POWER COUPLERS CONDITIONING AND MULTIPACTING SIMULATIONS FOR THE ESS-BILBAO ARGITU RFQ

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Abstract

The ARGITU RFQ at ESS-Bilbao is a 352.2 MHz, 4-vane RFQ that will accelerate protons from 45 keV to 3.0 MeV. The RF power comes from a modulator/klystron power chain by rectangular waveguides adapted to coaxial lines that are finished by the two loop power couplers. The couplers are made of copper and no brazing has been used in their production. For this reason, the vacuum/air window is made of PEEK material attached by mechanical pressure to the copper structure. For the initial stages of the ARGITU RFQ, the duty cycle will not rise above 1%, so these couplers were designed without active cooling. This paper summarizes the conditioning setup and focuses on the RF, thermal and multipacting simulations used to define safe high-power conditioning limits.

INTRODUCTION

The HiCANS Platform [1] will demonstrate the feasibility of a full high current accelerator driven neutron source in Europe. This platform will use the high current proton accelerator system (3 MeV) from ESS-Bilbao linac together with the target-moderator-reflector unit built and tested at JCNS [2] and the HERMES time-of-flight reflectometer instrument from LLB [3]. The proton accelerator consists of an ion source and a Low Energy Beam Transport (LEBT), which will inject the beam into an RFQ (Radio Frequency Quadrupole) linear accelerator. The RFQ will accelerate the 45 keV proton beam extracted from the source to the required 3 MeV.

The RFQ fabrication, tuning and low power testing are finished. Next steps are the conditioning of the power couplers and the RFQ itself. The RFQ [4–7] is a 4-vane RFQ that will accelerate protons from 45 keV to 3.0 MeV, in a 3.1-m long copper structure. The RFQ is powered by two power couplers. A set of two prototypes of the coupler design were built, tested at low power (at ESS-Bilbao facilities), and at high power connected to the FETS RFQ at RAL, as previously reported [8]. The dielectric window that separates the vacuum and air sections of the coaxial line is made of PEEK polymer, and it is fixed to the copper inner and outer conductors without using brazing or other welding technique. Therefore, the couplers could be disassembled and assembled again if some component needs replacement. Two new units of the same design were manufactured and will be used for RFQ operation.

Each power 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 (close to DN40). The coupler has a taper transition from the coaxial diameters of 45 mm (inner) and 103 mm (outer), to a coaxial section with diameters of 9.2 mm (inner) and 21.6 mm (outer). The small size of the final section makes it difficult to design and fabricate a loop and coaxial section that include channels for cooling water, so these couplers are a first iteration of the design procedure that therefore cannot operate at high duty cycles. The estimated RF power losses and the required beam power in the RFQ amount to a total power input close to 500 kW, so both couplers and the RFQ will be conditioned to a total peak power of 600 kW. This means that each coupler needs to stand a peak power of 300 kW at a maximum duty cycle of 1% without cooling. Operation at these power levels was already demonstrated in the tests at FETS-RAL RFQ [8]. This duty cycle will be used for the first stages of the HiCANS Platform project to demonstrate the production of neutrons in the facility. For latter stages, a new set of power couplers, with active cooling, will be used.

COUPLER CONDITIONING SETUP

Coupler conditioning will be performed in the copper-plated stainless-steel test box shown in Fig. 1. The re-entrant pillbox has ports for the two couplers, plunger tuners, vacuum diagnostics and sensors. The same RF chain foreseen for RFQ operation is used: the klystron feeds one coupler through the circulator, waveguide and coaxial transition, while the second coupler extracts the power to a waveguide load. The target is 300 kW peak power per coupler at up to 1 % duty cycle, reached by increasing RF power and pulse length up to about 1.5 ms at 7 Hz. Vacuum, arcs, RF power and coupler temperatures are interlocked and logged. Since the campaign is ongoing, the following sections focus on simulations defining safe conditioning limits.

COUPLER AND TESTBOX SIMULATIONS

Electromagnetic simulations of the couplers and test box system have been already reported [8]. These simulations are described here in connection to the thermal simulations and the temperature limits to be set in the conditioning control. Figure 2 shows the electric-field map for 300 kW of RF peak power injected through one coaxial port. The metallic surfaces are modeled with an impedance boundary condition using an effective copper surface resistance of 0.0052 Ω, including roughness, adjusted to reproduce the measured $Q_0 = 10757$.

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Figure 1: RFQ couplers attached to the testbox and to the coaxial waveguides.

RF losses from the electromagnetic model are transferred to a thermo-mechanical model and scaled by duty cycle. When attached to the RFQ, the coupler reaches about 52 °C at 300 kW peak power and 1 % duty cycle, with cooling only through contact with the RFQ flange (Fig. 3); RFQ cooling and tuning are described in [9]. In the conditioning test box, without active cooling, the inner conductor reaches about 73 °C at 1 % duty cycle (Fig. 4). These values are below the recommended limits for the PEEK window and vacuum gaskets, but external thermocouples will still generate RF interlocks if temperature increases above a limit.

