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# ESS-BILBAO RFQ POWER COUPLER: DESIGN, SIMULATIONS AND TESTS

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*Abstract*

ESS-Bilbao RFQ (Radio Frequency Quadrupole) power coupler is presented. The RFQ operates at 352.2 MHz and will accelerate the 32 mA proton beam extracted from the ion source up to 3.0 MeV. The RFQ will complete the ESS-Bilbao injector, that can be used by the ARGITU neutron source or as a stand-alone facility. The machining of the RFQ is finished, and vacuum tests as well as low power RF measurements have been carried out. The presented power coupler is a first iteration of the device, designed to be of easier and faster manufacturing than what might be needed for future upgrades of the linac. The coupler does not have active cooling and no brazing has been needed to assemble it. It can operate at the RF power required by the RFQ but at lower duty cycles. The dielectric window is made of polymeric material, so it can withhold the assembly using vacuum seals and bolts. Design and manufacturing issues are reported in the paper, as well as the RF tests that have been carried out at medium power. Multipacting calculations compared to measured values during conditioning are also reported. High power tests of the coupler have also been performed in the ISIS-FETS RFQ and are also described here.

## INTRODUCTION

ESS Bilbao is involved in developing a local project that includes the study of a multi-purpose light ion linear accelerator for a 30 MeV proton beam [1]. The first part of the linac comprises an Electron Cyclotron Resonance (ECR) proton ion source and Low Energy Beam Transport (LEBT) which can provide a proton beam of up to 40 mA at an energy of 45 keV. These are already on operation at the ESS Bilbao premises. The next section, the Radio Frequency Quadrupole (RFQ), is under manufacturing [2]. In parallel, we need to feed the RF power to the RFQ. In the last year, two couplers have been designed, manufactured and tested in low and high power. In the following sections we will describe the current status.

The power coupler of an RF accelerator cavity is the device that allows the injection of RF power into the cavity. To do so, it must excite the adequate resonant mode in the cavity and transmit the required RF power with as minimum losses as possible. In the case of the ESS-Bilbao RFQ, the coupler connects a 4-1/2 inch EIA coaxial waveguide that comes from the RF power chain to a loop that is inserted into the RFQ body through the RFQ coupler/tuners ports

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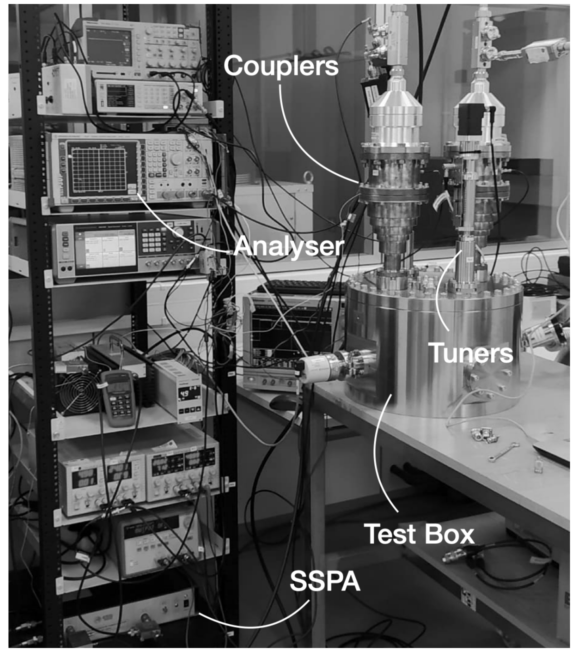


Figure 1: Test-bench for the RFQ couplers conditioning.

(close to DN40). Table 1 summarizes design parameters of the coupler. From the DC point of view, the loop is itself a short-circuit between the external and internal coaxial conductors. The design of a RF coupler is a challenge since it needs to provide a separation between air (waveguide) and vacuum (cavity) and transmit the RF power efficiently.

Table 1: RFQ and Coupler Design 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 $\pi$ mm mrad |
| Window Material | PEEK |
| RF Coaxial Interface | 4-1/2" EIA |
| Inner/Outer Radius | 4.6 / 10.58 mm |

To overcome the difficulties a first version has been designed [2] that does not need water cooling. Also, the fabrication was simplified, and no brazing was needed for the

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coupler [3]. The dielectric window is made of PEEK, instead than the alumina used for similar higher power couplers.

