A NEW HIGH DUTY FACTOR RFQ INJECTOR FOR ISIS[1]

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Abstract

The ISIS at RAL is going to be upgraded by a new injector. This injector will supply H^--ions with beam currents up to 50 mA. It consists of a new ion source and a four-rod RFQ accelerator, designed for a duty factor as high as 10 %. In this paper the RFQ accelerator and the status of the project is being described.

1. INTRODUCTION

Rutherford Appleton Laboratory has a long-term experience in operating the ISIS neutron source [1]. Presently, the H^--Penning source is followed by a Cockroft-Walton injector and an Alvarez Drift Tube Linac. The ion beam is injected into the Synchrotron by charge change injection and finally sent to a heavy metal target.

The general data of the accelerator are the ion source extraction voltage of 35 kV, the injector output energy of 665 keV, the linac output energy of 70 MeV and the ISIS final energy of 800 MeV. In early 1997, a beam current of more than 55 mA has been reached with a stable operation at 2.5 % duty cycle. As the average beam current in regular operation is 0.2 mA, the average beam power at the target is as high as 160 kW. For the next generation neutron source, the European Spallation Source ESS, a duty cycle of 6.5 % is planned, with a beam power of 5 MW (1.34 GeV).

A new RFQ injector is being built for ISIS. The resonance frequency of the existing Alvarez Drift Tube Linac, and therefore of the new RFQ is 202.56 MHz It will be able to accelerate beam currents of 50 mA with high transmission. A later upgrade would allow beam currents up to 100 mA with 85 % transmission.

The main design feature of the new RFQ is the high duty cycle of 10 %, which is comparatively high for this kind of RF proton accelerators. Higher duty cycles have been used for heavy ion acceleration, e. g. at GSI for the HLI [2], but at lower frequencies.

The ISIS upgrade is a project which will improve the performance of ISIS and be helpful for the medium-term installation of ESS, because the injector can be tested under realistic conditions and later on be used for ESS. So it serves as a test bench for the future ESS injector.

The present plans for the European Spallation Source provide ESS project 107 mA beam current. This will be achieved with two RFQs, each accelerating 54 mA at 175 MHz, values, close to the parameters of the ISIS injector upgrade.

2. HIGH DUTY CYCLE RFQ

High Duty Factor accelerators have been used successfully for lower frequencies. At GSI Darmstadt, the Unilac HLI is working at 108.5 MHz at 25 % duty factor. Lower frequencies usually go along with larger resonators, therefore the power load is distributed on a larger surface. In the case of the four-rod-RFQ-structure most of the power is concentrated on the resonator insert, 33 % of the power is lost on the electrodes. Therefore, the electrodes are cooled by cooling tubes brazed to the back side of each electrode. Good experiences with this electrode cooling system have been made at GSI, the HLI-RFQ has been operated with an average power up to 15 kW/m.

A similar design will be used in the case of the H^--RFQ (202.56 MHz), where 40 % of the power is lost on the electrodes.

A short RFQ-resonator structure for high power operation (c.w.) has been built and tested. It worked well at c. w. at 20 kW/0.3 m, which corresponds to 60 kW/m, well above the required power for the ISIS upgrade [3].

3. PARTICLE DYNAMICS

The particle dynamics design is based on the methods used for compact RFQs [4]. It uses adiabatic variation of parameters and rather high electrode voltage of 80 kV to have a high acceptance at a large aperture. The results have been tested with PARMTEQ simulations. Table 1 shows the beam dynamics parameters. Figure 1 shows results for simulations using the ideal two term potential.

E in	35 keV
E out	665 keV
ε^{in}_{norm}	1.00 π mm mrad
ε^{out}_{norm} (50 mA)	1.05 π mm mrad
ε^{out}_{norm} (100 mA)	1.15 π mm mrad
$\varepsilon_{,rms}$	0.07 °MeV

Table 1: Beam parameters of the RFQ.

