DESIGN OF A HIGH CURRENT H^--RFQ INJECTOR *

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Abstract

High current H^--RFQs are injectors for the planned new spallation sources like ESS and NSNS. Critical points are the high current, the low emittance and the high duty factor of the injector. The strongest existing spallation source ISIS at RAL presently is still operating with a Cockroft-Walton injector. RAL now will upgrade that column by a new RFQ injector, where some of the features of the new proposed ESS injectors can be tested. A Four-Rod RFQ at 202 MHz with a duty factor up to 10% and H^- currents of 50 mA are input values for the rf-structure design and beam dynamics. Results of this design work will be presented.

1 GENERAL

The most critical point of the RFQ operation is a high duty cycle. Table 1 shows RFQ structures in operation or designs. One can see that the duty cycle of these types is bigger than the average duty factor values of other structures.

RFQ	Beam Current	Duty cycle
HLI	U^{28+} 5 µA	25 %
HSI	U^{4+} 25 mA	1 %
DESY	H^- 20 mA	< 0.1 %
CERN	H^- 150 mA	< 0.1 %
Design:		
APT	H^+ 100 mA	100 %
ESS	H^- 107 mA	6.5 %
RAL	H^- 50 mA	10 %

Table 1: Different RFQ Structures.

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1.1 High Duty Cycle RFQs

The first c.w. RFQ applications were the normal conducting IFMIF [1] and the cryogenic CWDD [2], the APT (Accelerator Production of Tritium) [3, 4] and Ground Test Accelerator RFQs.

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In both cases cooling was a critical part of the design and required most engineering efforts. For the Four-Rod structure c.w. operation was done at early work for convenience at rather low average power [5].

We have started again investigation of high duty factor RFQs: The GSI-HLI has a duty factor of 25 % and a thermal power of 15 kW/m, the cyclotron injector for the HMI Berlin will operate at continuous wave and 15 kW/m, too.

A special resonator for c.w. operation has been built and tested [6]. This prototype is a four-stem model with unmodulated electrodes for testing RF properties. It had 16 small viton seals (water - vacuum). Although this concept worked reliably at 20 kW thermal power (20 kW c.w.), it will not be used in a real working RFQ, as the use of water-vacuum seals is not the choice for operational reliable Four-Rod RFQs at high power operation. For an operating RFQ the 10 % duty factor envisaged for RAL is one step in the direction of continuous wave.

1.2 Intense Spallation Ion Source

The ISIS at Rutherford has a long term operation experience with Penning sources [7, 8]. Recently, more than 55 mA of H^- ions have been extracted stably with 2.5 % duty cycle. The 6.5 % d. c., as required for ESS, can be possible with more cooling operation.

1.3 ESS Specifications and Requirements

The design concept for the european spallation source project ESS [9] requires beam currents of 107 mA at the beginning of the DTL. Two RFQ injector linacs with 54 mA each are funnelled into that first DTL stage at an energy of 5 MeV. The beam has to be bunched, so that it can be accelerated in a High Energy Linac to an energy of 1.334 GeV, and then be injected into two compressor rings. Therefore two beams with 54 mA each have to be funneled in a two beam RFQ and a Funnel Section, with a bunch repetition rate of 350 MHz. For a proper operation of the compressor rings the Linac beam has to be chopped with a 60 % duty factor at the ring revolution frequency of 1.67 MHz (360 ns pulse and 240 ns gaps, within a macro pulse of 1.2 ms).

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2 SPALLATION SOURCE APPLICATION

The RAL Injector

The ISIS-Facility at the Rutherford Appleton Laboratories is still the most powerful pulsed neutron source in operation. The Linac consists of a 665 keV Cockroft-Walton injector and an Alvarez DTL (202 MHz), accelerating up to 70 MeV for charge exchange injection into the 800 MeV ISIS-Synchrotron. The average beam current is 0.2 mA, the beam power at the target as high as 160 kW.

The existing H^- Penning ion source works at an extraction voltage of 35 kV. The Cockroft-Walton generator will be replaced by a Four-Rod RFQ, which must be able to accelerate H^- ions with a beam current of 50 mA. It is designed in a way that for future upgrade the current can be increased up to 100 mA with 85 % transmission.

