

STATUS OF THE ESS RFQ

D. Chirpaz-Cerbat[†], A. Albéri, G. Bourdelle, A-C. Chauveau, M. Lacroix, N. Misiara, G. Perreu, O. Piquet, H. Przybilski, N. Sellami, N. Berton, M. Desmons, A.C. France, V. Hennion, P-A. Leroy, B. Pottin, CEA/DRF/IRFU, Saclay, France

Abstract

The ESS Radio-Frequency Quadrupole (RFQ) is a 4-vanes resonant cavity designed at the frequency of 352.21 MHz. It must accelerate and bunch a 70 mA proton beam from 75 keV to 3.62 MeV with a 4% duty cycle. The RFQ design has already been done, and documented in other papers. This one will present the global status of the RFQ, with technical solutions chosen for the main components (for fabrication and operation) and the present status of the RFQ fabrication.

INTRODUCTION

Involved in the ESS Project [1], CEA is in charge of the Radio-Frequency Quadrupole (RFQ) design, manufacturing and installation at ESS (Lund). It is also in charge of the RFQ subcomponents, like tuners and couplers, and mechanical support. This includes RF [2, 3], thermo-mechanical [4], water cooling and mechanical design (vacuum and beam dynamics studies [5, 6] are performed by ESS), but also manufacturing, and finally installation and tests in the tunnel in Lund. Moreover, a test cavity was designed to validate technical choices made for the RFQ, the couplers (also for conditioning), adaptable tuners, vacuum brazing and manufacturing processes. Finally, CEA will assist and may provide expertise for the RF conditioning of the RFQ at Lund. The present paper briefly focuses on the main technical design and engineering aspects for this RFQ, and the status of the ESS RFQ project.

RADIOFREQUENCY QUADRUPOLE

The RFQ for the ESS accelerator is composed of 5 sections, assembled using positioning pins, RF seals and Helicoflex seals (or gaskets). The RFQ is also equipped with:

- 60 tuners,
- 2 couplers (*4 coupler ports in total*),
- 8 to 10 turbomolecular pumps (*36 vacuum ports in total*),
- 22 pick-up, including 2 for LLRF (*28 pick-up ports in total*),
- 80 cooling connectors on 40 cooling plates,

Fabrication Design of the RFQ Cavity

Each section is made of four poles (one per vane) in pure copper, two minors and two majors, as seen on Fig. 1. Pure copper (Cu-OFE, 99.99 % Cu) is the main material used, for the bulk of the RFQ, components and ports (except flanges in stainless steel). It has been chosen for its

high electrical and thermal conductivity as well as for its brazing possibilities. Every pole (20 poles in copper) is 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 added to the manufacturing of the RFQ to avoid any millimetric shrinkage defect or porosity in the copper (cf. fig. 2). The ports are also in pure copper (tube) with a stainless steel flange.

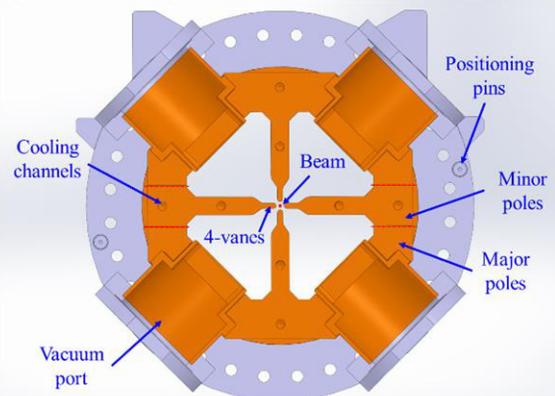


Figure 1. Cut of the RFQ section, showing the 4 poles, cooling channel and vacuum port.

Poles are machined with a precision of 20 μm and then positioned and brazed with a 30 μm precision, according to beam dynamics and RF studies and design. To achieve this precision, all necessary precautions will be taken for materials, process and qualification. That is why tests and measurements are planned all along the manufacturing lifecycle like 3D measurements, bead pull or vacuum leak check.

The assembly of these poles and ports are done in two brazing steps under vacuum. The first is a bi-metal brazing between the copper tube and the stainless steel flange, at high temperature, to obtain a “port” (vacuum, tuner, pick up or coupler port). The second step is a copper-copper brazing, under 1000 °C, to definitively assemble the four poles and the ports on the poles. The manufacturing process includes different machining steps under thermalised area, and cleaning processes in adequacy with brazing, vacuum and RF conditions.



Figure 2. Example of shrinkage defect in copper, seen on IPHI RFQ after machining.

