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ESS RFQ: CONSTRUCTION STATUS AND POWER COUPLERS QUALIFICATION

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Abstract

The 352 MHz Radio Frequency Quadrupole (RFQ) for the European Spallation Source ERIC (ESS) will be delivered during 2019. It is provided by CEA, IRFU, Saclay/France. It consists of five sections with a total length of 4.6 m and accelerates the proton beam from 75 keV up to 3.6 MeV. It will be fed with 1.6 MW peak power through two coaxial loop couplers. This paper will present the manufacturing status of the five sections and the qualification test of the RF power couplers.

INTRODUCTION

Involved in the ESS Project, CEA is in charge of the Radio-Frequency Quadrupole (RFQ) design, manufacturing, installation and conditioning at ESS (Lund) [1].

The RFQ for the ESS accelerator is composed of 5 sections, assembled using positioning pins, RF seals and Helicoflex seals. The RFQ is also equipped with [2]:

- 60 tuners,
- 2 RF power couplers (4 coupler ports in total),
- 10 turbomolecular pumps (36 vacuum ports in total),
- 22 pick-up, including 2 for LLRF,
- 80 cooling connectors on 40 cooling plates.

The two power couplers, that will feed the RFQ with a maximum of 1.6 MW peak power have been successfully manufactured, assembled and tested on a dedicated test stand [3].

RFQ FABRICATION

RFQ Manufacturing

For the construction of the 5 sections of the RFQ we adopted a conservative construction procedure (with the lessons learnt of IPHI RFQ construction [4]) and with a very detailed quality control for all the steps. All the vanes are from the same casting to have identical properties. They undergo several heat treatments (annealing, stress relieving) at different steps of the manufacturing process to avoid any stress or constraint in the material. Moreover, a HIP (High Isostatic Pressing) treatment has also been done for the RFQ of ESS to avoid any millimetric shrinkage defect or porosity in the copper.

RFQ vanes (2 called major and 2 called minor for each section) are machined with a precision of 20 µm, and then positioned and brazed with a 30 µm precision (Fig.1), according to beam dynamics and RF designs results.

Ports (vacuum, tuner, pick up or coupler port) are firstly built using bi-metal brazing between the copper tube and the stainless steel flange (above 1000 °C). Then the assembly of the 4 vanes and ports (Fig. 1) are done in one brazing step (copper-copper brazing, under 1000 °C).

A considerable amount of metrology checks with several 3D measurements have been performed during manufacturing in order to assess that the fabrication was progressing well according to the tolerances. For the same reason, particular attention has been put into the RF bead-pull measurements, which were performed at each step of the assembly phase: mechanical assembly, before brazing and at reception.

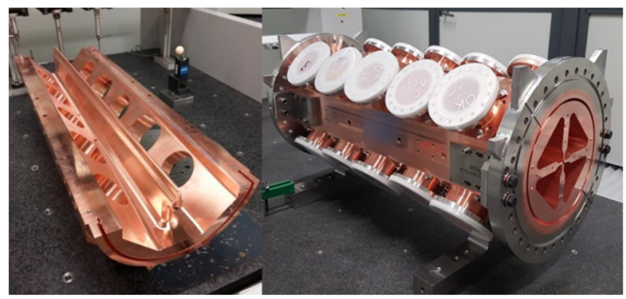

Figure 1: Major vane and finished section.

Receptions Tests

At CEA Saclay vacuum leak test and beadpull measurements are performed in the framework of the Site Acceptance Tests (SAT).

According to ESS specification, no helium leak higher than 1.10^{-10} mbar.l.s^{-1} shall be detected. Global leak tests have been performed at CEA-Saclay after transport (and compared with the done just after brazing). Figure 2 shows section 3 under leak test.

This global leak test is carried out just after hydraulic tests of the cooling channels which are filled with helium at 10 bars during pressure test.

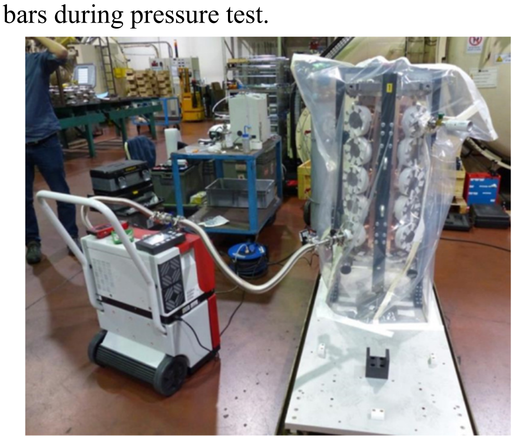

Figure 2: Leak test of section.

The evolution of the manufacturing errors is also traced with RF bead-pull measurements, in particular by looking

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the asymmetries between the four quadrants, which can be referred to capacitance errors associated to the main quadrupole (QQ) and dipole modes (SQ and TQ) in the cavity.