The Four-Rod RFQ Resonator

The principle of a Four-Rod RFQ structure is shown in figure 1. The electrodes are carried by stems, which are about 10 mm thick, in case of typical small values for the power loss. If higher power losses have to be considered, special cooling pipes (see figure 4) have to be inserted and therefore the stems have to be thicker. MAFIA Calculations have been made concerning the resonance frequency as function of the thickness of the stems. Figure 5 shows the resonance frequencies for different stem thicknesses. Other MAFIA calculations gave the distribution of the power loss on the RFQ structure, as shown in the following table.

Power Loss Distribution	
Electrodes	34 %
Stems	44%
Ground Plate	22 %

For the new RFQ injector rf power supplies up to 300 kW are available at RAL, but only about 200 kW will be necessary, plus 35 kW beam loading. With the duty cycle of max. 10 % (four times more than the duty factor at present) the thermal power is about 20 kW, for that reason a special cooling concept for the RFQ resonator will be used, which follows the design successfully tested at GSI. A backing cooling tube at the electrodes will be used for that resonator (figures 1, 3 and 4).

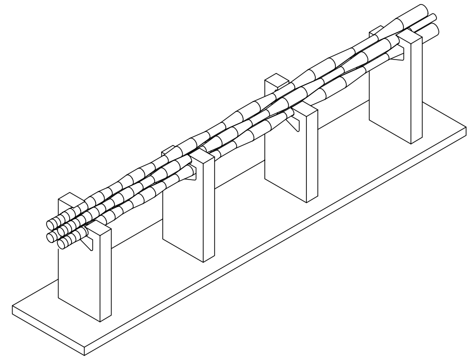

Fig. 1 : Principle of a Four-Rod RFQ Structure.

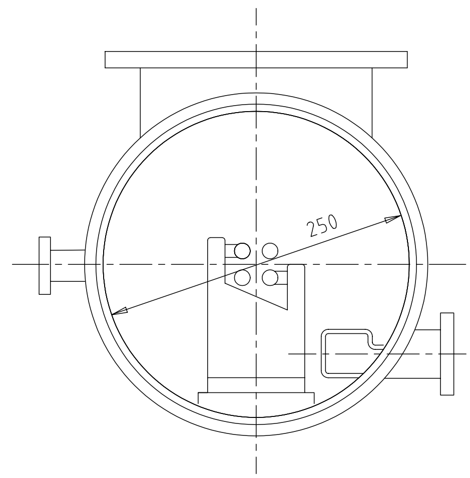

Fig. 2: Typical cross section of a Four-Rod RFQ resonator.

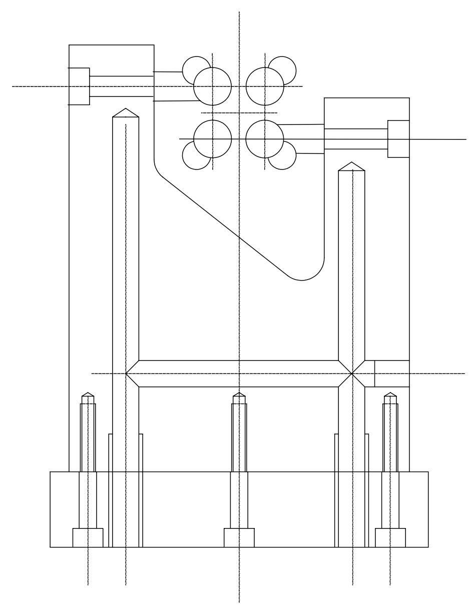

Fig. 3: Cross-section of the stems.

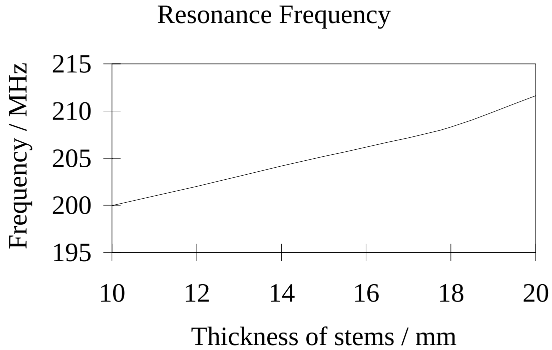

Fig. 4: Resonance frequency for different stems.

3 PARTICLE DYNAMICS

Particle dynamics calculations have been done with the code PARMTEQ [10]. The results are shown in figure 5, the output emittances for 50 mA in the following table.

