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STATUS AND RF DEVELOPMENTS OF ESS BILBAO RFQ*

N. Garmendia†, J. L. Muñoz, I. Bustinduy, P. González, A. Kaftoosian, J. Martin, A. Conde, A. Rodríguez, S. Masa, ESS Bilbao Consortium, Zamudio, Spain

Abstract

Within the framework of the plans for study of a light-ion linear accelerator, ESS Bilbao is manufacturing a radio frequency quadrupole (RFQ) aimed at accelerating up to 3 MeV the protons generated in the ion source. The progress made and the difficulties encountered with the RFQ are discussed in this paper. A power coupler prototype for the RFQ has been developed while several mechanical constraints were also studied in the final coupler. This prototype operates at a lower power, then it can work using PEEK window for the vacuum interface and it does not require neither brazing nor cooling system. Also, a complete RF test stand is being implemented to perform the high-power conditioning in traveling and standing wave mode, to verify the power handling capability of the coupler and its thermal behaviour. The RF test stand, based on EPICS environment, can provide up to 2 MW peak power at 352.2 MHz in a pulse operation of 14 Hz and a duty cycle of 4.9%.

INTRODUCTION

ESS Bilbao oversees the Spanish in-kind contributions to the contributions to the European at the same time we are involve in developing local project such as the study of a multi-purpose light ion linear accelerator of 30 MeV proton beam [1].

The first part, an Electron Cyclotron Resonance (ECR) proton ion source and Low Energy Beam Transport (LEBT), which already are under operation at the ESS Bilbao premises, can provide a proton beam of up to 40 mA at an energy of 45 kV.

The next linac part is the Radio Frequency Quadrupole (RFQ), which is under manufacturing [2].

Table 1: ARGITU-RFQ Main Specifications

Parameter	Value
Specimen	H+
Beam current	32 mA
Beam energy	45 keV→3 MeV
RF Frequency	352.2 MHz
Pulse Operation	30 Hz; 1.5 ms; 4.5 %
Intervane Voltage	85 kV
Kilpatrick	1.85
Input emittance	0.25 π mm rad

The next steps of the RFQ project have been launched, such as the coupler and the RF system for the conditioning. The main details of each phase are presented in the next sections.

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†ngarmendia@essbilbao.org

RFQ STATUS

The ESS Bilbao RFQ has a total length of about 3.12 m (3,66 λ) and 273 cells, composed of 4 segments of 800 mm in length. Each segment is itself an assembly of four components using O-ring system, with polymeric vacuum gaskets, therefore avoiding the brazing.

The RFQ first segment is already manufactured and experimentally validated [3], so the next segment manufacturing has started. The metrology of the one vane has let validate one of the key parameters of the RFQ design, the 2-term modulation curve. The design and experimental data of the modulation curve of the vane have been compared and it can be checked the good agreement with a 5 µm of tolerance (Fig. 1).

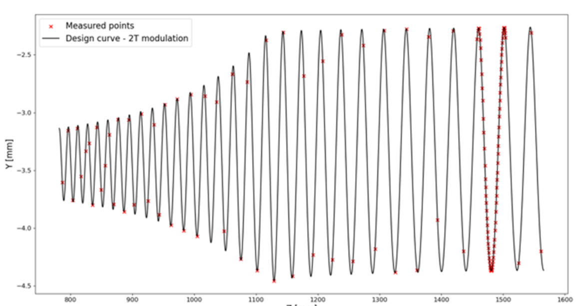

Figure 1: Modulation curve of the major vane of the second RFQ segment. Metrology results of vane seems to agree within 5 µm tolerance

POWER COUPLER DESIGN

The injection of the RF power as well of the vacuum interface in the RFQ is achieve by means of adequate RF power couplers. The designed coupler is based in magnetic loop coupling with a mechanical interface of standard Con-Flat 2 3/4". Two couplers are required to provide the required power.

Due to the reduced size of the mechanical interface, several difficulties have appeared to fulfil all the coupler requirements in terms of maximum electric field and thermal behaviour. With the aim to overcome these issues

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alternative low-power coupler has been designed reducing its power requirements and simplifying the manufacturing process.

RF Design

One of the main advantages of the magnetic couplers is the easiness of coupling factor tuning. Only it is necessary to rotate the loop to vary the effective area coupled with the magnetic field lines.

To design the coupler loop is necessary to know the required coupling factor which derives from the next parameters power dissipated in the cavity (Pdiss, function of unloaded quality factor, Qo), power required to accelerate the beam (Pbeam) depending on the beam current and increase of particle voltage) and finally the number of coupler (N) as the next formula shows:

$$\beta o = \frac{Pdiss + Pbeam}{NPdiss}$$

An estimation of coupler factor of 1.3 has been calculated considering a worst case of parameters: Qo = 7500, Pdiss= 400 kW, I beam = 32 mA; ΔE = (3–0.045) MeV and N =2 couplers.