Figure 3 presents capacitance errors that can be corrected by the available range of the tuners which is ±1.85% for the quadrupole mode and 2.35% for the dipole modes.

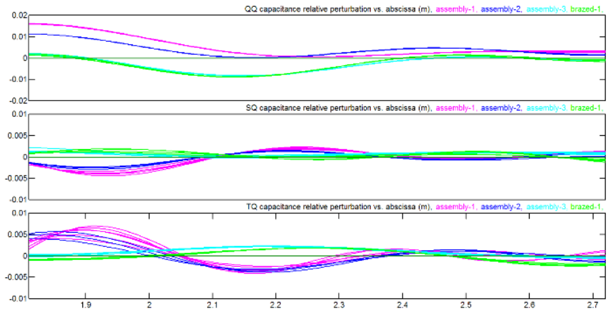

Figure 3: Comparison of beadpull measurements for Section 3 manufacturing.

Two Sections Assembly at CEA Saclay

In order to check the dedicated tools and the procedure of RFQ installation at ESS/Lund, 2 sections have been assembled at CEA Saclay (Fig. 4). The principle of 2 sections assembly is based upon very precise metrology measurements of the reference points located at the entrance and exit of each module. The connection between adjacent modules is realized by means of section 2 precision pins inserted in section 1 locating holes. Pins were machined so to bring the optimized beam axis of the two modules to coincide within ± 30µm of the theorical axis. This test has permit to check the correct fit of the metallic seal between 2 sections with a measured vacuum leak lower than 10^{-10} mbar-l/s.

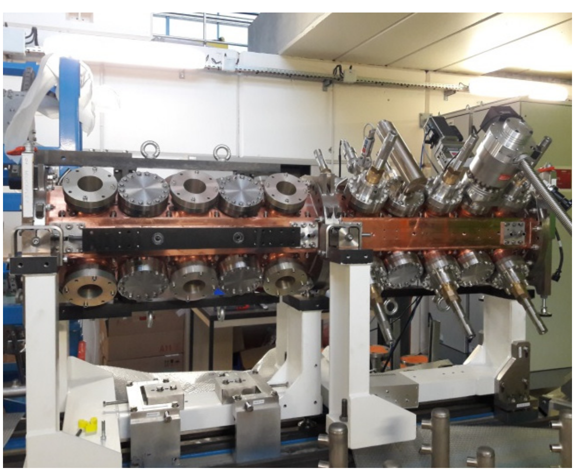
Figure 4: Two assembled sections at CEA/Saclay.

RFQ Sections Status

The manufacturing of Section1 started in March 2018. The first assembly was done at the beginning of October 2018 and directly followed by the first beadpull measurement. The brazing was done at the end of October. The SAT at Saclay was carried out the 31 January 2019. The final vacuum leak test showed a leak of 8.10^{-9} mbar l s^{-1}, but this was accepted by ESS project.

The manufacturing of the 4 other sections was started mid-2018, before the end of the first section realization.

The brazing of section 2 and 3 were done respectively February the 4th and 11th of March 2019 with successful SATs at CEA Saclay respectively the 20th of March and 4th of April 2019. For section 4, the machining of one pole was not successful and this has delayed the first brazing for the end of June 2019. The section 5 has been brazed the 15th of May 2019.

POWER TEST OF COUPLERS

Two coaxial loop power couplers (Fig. 5) 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 couplers can be rotated along their axis in order to get the right coupling factor into the RFQ [3].

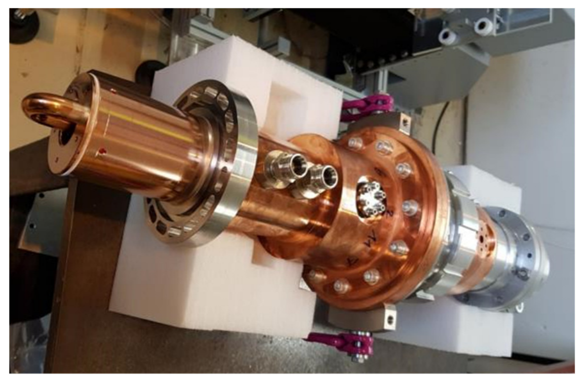
Figure 5: Power coupler.

Coupler Test-stand at CEA Saclay

A dedicated tests-stand has been built at Saclay with a 2.3 MW peak power klystron, protected by a circulator, to produce the necessary RF power to achieve the coupler requirements.

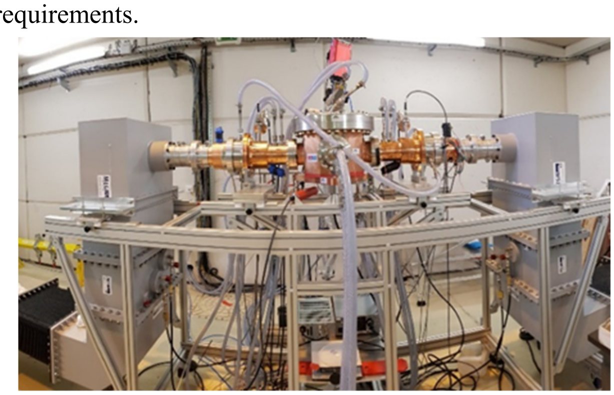
Figure 6: Coupler test-stand at CEA Saclay.