Beam dynamics parameters	
$\varepsilon^{in}_{rms\ norm}$	1.00 πmmmrad
$\varepsilon^{out}_{rms\ norm}$ (50 mA)	1.05 πmmmrad
$\varepsilon^{out}_{rms\ norm}$ (100 mA)	1.15 πmmmrad
$\varepsilon_{l,\ rms}$	0.07 °MeV

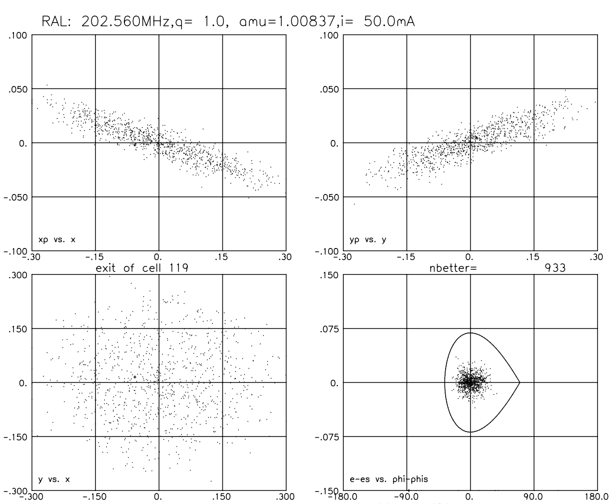

Fig. 5: Particle Output Distribution of the RAL-RFQ.

4 STATUS OF THE WORK

The electrode design calculations for the RAL-Injector are finished. Decisions concerning the resonator design have been made, taking into account the high duty cycle requirements. The construction of the resonance structure is now in progress. RAL has already prepared a complete test stand, where the properties of the new structure will be tested before it can finally replace the Cockroft-Walton generator at the ISIS Linac.

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REFERENCES

[1] D.D. Armstrong, ´Recent Performance of the FMIT RFQ´, Proc. Linac 84, GSI 84-11(1984), p. 53,

[2] G. McMichael, J. Carwardine, I. Clarkson, P. Den Hartog, R. Paopsco, G. Pile, L. Sagalovsky, T. Yule, ´CWDD Accelerator at Argonne - Status an Future Opportunities´, Proc. EPAC 94, p. 131,

[3] G. Lawrence, D. Barlow, J. Billen, B. Bing, K. C. D. Chan, R. Garnett, R. Gentzlinger, E. Gray, D. Gurd, F. Krawcyzk, M. Lynch, S. Nath, A. Regan, D. Rees, A. Rohlev, B. Rusnack, R. Ryne, J. D. Schneider, D. Schrage, R. Shafer, J. Sherman, J. Stovall, H. Takeda, P. Tallerico, T. Wangler, R. Wood, L. Young, ´Conventional and Superconducting RF Linac Design for the APT Project´, Proc. Linac 1996, p. 710,

[4] D. Schrage, P. Roybal, L. Young, W. Clark, R. Depaula, F. Martinez, A New RFQ Linac Fabrication Technique, Proc. Linac 94, KEK, Tsukuba (1994) p.152,

[5] A. Schempp, H. Klein, H. Deitinghoff, P. Junior, M. Ferch, A. Gerhard, K. Langbein, N. Zoubek, ´Zero-Mode-RFQ Development in Frankfurt´, Proc. Linac 84, p. 150,

[6] U. Beisel, ´Aufbau und Untersuchung eines RFQ-Beschleuniger-Moduls für hohe mittlere Leistungen´, Diploma Thesis, Institut fuer Angewandte Physik, Frankfurt (1996),

[7] R. Sidlow, P.J.S. Barratt, A. P. Letchford, M. Perkins, C. W. Planner,´Operational Experience of Penning H^- Ion Sources at ISIS´, Proc. EPAC 1996, p. 1525,

[8] N. D. West, ´The Rutherford Laboratory 70 MeV Linear Accelerator´, Proc. Linac 79, p. 88,

[9] A. Schempp, J. Madlung, A. Firjahn-Andersch, H. Deitinghoff, G. Parisi, ´RFQ-, Chopping-, and Funneling-Studies for the ESS-Injector´, Proc. XVII International Linear Accelerator Conf., CERN 96-07 (1996) p. 47,

[10] J. Billen, L. Young, ATO, LANL Code Group.