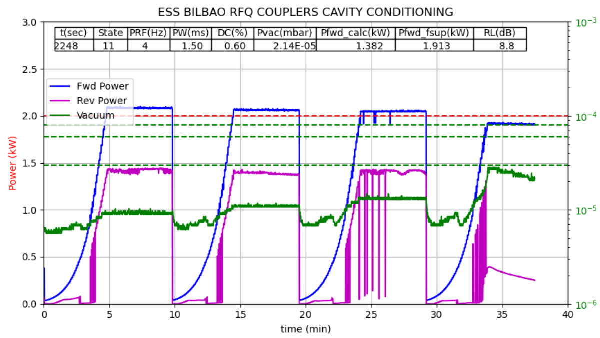


Figure 2: Conditioning PRR 4 Hz cycle. Multi-pacting bands effects in the vacuum and reflected power level.

## LOW POWER RF TESTS AND CONDITIONING

After the low power and S-parameters characterization, the conditioning procedure parameters must be established considering the power and pulse specifications. A complete RF chain has been implemented based on 2 kW SSPA, designed in ESS Bilbao, and a test box. Figure 1 shows the conditioning test bench implemented. The defined conditioning steps are:

**Pulse widths (PW):** 0.25, 0.5, 1.0 and 1.5 ms

**Pulse repetition rates (PRR):** 1, 2, 4, 8, 14 and 30 Hz

**RF Power ramp:** from -16 to 0 dBm at RF generator (0.5 to 2000 W at coupler input)

During the conditioning, several conditions and parameters must be checked and kept under control: vacuum level; arc detection events on both coupler air side, RF forward and reflected power at the couplers, temperature (near window, water) and water flow.

Based on the previous experience [4], the control system allow the operator to set up a sequence of sweeps, thus delivering RF power to the coupler and the cavity with gradually increasing power, pulse width and repetition rate in nested loops, until the nominal operating conditions are achieved, while the vacuum level is acceptable.

Vacuum pressure inside the cavity is continuously monitored. The interlock threshold ($2 \times 10^{-5}$ mbar) is defined, such that, above this level, the local protection system turns RF permission off until it is reset. We have three software vacuum thresholds, on top of the hardware interlock trip level. At certain conditions we can observe the reverse power might be unstable and fluctuating (see magenta line in Fig. 2), however with the time it seems that it becomes stable, and it decreases its value with a soft slope until meet an expected low value (see Fig. 3). At the same time, the vacuum is improving. During the conditioning process, multi-pacting bands can be crossed, when this happens, surfaces electrons activity causes an increase in the vacuum level (represented in green).

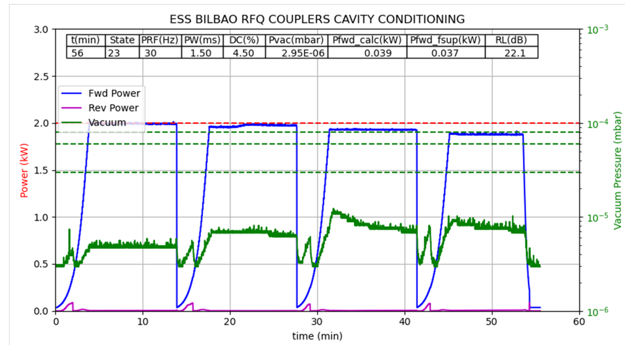


Figure 3: Conditioning PRR 30 Hz cycle. For PW: 0.25, 0.5, 1.0 and 1.5 ms.

### *Multipacting Simulations*

Multipacting effects have been also analyzed for the coupler. An in-house code, capable of simulating in any geometry, has been used [5]. As power increases, the computation points out that there is peak of multipacting activity around 0.8 kW. This has also been detected during conditioning, as can be seen in the magenta lines in Figs. 2 and 3. The multipacting activity is caused by resonant electron emission, that in this case is located in the narrow coaxial part of the coupler.

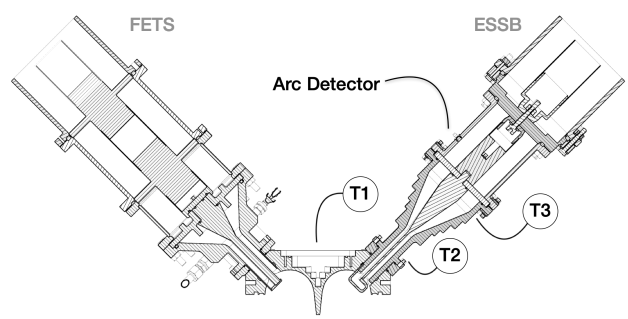


Figure 4: Looking downstream, on the left side FETS coupler, and on the right the ESS-BILBAO coupler. Locations of the different sensors are also indicated as letters.