Two Couplers have been assembled on a RF test box made in OFE copper and comprising a pumping system (Fig. 6). Its design aims to safely condition the couplers with relatively low power losses inside the cavity and to

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have identical mechanical interface (EM and vacuum tightness) as the RFQ.

The parameters controlled during the RF processing of the power couplers are:

- Vacuum: 1 gauge on each coupler and 1 gauge at the input of the pumping port of the coupling cavity.
- Electron measurement with a pick-up on each coupler.
- Arc detection: 2 photomultipliers (PM) for each coupler (1 on the air side of the ceramic window and 1 on the vacuum side),
- RF signals: WR2300 bidirectional couplers are used to measure the forward and reflected powers at the input and output of the test-bench. One pick-up is also installed on the cavity to measure its voltage.
- Temperatures: 2 probes (PT100) are used to check the temperatures of the window and RF loop of each coupler. Two other probes check the temperature of the coupling cavity.
- Water flow: flowmeters control the water flow for the cooling circuit of the ceramic window and the RF loop. Two more cooling circuits are used (and controlled) for the coupling cavity.

These different measurements are used to ensure the security of couplers. RF measurements (for the reflected power), electron current measurements, light emission (arc detection) and vacuum measurement are compared to adjustable thresholds and then used to drive a fast interlock of the RF chain in order to stop RF in less than 20 µs.

Temperature measurements and water flow are used as slow interlock (software interlocks are defined in the EPICS environment for temperature measurements). Before conditioning process, the temperatures of the cooling system (for the couplers and the coupling cavity) are set to 26 °C.

The fast acquisition system is based on the single board computer IFC 1210 from IOxOS Technologies, which receives two FMC mezzanine modules with 8 channels ADC 3111 from IOxOS Technologies. This platform is characterized by the need for synchronized actions and processing in real-time and the acquisitions of analogue signals at the speed of 1 MSample/s and high-speed processing with FPGAs capability to handle large data rates and volumes.Timing control is done with a PMC-EVR-230 card from Micro Research Finland (MRF) installed on the IFC 1210 device and synchronized with a VME-EVG-230 (EVG: Event generator) which drives the RF power source.

An automatic sequence gradually submits the couplers to RF power from 100 µs to 3.6 ms duration, with RF power ramps performed from 1 kW up to 1 MW and at repetition frequency from 1 Hz to 14 Hz. RF power from klystron is increased according the level of vacuum inside couplers and coupling cavity. A hardware threshold stops the RF power whereas a software threshold decreases the power until vacuum becomes correct. The first ramp at the repetition rate of 1 Hz, 100 µs for the pulse duration and a starting power of 1 kW requires the longest time. At 1 MW in the first coupler, the power on the second coupler is 960 kW due to 40 kW RF losses of the coupling cavity.

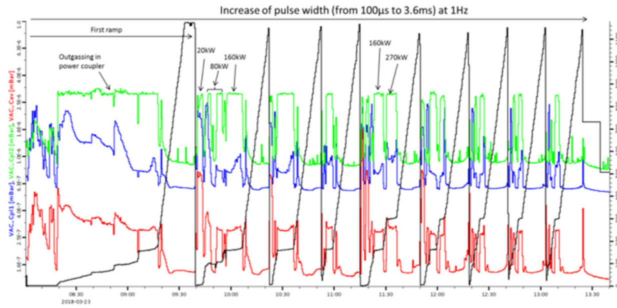

Figure 7: Coupler test-stand at CEA Saclay.

Outgassing is present at low power, between 1 kW and 300kW and mainly inside multipacting power band at about 20, 80, 160 and 270 kW. The width of these bands decreases during the conditioning (Fig. 7).

Electron activity and light emission are principally present at the beginning of the conditioning and inside multipacting bands. Thresholds of pick-up measurements and arc-detectors have been set according to vacuum activity: If electron activity and light emission do not degrade vacuum level, thresholds can be increase while the vacuum levels in the couplers and cavity do not reach their software thresholds.

Twenty hours of RF conditioning are typically required to obtain the final setup for the RF pulse.

At the end of the conditioning sequence, the final setup (1 MW peak power and 3.6 ms for the pulse width at the repletion rate of 14 Hz) is held during at least 12 hours.

CONCLUSION

The 3 first sections have been delivered at Saclay. The 2 last sections will be finished in July 2019. All the sections will be delivered at ESS in August. The RFQ assembly in the accelerator building will start at the end of August.

Three Power couplers have been tested at Saclay with the maximum power (and some margin) required by the RFQ. These couplers will be delivered at ESS in August.

The conditioning of the RFQ is scheduled for next year.

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