[†] didier.chirpaz@cea.fr

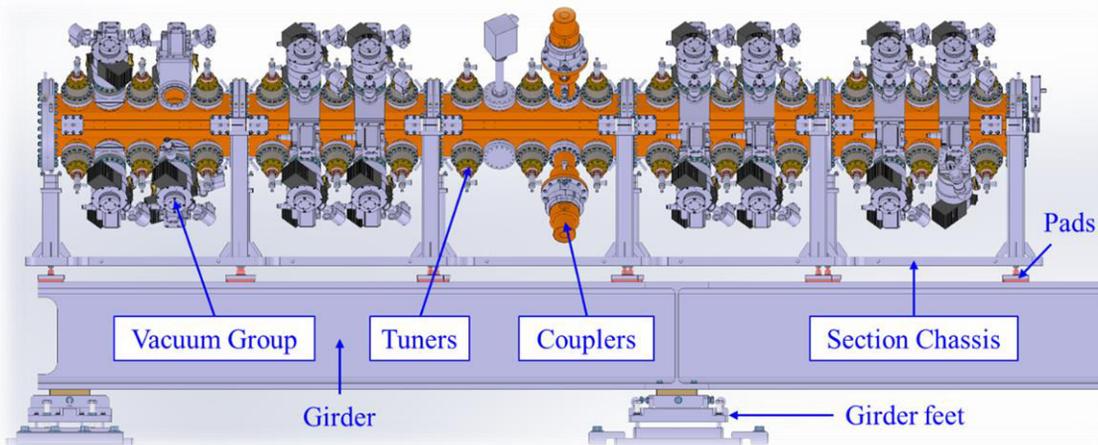


Figure 3. Assembled RFQ with tuners, couplers, cooling plates and vacuum equipment, on its support. This view shows the case where each vacuum port is used, this case is not expected in operation.

To compensate a part of the fabrication tolerances, besides adjustable tuners, the design of the vacuum ports allows them to act as a permanent tuners: every vacuum port has an adjustable machined part before being brazed on the pole to get a better voltage profile. Specific penetration depth into the cavity for each vacuum port will be defined by a bead pull measurement. RFQ end plates design also includes dismountable tuning rods.

RFQ Supporting Structure

Each section is supported on a Section Chassis on three points which are located on entrance and exit flanges. The five sections on their Section Chassis are placed on the RFQ support, a 5 meter long metallic girder (cf. fig. 3 and 4). Pads are used as an interface between the Section Chassis and the girder. The RFQ sections will not endure any stress from dilatation or supporting thanks to the displacement pads and the Section Chassis flexibility. The girder is set on three girder feet on the ground. For alignment purpose, the girder is on three feet, adjustable in the three directions (± 50 mm).

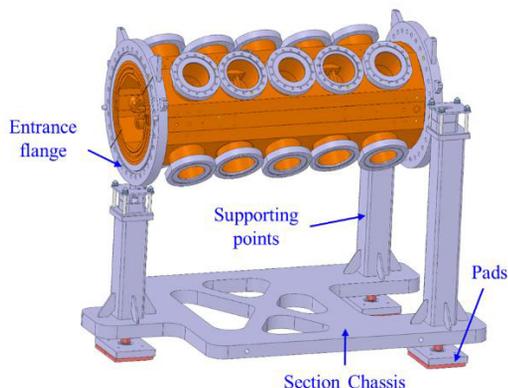


Figure 4. A section on its Section Chassis, with pads.

Cooling

To keep RF critical dimensions [2, 3] during operation, the RFQ is thermalised by water flow through 8 channels per section (one body channel and one vane channel per vane). These are obtained by one meter long drilling with

a ± 0.5 mm tolerance over one meter long, which is critical in annealed pure copper. As the ESS accelerator operates in pulsed mode (4% duty cycle), the cooling system sizing is not as critical as the one needed for other CW RFQs (IPHI for example), but issues (design, machining etc.) are similar. Specific cooling plates and a complete cooling system, including a skid, are expected to provide about 1200 l.min⁻¹ [4], in accordance with thermomechanical studies [4] and RF design [2, 3].

TEST CAVITY

A Test Cavity was designed to validate the new RFQ element design as well as manufacturing and assembly processes for the RFQ, such as:

- tuner and coupler
- large brazing of the exit section flange and brazing groove to avoid stress
- mechanical assembly

COUPLERS

The RF power is coupled to the RFQ by two half-circular loops (couplers), located on the third section. Both couplers are installed, instead of pumping ports, respectively located at 90° relative one to the other. Each coupler is designed for a maximum RF power of 1 MW whereas the nominal power to be coupled to the RFQ is 1600 kW (beam power is about 225 kW and RF power dissipated in pure copper is about 1375 kW) [3, 4, 5, 6]. The mechanical design is shown on Fig. 5.