## HIGH POWER TESTS IN FETS

As part of the validation tests, due to some delays on the repair of the CPI klystron, the coupler was tested in ISIS-FETS RFQ [6]. This 324 MHz RFQ uses two couplers to feed the RFQ, one was removed in order to install the ESS-BILBAO (see Fig. 4). In order to integrate it, a few additional parts were machined to cope with mechanical restrictions. The coupler was installed and oriented to have same coupling factor as the one already installed. Even our coupler was designed for 352.2 MHz, we measured −32.53 dB input reflection coefficient at 324 MHz. The main objective was to

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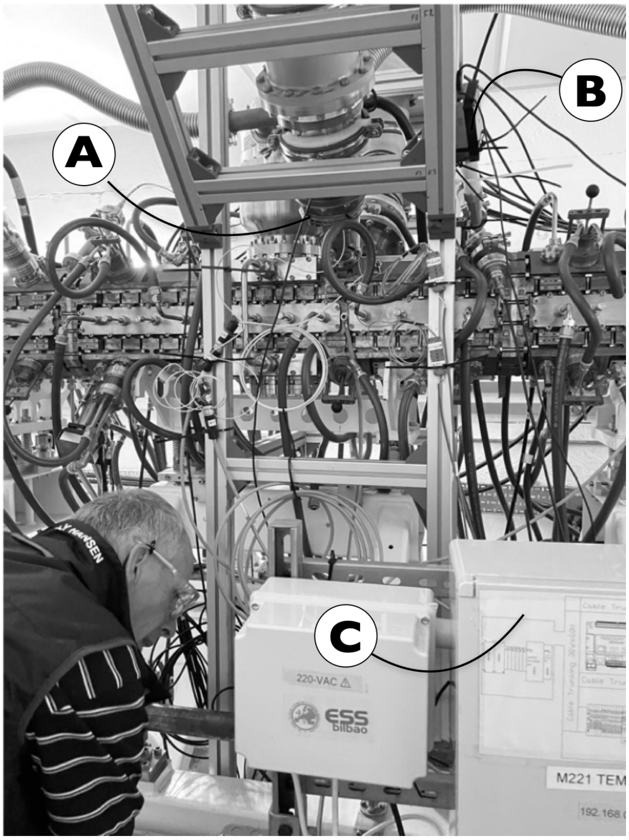


Figure 5: Setup in the ISIS FETS tunnel. A: RF Coupler under tests. B: x-ray spectrometer. C: Temperature Monitoring and arc detector PLC.

probe that the PEEK window coupler is perfectly capable of sustain the power required for the RFQ without active cooling. Different sensors were placed along the system; an arc detector in the air side of the coupler, and various temperature sensors: one in the RFQ body (T1), one in the waist of the coupler (T2), and one near the RF window (T3) to monitor temperature evolution (see Fig. 4 and Fig. 5). While conditioning, several parameters were monitored: Total forward power, reflected power in each coupler and four RF pickup signals together with vacuum levels along the RFQ.

The pulse length was controlled by a signal generator. We could increase repetition rate by factors of $50/2^n$. At the time of writing, the nominal power in the RFQ cavity was achieved (545 kW measured at pick-ups), at a 0.125 % duty factor (PW 200 µs, PRR 6.25 Hz). During these tests temperature never exceeded 25 °C, and we only recorded three arcs. The inter-vane voltage was inferred [7] to be 84.6 keV by analysing x-ray spectrum (see Fig. 6).

## DISCUSSION

Unfortunately we had to put on hold our plan to run with beam through the RFQ because of issues with the ion source control system. We hope we can resume the experiment shortly.

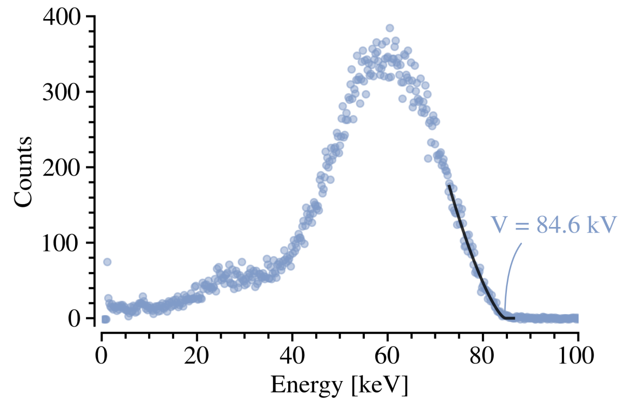


Figure 6: FETS RFQ structure x-ray emission data spectrum collected during coupler tests.

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