The loop has to present enough margin to be tuned by rotation, therefore the loop has been optimised, increasing as much as possible the loop area, to achieve enough coupling factor (see Fig. 2). The coupling factor have been simulated by the s-parameter frequency sweep as well as the Balleyguier method [4].

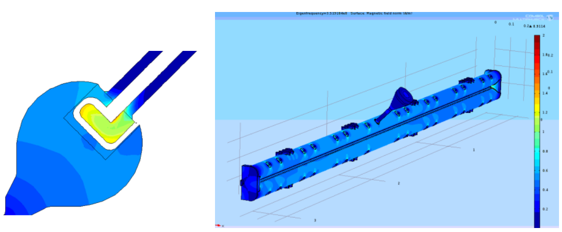

Figure 2: Simulation of the coupler coupling loop.

Thermal Design

The power capability of the low-power coupler has been studied with thermal simulations to determine the new reliable operation scenario (Fig. 3). Considering the simulation results, including the contact with the RFQ body (fixing the flange temperature at 20 ºC), the coupler temperature reaches slightly above 50 ºC for the next operation conditions: nominal peak power of 300 kW and a duty cycle of 1 % to obtain 3 kW of average power.

The highest temperature is observed in the internal conductor. The external one is cooled down by natural air convection, and the loop is cooled down by the contact with the copper body.

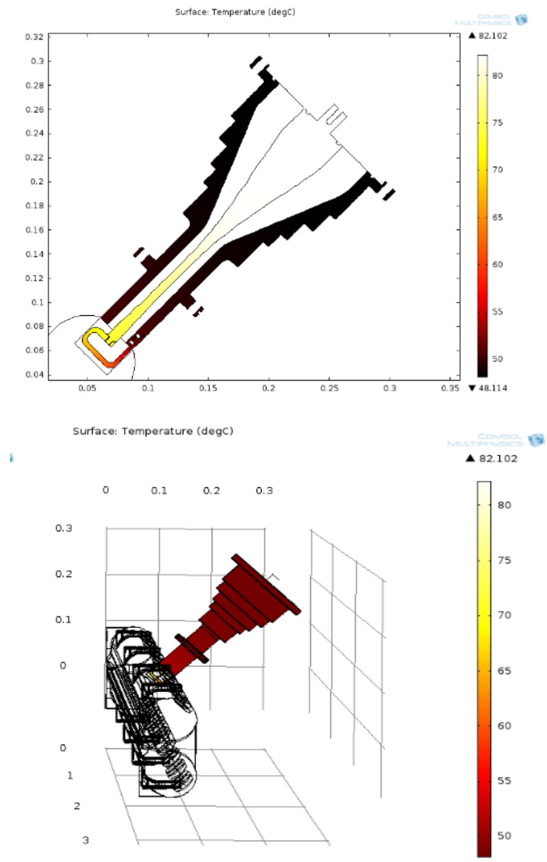

Figure 3: Coupler thermal simulations.

Mechanical Design and Manufacturing

The coupler matches the 4 1/2 coaxial from the RF system to the CF 2 3/4" RFQ coupler port.

The transition is done in taper shape, changing linearly the input internal and external radius to maintain the impedance value.

One of the aims is to advance as much as possible in all the RFQ project phases, and for these terms the prototype design is based on a balance between the power requirements and simple manufacturing.

The main decisions taken are the use of PEEK polymer window instead of Alumina for vacuum interface and the omission of the water cooling. This implies a much straightforward and quicker manufacturing process since the vacuum will be guaranteed using gaskets, and then avoiding the brazing (Fig. 4).

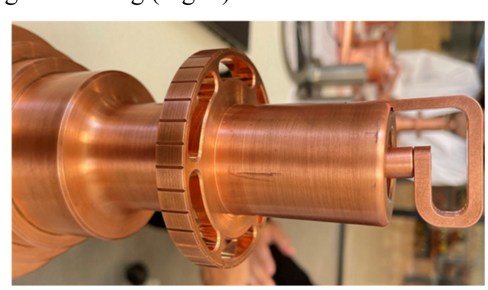

Figure 4: Coupler manufacturing.

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RF SYSTEM

The RF system to provide the required power to conditionate and operate the RFQ is based on a klystron, a modulator, a WR2300 distributions system, a fast and a slow interlock system everything integrated with an EPICS control system. The first step is to prepare the set-up for the couplers conditioning, both in TW and SW mode, including the test box, as shown in Fig. 5

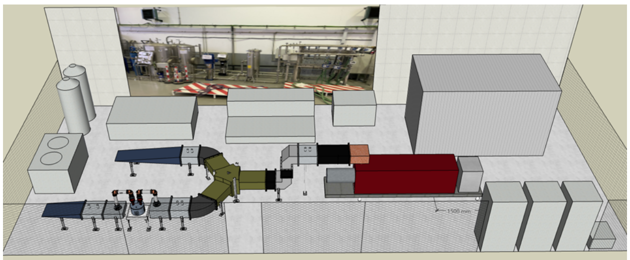

Figure 5: RF Test Stand layout to the RFQ couplers conditioning.