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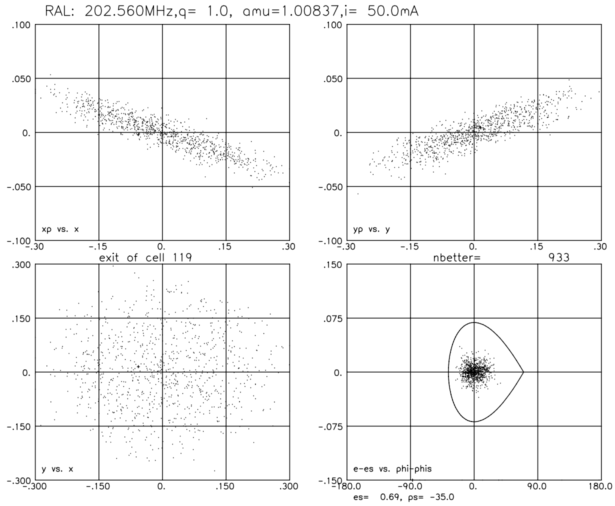

Figure 1: Particle output distribution.

A particle dynamics code which solves the field equations with respect to higher multipole components has been developed by Letchford [5]. These components appear due to the non-hyperbolic shape of the rod electrodes and the ratio of aperture to rod diameter chosen. The calculations showed that the design done for ideal quadrupoles needs only small modifications to match the properties of the hyperbolicly shaped electrodes, respectively the geometric parameters have to be changed slightly to give the same beam dynamic results as for the ideal profile.

The multipole components can also be taken from MAFIA calculations, regarding the unavoidable multipole effects of the four rod structure with stems [6].

For achieving a good output emittance matching, the last cell of the accelerator has a special shape: it consists of half a RFQ-cell and one half cell with a symmetrical output matcher [7].

4. RF CALCULATIONS

Two requirements had to be combined in the new RFQ injector: High duty cycle and high electrode voltage, resulting in a very high average power load on the resonator.

MAFIA calculations have been done for optimizing the efficiency of the resonator and the field distribution.

One important topic was the increase of the resonance frequeny with use of thicker stems, compared to earlier designs. The frequency of a resonator with standard stems is lower than 200 MHz. To reach the desired resonance frequency of 202.56 MHz, a set of tuning plates is mounted between the stems. With bigger stems the basic resonance frequency is somewhat higher than for RFQs for lower duty cycle.

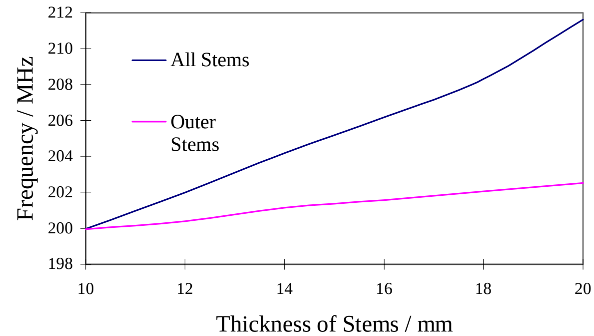

Figure 2: Resonance frequency vs. stem thickness.

For reaching a good flatness along the beam line, various arrangements of tuning plates have been calculated with MAFIA. Figure 3 shows a plot of a field distribution for four tuning plate positions. The flatness percentage means the difference between the interelectrode voltage at the position z and the average intervane voltage ($f_z=(E-E_{av})/E_{av}$) along the beam axes. The parameters are the distance of the tuning plates, placed in the structure, to the beam axis, in the first and the last resonator cell.

Figure 3: Flatness.

Figure 4 shows the power loss distribution in one cell, where brighter shades mean higher current densities and power loss per area. Figure 5 shows a Mafia plot of the resonator structure.

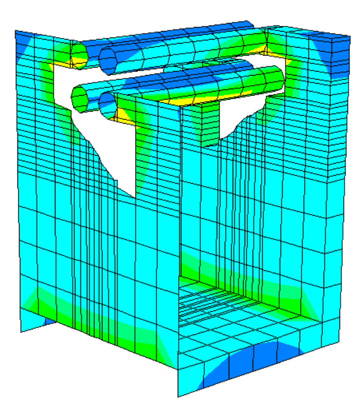

Figure 4: Power loss distribution in one resonator cell.