Multipacting

Multipacting is expected to occur in the coaxial sections of the coupler. This effect has been studied in the RFQ couplers using *mpcx2*, the multipacting module of the ELCANO electromagnetic suite (home-brewed at ESS-Bilbao). The FEM electromagnetic solution is reused for electron tracking on the same mesh. For each RF power, a random electron population is generated on selected surfaces, tracked with a Boris-type integrator and multiplied according to a secondary-emission model after each impact that considers energy, angle and surface conditions. The calculation provides electron population growth and impact statistics as a

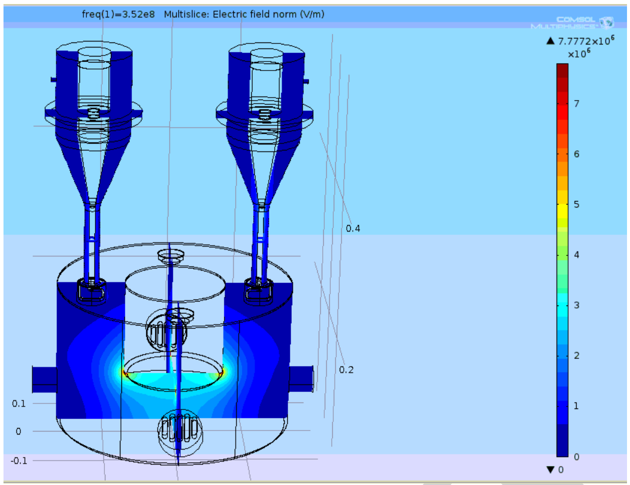

Figure 2: Electric field distribution in the couplers and test-box system. RF power (300 kW) is injected through one of the coaxial ports of the couplers.

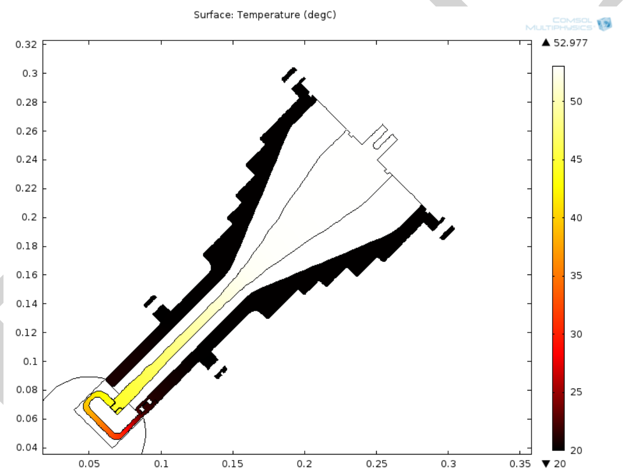

Figure 3: Temperature map in a coupler cross-section, when couplers are attached to the cooled-down RFQ body.

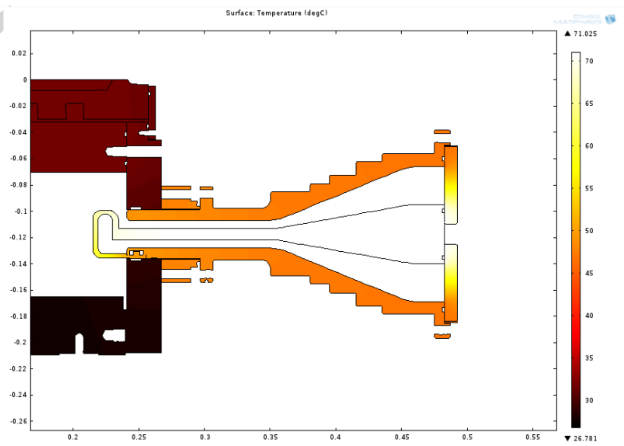

Figure 4: Temperature map in a coupler cross-section, when couplers are attached to the test box for conditioning, where there is no active cooling.

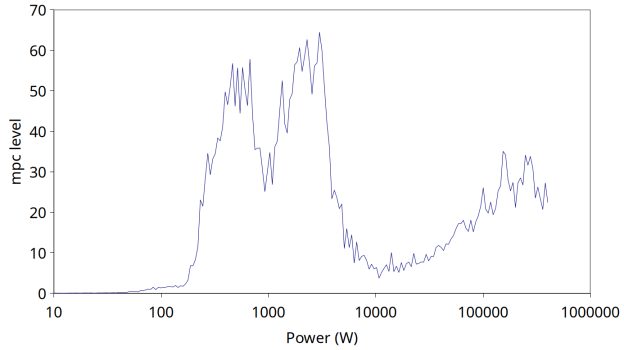

Figure 5: Multipacting (relative number of electrons with respect to the initial ones, after 10 generations) for the RFQ couplers attached to the test box. Bands of strong multipacting are clear for RF power below 10 kW.

