figure 4: Section of a high power coupler.

The mechanical interface are a non-rotating DN100 flange on the RFQ (and test cavity) and an SMS 4½" standard coaxial connector. The coupler can be disassembled in two elementary components: the cooling loop and its body, and the ceramic window. The interface between the two components ensures the electric continuity of both inner and outer conductors, the vacuum tightness and the mechanical stability. Both sub-assemblies weight more than 20 kg each, being too heavy and fragile, to be handled by operators otherwise than using specific tools for every steps of the assembly and installation procedure.

TEST CAVITY

Its design aims to safely condition the couplers with relatively low power losses inside, but also to test the coupling with an identical mechanical interface (EM and vacuum tightness). Innovative manufacturing processes foreseen for the RFQ, have been qualified on the test cavity. After manufacturing, its resonance frequency was measured at about 20°C: approximately 347 MHz. This frequency shift was corrected by the adjustable tuner. The following figure presents a cross section of the cavity.

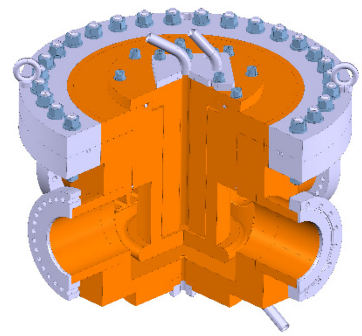

Figure 5: High power test cavity.

The main test cavity parameters are the following:

-Maximum dissipated power: 40 kW at 1 MW;
-IL (Insertion Loss) = 0.2 dB @ 352.21 MHz;
-RL (Return Loss) = 27 dB@ 352.21 MHz.
-$Q_0 \approx 6000$ and $Q_{ext} \approx 90$.

The test cavity is designed to house and test the auxiliairy components, in the same normal conditions as in the configuration on the RFQ. So, two power couplers, an adjustable tuner and a pumping grid are implemented on the cavity. The vacuum system is designed to reach and maintain a suitable pressure, of less than 8.0.10^{-7} mbar (otherwise interlocking the klystron) into the cavity. It must also overpass the outgassing naturally occurring during the high power tests. A Dry Pump (DP) is associated with a Turbo Molecular Pump (TMP) with a 340 l.s^{-1} volumetric flow on a CF100 port. Multiple type of vacuum gauge monitor the pressure inside the system and keep the components safe: CCG (Cold Cathode Gauge) and Pirani Gauges (PG). Additionally, a RGA (Residual Gas Analyser) is installed to study the outgassing of elements, especially during the power processing.

ADJUSTABLE TUNERS

A single adjustable tuner is installed on the test cavity, even if a total of 60 tuners will be installed on the RFQ. It is designed to compensate the frequency and voltage errors resulting from manufacturing tolerances. The tuner is equipped with a stainless steel edge welded bellow, allowing to be adjusted even with vacuum inside the test cavity (or RFQ) under vacuum. Figure 6 presents a picture of the adjustable tuner prototype.

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Figure 6: Adjustable tuner.

A precise thread (0.5 mm pitch), associated with an angular graduation, allows to reach a resolution of few hundredth of millimetre, regarding the movement of the body of the tuner into the port on the cavity. The tuning sensitivity of the tuner is 250 kHz/mm with nominal vacuum inside the cavity. The tuning range of a tuner is 60 mm centered on the nominal position of the tuner. During repeated tuning test under nominal vacuum, the tuner showed satisfactory repeatability, as the frequency of the cavity was measured using a network analyser. Furthermore, to maintain its structural stability at high power, a cooling circuit, 15 l/min ($25x10^{-5}$ $m^3.s^{-1}$), travels through the central axis of the tuner, cooling down the body made of copper (CuC2 OFE). In fact, the power dissipated on the body reaches 3 kW peak in the worst configuration (on the RFQ).

INTEGRATION OF THE COUPLERS

After the manufacturing process, those last were submitted to an extensive set of tests (vacuum and hydraulic tightness) and controls (visual inspections and CMM measurements). The design of the couplers allows to separate a coupler into two sub-assemblies, the cooling loop and the ceramic window. The assembly procedure requests additional tools to handle the sub-assemblies, and finally the couplers, between the different test or assembly stations installed next to the test cavity in the test stand.

Once the installation on the test cavity was achieved, the different instruments and security equipment mandatory to undertake the conditioning, had also been installed. As detailed in Figure 2, each couplers is equipped with: an electron probe (pick-up), two PMs (Photomultiplier) pointed at the vacuum side and air side of the ceramic window to detect arcs, a CCG to measure the pressure near the ceramic (where most outgassing occurs) and PT100 temperature probes positioned on various locations on the coupler. The Figure 7 presents the inlet coupler fully equipped and connected to the inlet TWC, ready to be conditioned.

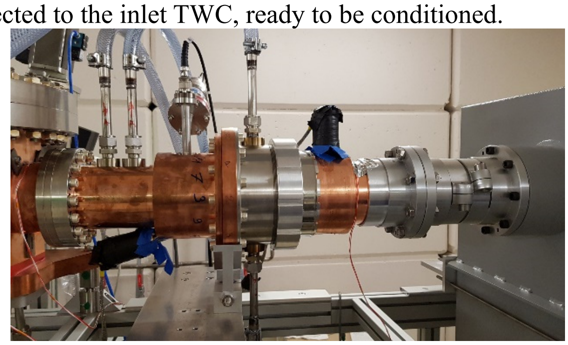

Figure 7: RFQ coupler high power test stand.

Two types of interlocks are set up, regarding their time of response: fast interlock (20 µs max) and slow interlocks (few tens of ms), to interlock the klystron during the conditioning.

CONCLUSION

The dedicated test facility has successfully been set up and all the critical equipment were manufactured and controlled to ensure the conditioning of the couplers in nominal operation configuration (Figure 8). The couplers were assembled, and reached the requirements of vacuum and hydraulic tightness. The different probes and instruments were connected and tested. During the conditioning, an automatic sequence gradually submits the couplers to a RF power ramp from 1 kW to 1 MW, with a pulse length from 100 µs to 3.6ms and for a repetition frequency from 1 Hz to 14 Hz. These sequences are repeated, until the resulting outgassing of the structure decreases. A first pair of coupler has already been power processed at 1 MW, 3.6 ms at 14 Hz during 48 hours.

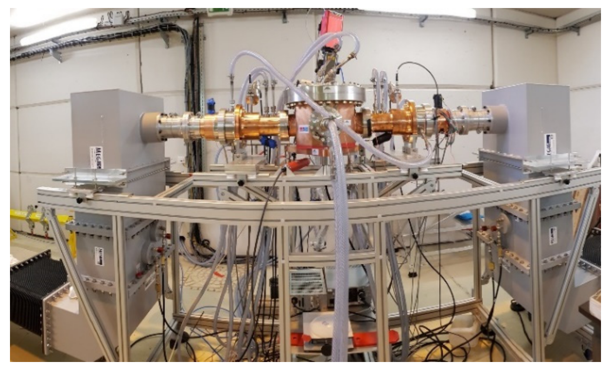

Figure 8: RFQ coupler high power test stand.

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