DEVELOPMENT OF SPLIT COAXIAL HEAVY ION RFQ ACCELERATORS*

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Abstract

A 1:4 scaled proton model of a heavy ion RFQ has been built up at the Institut für Angewandte Physik. New experimental results are presented together with beam simulations using the PARMTEQ-code. Whereas the rf and general accelerating properties proved to be satisfying as expected, problems arose with mechanical adjustment and the beam matching due to the chosen phase advance and the effects of higher spatial harmonics. The experience was taken into consideration for an improved RFQ design with higher σ_{0t} and suggested to build up the MAXILAC at GSI without any further model studies. Beam simulations show the improvement of the MAXILAC design.

A split coaxial resonator has also been used in a recent beam transport experiment.

Design A - The proton model

Based on a proposal for a heavy ion RFQ using split coaxial resonators (SCR) with drift tubes and focussing fingers[1] a proton model has been operated satisfactorily. Structure data are listed in tab. 1. The electrode voltage chosen corresponds to 2 times Kilpatrik's limit in the heavy ion case. In spite of this high value the phase advance is only as high as 15°-23°. In comparison to our previous reports[2,3,9] the following alterations have been made:

- The drift tubes in section 3 have been realigned, because a former misalignment caused a drop in transmission.
- A new 1 kW transmitter allowes the operation of the proton model up to voltages of 5000 Volt.
- A new ion source with a new extraction system together with an Einzellens-system provides a higher current in lower emittance at better matching conditions. (fig. 1)
- As opposed to the previous acceleration of protons a beam consisting mainly of H_2^+-ions (80%) is now injected directly without any mass separation. With the injection energy of 5 keV and a design rf-voltage of 3800 V acceptances remain unchanged for H_2^+-ions, whereas the current limit is doubled.

The proton model is operated at different rf-voltages to test beam dynamics and to compare results with computer simulations. The output energy remains nearly unchanged because of the fixed velocity profile of the RFQ. Here a new synchronous phase is adjusted in such a way that $V \cdot \cos\phi_s$ remains constant. Simultaneously the transverse phase advance σ_{0t} can be raised from the design value of 15°-23° to over 90°. In this way the proton model offers a variety of possibilities to test the RFQ-design with different ions, input energies and rf-voltages.

Tab. 1 Structure data of SCR accelerators

	proton model	MAXILAC design A	MAXILAC design B
place	IAP Frankfurt	not built	GSI
ion	H_2^+	U^{2+}	U^{2+}
rf-frequency	54 MHz	13.5 MHz	13.5 MHz
aperture diameter	6 mm	24 mm	12 mm
σ_{0t}	23°	23°	77°→36°
σ_{0l}	45°→16°	45°→16°→7°	40°→10°
β_{in}	0.23 %	0.23 %	0.23 %
β_{out}	1.07 %	2.3 % (1 %)	1.5 %
length	2.2 m	38.6m (8.8m)	20.4 m
rf-voltage	3.8 kV	225 kV	146 kV
current limit	0.4 mA	15 mA	30 mA

Fig. 2,3,4 and 5 show the measured energy spectra behind sections 2 to 5 as a function of rf-voltage. H_2^+-ions (W_{inj} = 5 keV) are accelerated to 30, 54, 86 and 115 keV respectively. These energies agree well to the design values and can be compared to the calculated spectra in fig. 6. For rf-voltages above 4000 V (2•design voltage for protons) the energy acceptance is even adequate for the acceleration of protons with the (wrong) input energy of 5 keV. Proton output energies are 15, 26, 42 and 57 keV behind the different sections. In addition the beam transport of ions with masses at about 18 amu is apparent at about 90 amu•keV.

A significant progress has been achieved in beam transmission. In comparison to former experiments with protons the transmitted H_2^+-current has been raised by a factor of 3 for the first 2 sections with same acceptance. In sections 3 to 5 an additional gain in transmission was achieved by realignment. Here the current is 10 times higher than before. Fig. 7 shows the transmitted current as a function of rf-voltage. The drop with number of sections is caused by the reduction of the transverse acceptance along the proton model and by still existing alignment problems due to the modular set-up of the resonators. Compared to the injected current we obtained a transmission of 25 % for H_2^+-ions behind section 2.

Although the transmitted current was raised, the expected space charge limit has not been reached, now being 2 times higher than for protons. PARMTEQ-simulation revealed a significant drop in acceptances as well as in current limits due to the effects of higher spatial harmonics in the RFQ potential compared to smooth-approximation results. Such behaviour necessarily occurs with heavy ion accelerators, where the phase advances have to be chosen small. In addition the source emittance is still too high to correspond to theoretical current limits of formulaes 10,11). Tab. 2 shows theoretical and experimental current limits.