The coupling loop is cooled using water through two concentric tubes. The window between air and vacuum is made of pure Alumina (97.6 %) with a thin coat of TiN (10 nm \pm 5 nm) on vacuum side and brazed on an approximately 1 mm thick tube made of pure copper. Water cooling is also planned for the window for more safety.

To adjust and optimize the RF coupling, the loop orientation inside the RFQ can be changed from 0 to 90° *in situ*, using EPDM seals and specific flange.

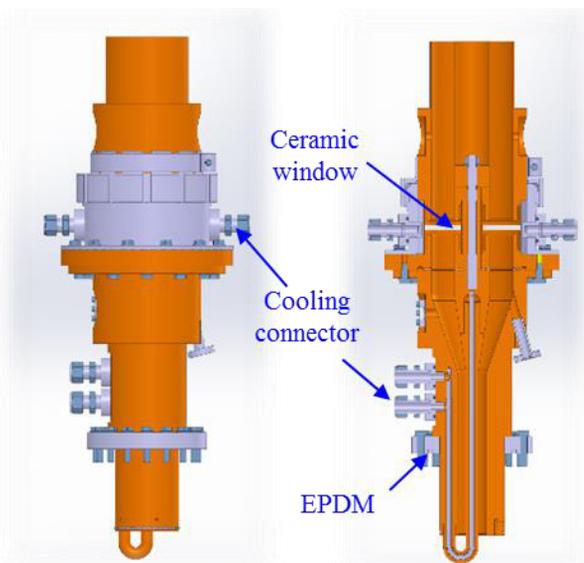


Figure 5. The ESS RFQ couplers.

As the ceramic window is generally the very critical part of the coupler, the present design includes some particularities. Firstly, a rigid structure was added to the coupler to avoid any mechanical stress on the window, as well as handling tools are designed for the coupler insertion into the RFQ, and to set up the RF transition onto the coupler. Secondly, the coupler is made of two dismountable parts which allow to change only the window part, without having to manufacture another loop part.

Before starting coupler's production, qualifications phases with representative mock-ups will be manufactured to validate critical parts: TiN thin deposition, and control, and ceramic brazing on thin copper tube.

For diagnostic and safety reasons during conditioning and operation, one cold cathode gauge for pressure measurement, one Photo Multiplier (PM) and one electron pick up are set on vacuum side, and one PM on air side. Before being mounted and used on the RFQ, the two couplers will be tested and conditioned on the cavity mentioned above.

TUNERS

Tuners are used to adapt the cavity volume in order to re-adjust the voltage profile along the beam axis and allow to correct fabrication errors (machining, positioning, brazing). The design is presented on Fig. 6. As already mentioned, the RFQ for ESS is composed of 60 tuners, 12 per section. The final depth position of each tuner will be set during the RF Tuning phase done on the final site in Lund.

For higher efficiency and time saving during the RF Tuning, the new design of this tuner includes a depth adjustable function *in situ* thanks to a bellows with a screw/nut system (setting shims, tooling and depth gauge are no more needed).

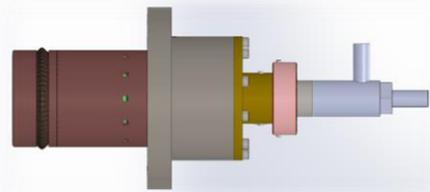


Figure 6. Design of the adjustable tuner.

Tuners will be installed with CF100 Cu gasket and RF seals; in addition each tuner is water cooled. A prototype of this new design is currently under production and will be tested before summer 2016 with tooling to validate the design, particularly vacuum tightness and mechanical properties (compression-extension of bellows after brazing-like heat treatment). Qualification under RF conditions will be done on the Test Cavity.

FABRICATION STATUS

Pure copper for the RFQ poles, tuners and ports have already been delivered at CEA/Saclay. A HIP process has already been qualified and tests already show its utility. Adjustable tuner prototype is under production and planned to be tested in the next few months. Critical Design Reviews (CDR), in 2014 and 2015, have been done with the ESS staff to validate components design. Fabrication contracts for RFQ, test cavity and couplers will be signed with industrial companies before summer 2016. The test cavity is expected to be received in Saclay in September 2016, which will allow validating a large part of the mechanical designs, fabrication and assembly processes presented in this paper. The RFQ poles machining should start at the beginning of the second semester 2016.

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