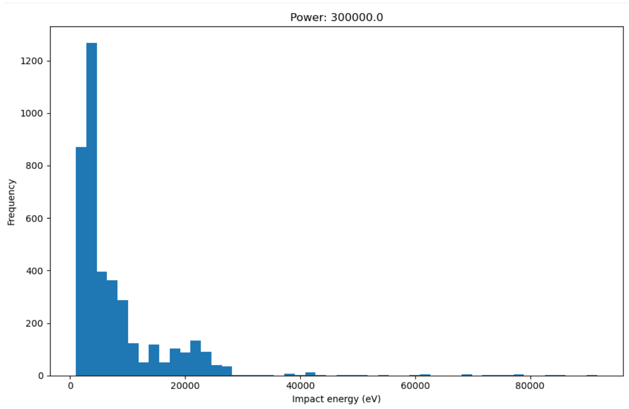

Figure 6: Spectrum of impact energies of the electrons on the surfaces of the couplers and test box system, at an RF power of 300 kW. This will be the energy of the x-rays emitted from the impact.

function of RF power. The software is fully scalable and can run in HPC computers for high numbers of electrons.

For the couplers in the test box, the main multipacting bands are found below 10 kW (Fig. 5), consistent with low-power conditioning observations [8]. At higher power the calculated electron population increases more gradually and can contribute to vacuum activity or perturb RF signals during conditioning. Multipacting in the couplers happens mainly in the taper section of the coupler, as well as in other parts of the coaxial sections.

The impact kinetic energy is also stored, giving information on the possible x-ray spectrum generated by electron impacts. Figure 6 shows the impact-energy distribution at 300 kW. Most impacts occur at low energy and will be shielded by the copper body, while the high-energy tail is relevant for radiation-shielding estimates. The corresponding maximum and average impact energies increase with RF power, as shown in Fig. 7. A corresponding attenuation function can be applied to the emission spectra to create a correct spectrum. The x-rays intensity detected outside can then be calibrated using reference calculations or measurements. The maximum energy of x-rays produced in the couplers

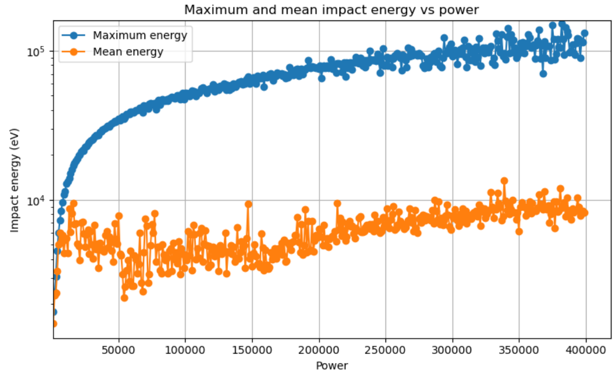

Figure 7: Maximum energy and average energy of the electrons when colliding with the metallic surface. X-rays of low energy will be fully shielded by the copper body.

increases with the square root of input power, proportional to maximum electric field. The average value also increases with power.

REFERENCES

[1] M. Pérez, F. Sordo, I. Bustinduy, J. L. Muñoz, and F. J. Villacorta, “ARGITU compact accelerator neutron source: a unique infrastructure fostering R&D ecosystem in Euskadi”, *Neutron News*, vol. 31, no. 2-4, pp. 19–25, 2020. doi:10.1080/10448632.2020.1819140

[2] J. Baggemann *et al.*, “High power target for the High Brilliance Neutron Source”, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 1069, p. 169912, 2024. doi:10.1016/j.nima.2024.169912

[3] Paulin, Mariano Andrés *et al.*, “The HERMES reflectometer at the JULIC neutron platform”, *EPJ Web Conf.*, vol. 286, p. 03003, 2023. doi:10.1051/epjconf/202328603003

[4] J. L. Muñoz, I. Bustinduy, I. Rueda, and D. de Cos, “Development of the radio frequency quadrupole proton linac for ESS-Bilbao”, *EPJ Web Conf.*, vol. 231, no. 02001, pp. 173–196, 2020. doi:10.1051/epjconf/202023102001

[5] “ESS-Bilbao RFQ Technical Design Report”, ESS-Bilbao, Zamudio, Rep., May 2015.

[6] J. L. Muñoz *et al.*, “Update on ESS-Bilbao RFQ LINAC”, LINAC2024, Chicago, IL, USA. (MOPB034), 2024, doi:10.18429/JACoW-LINAC2024-MOPB034,

[7] J. L. Muñoz, I. Bustinduy, D. Fernandez-Cañoto, and e. a. Garmendia, “ARGITU RFQ bead-pull tuning and RF tests at ESS-Bilbao”, presented at IPAC’26, Deauville, France, May 2026, paper THP4030, this conference.

[8] I. Bustinduy *et al.*, “ESS-Bilbao RFQ Power Coupler: Design, Simulations and Tests”, in *Proc. HB’23*, Geneva, Switzerland, pp. 433–435, Mar. 2024. doi:10.18429/JACoW-HB2023-THBP01

[9] J. L. Muñoz, I. Bustinduy, D. Fernandez-Cañoto, and e. a. Garmendia, “Cooling skid, thermal characterization and simulation for the ARGITU RFQ at ESS-Bilbao”, in *presented at the 17th International Particle Accelerator Conf. (IPAC’26), Deauville, France, May 2026, THP4031, this conference.*, 2026.