Klystron Failure and SSPA Design

During the test stand start up, the klystron presented an anomaly in the vacuum level. Different, exhausted long test were performed under the manufacture's premises, but finally the klystron was sent to CPI to be checked. They found a leak in the braze joint between the output cavity cylinder and end wall due to a crack. Several options are under study to be repaired since it is not a simple failure.

This circumstance let us adopt again an alternative to progress with the project until the klystron was repaired. A first solid-state amplifier SSPA of 2 kW peak power has been designed, assembled and tested under a maximum duty cycle of 6.5 % (14 Hz of frequency repetition rate and RF pulse width of 4.6 ms), providing 130 Watt of average power (Figs. 6 and 7). Currently, the design of SSPA based on the combinations of this 2kW module increase is being studied to increase the power of RF chain.

Conditioning Test box

The test box designed is a re-entrant pillbox cavity with two tuners, one fixed and one movable to tune the cavity frequency in operation. The key point is to control the re-entrant cylinder since it is very sensitive to the cavity resonant frequency.

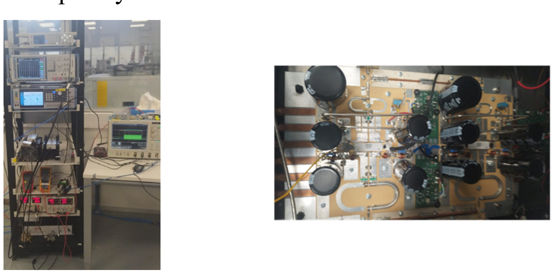

Figure 6: Set-up for the SSPA measurements.

LOW POWER TEST

The first low power characterization has been performed to check the simulation parameters. All the main values agree with the simulations (Figs. 8 and 9).

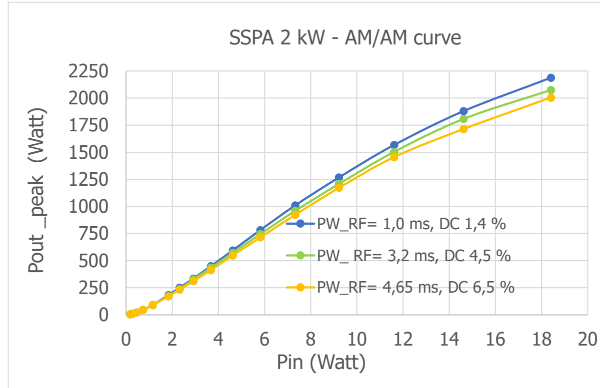

Figure 7: 2 kW SSPA module tests: AM/AM curve.

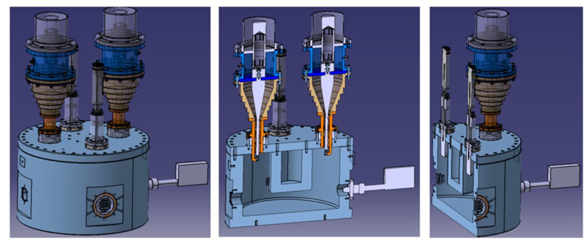

Figure 8: Couplers and test box CAD design

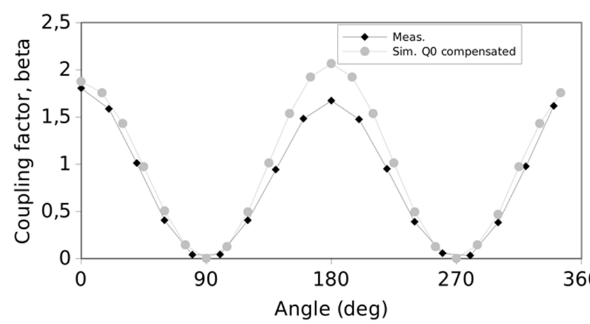

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Figure 9: Low power test of RFQ couplers with test box.

CONCLUSION

After the experimental validation of the RFQ first segment, the manufacturing of the next pieces progress correctly. However different issues have appeared with the coupler design and the klystron operation of the RF system. To minimize delays on the whole RFQ project, alternatives solutions have been taken to overcome risks and requirements constrains.

On one hand, a coupler with simplified manufacturing process and with lower power handle capability have been designed. On the other hand, the use of SSPA technology to substitute the klystron is under study with different possibilities, including the design of SSPA modules until the klystron was repaired.

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