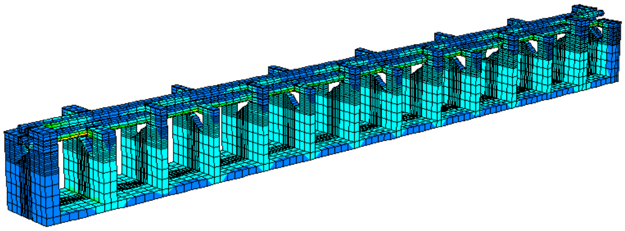

Figure 5: Mafia plot of the rf structure.

5. MECHANICAL DESIGN

For the layout of the cooling system indirect cooling by heat conduction in massive copper must be compared with cooling with a maximum number of cooling water tubes. It is important that the largest temperature difference for heat transport occurs at the transition from hot surfaces to flowing cooling fluids. Nevertheless, the effect of direct water cooling can only be exceeded if big solid copper parts are used. Cooling by massive copper parts can be comparable e.g. at the base plate of the RFQ insert.

For the ISIS RFQ a resonator without any water-to-vacuum seals has been chosen. Where pipes have to be connected to massive copper stems inside the vacuum, they are brazed. The sealing of the cooling tubes against air is done with viton seals, sealing the stainless steel cooling pipes at the back of the resonance insert against the ground plate of the vacuum tank

The vacuum tank for the 4-Rod-RFQ has been slightly modified for high power operation to allow the pass-through of the 32 cooling pipes through the massive base plate.

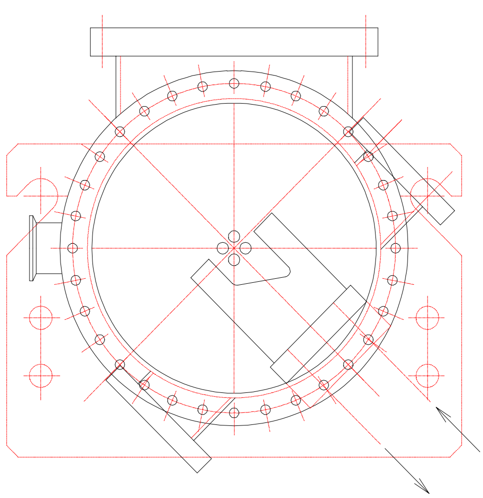

Figure 6: Cross section of the RFQ.

Calculations of heat transportation in the rf structure showed that a direct cooling of the ground plate is not necessary, as long as the stems are cooled. The temperature of the water will rise about less than 10°C at the electrodes and the stems with a water flow of 3 l/min. The highest surface temperatures on the copper will be 55°C. Detailed calculations have been done by Murdoch [8] with a Finite Element Algorithm code. Experiments with models have been in good agreement with the simulations. Figure 7 shows a cross section of a directly cooled stem.

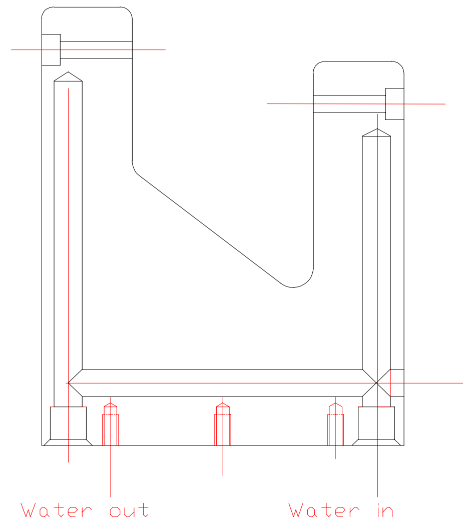

Figure 7: Cross section of a stem.

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Table 2: RFQ specifications

Total Length	1190 mm
Diameter	250 mm
Frequency	202.56 MHz
Q-Value	3000
Shunt Impedance	65 kΩ

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