Tab. 2 Current limits in the proton model (H_2^+)

rf-voltage	theor. value	PARMTEQ-simulation	reached after section 2
4000 V	400 μA	120 μA	35 μA
6000 V	3000 μA	600 μA	125 μA

Design B - The MAXILAC heavy ion RFQ

The results of the proton model operation confirmed the SCR-concept. The rf-properties showed good coupling between the SCR-sections without disturbing rf-modes. Misalignments only locally disturbing the RFQ-field distribution do not influence the rf-properties. Matching problems have been explained with computer simulations, which showed that the effect of spatial harmonics have been too high in the first design.

Thus it was possible to built up the MAXILAC at GSI without any further model studies with a new design.[4] (see tab. 1) A higher σ_{0t} was chosen and the influence of spatial harmonics was reduced as well. A shaper section was included raising the phase acceptance from 276° to 294° at initial ϕ_s = 81°. The improved properties of this design have been confirmed by PARMTEQsimulations[6]. Fig. 8 shows transverse acceptances before the matching section. Fig. 9 shows particle oscillations in energy-phase-space for the current limit case of 9.6 mA (Ar^+-ions) while theory yields a limit of 10 mA (tune depression 0.4). In first beam experiments at GSI[4,5] 6 mA Ar^+-ions have been accelerated. Results of the experiment are reported at this conference.[7]

SCR - beam transport experiment

A SCR with unmodulated electrodes has been constructed for experiments near space charge limits. (Fig. 10) Structure data and beam parameters are listed in tab. 3.

Tab. 3 Parameters of the SCR beam transport resonator

tank length: 38.5 cm	structure length: 43 $\beta\lambda/2$
tank diameter: 32.0 cm	frequency: 70.5 MHz
aperture: 5 mm	R_p – value: 130 kΩ

matching sections (in and out): $3\beta\lambda$ (linear taper)

Injected beam: H_2^+ 10 keV 0–7 mA

Tab. 4 shows phase advances, acceptances and current limits, the latter ones being compared to our measurements in fig. 11. Compared to the proton model it was possible to adapt the design of this SCR to the emittance and output current of the ion source; thus 70-80 % of the current limit were easily obtained. Our next aim is to operate this SCR with different input energies to investigate effects of the matching sections[8]. for different lengthes measured in terms of $\beta\lambda$.

Tab. 4 Phase advances and current limits of the SCR beam transport experiment

rf–Voltage	σ_{0t} (°)	α_{0t} (mm·mrad) unnorm.	I_{lim}(mA) (100%)	I_{exp}(mA)
2000 V	4.9	150	1.0	0.8
3000 V	7.4	220	2.2	1.7
4000 V	9.8	288	3.9	3.0
5000 V	12.3	354	6.0	4.0
6000 V	14.7	418	8.5	4.1

Conclusions

The SCR concept for RFQ-accelerators may now be considered as well developped. These resonators are very compact and can be combined in a modular way. Problems which arose concerning alignment and cooling have been solved. The coaxial inner conductor can be provided with various RFQ-electrodes (drift tubes with fingers, rods-modulated or not) making this concept applicable for many purposes. SCR resonators are most suitable for heavy ion RFQ's at low frequencies.

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References:

1) R.W. Müller, GSI-Report 79-7 (1979)
2) H. Klein et.al., IEEE Trans. Nucl. Sci. Vol. NS-30 4 (1983), part II, p.3313
3) GSI annual report 1983, (1984)
4) R.W. Müller et. al. GSI 84-5 preprint
5) H. Klein et.al., R.W. Müller, E.H.A.Granneman et.al., Low energy accelerating structures Proc. of the Int. Symp. on Heavy Ion Acc. and Appl. to Inertial Fusion, Tokyo (1984) (to be published)
6) W. Neumann, Inst. f. Angew. Physik, Int. Rep. 83-25 (unpubl.)
7) R. W. Müller et.al., this conference
8) R. Becker, N. Zoubek, this conference
9) J. Müller, doctoral thesis, University of Frankfurt, Inst. f. Angew. Physik (1983)
10) M. Reiser, Part. Acc. 8 (1978), p.167
11) P. Junior, Part. Acc. 13 ;3-4 (1983)p.231

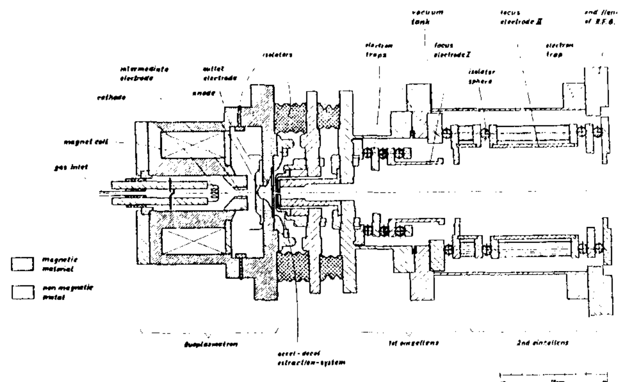

Fig. 1 Injection system with duoplasmatron ion source an new einzellens-system

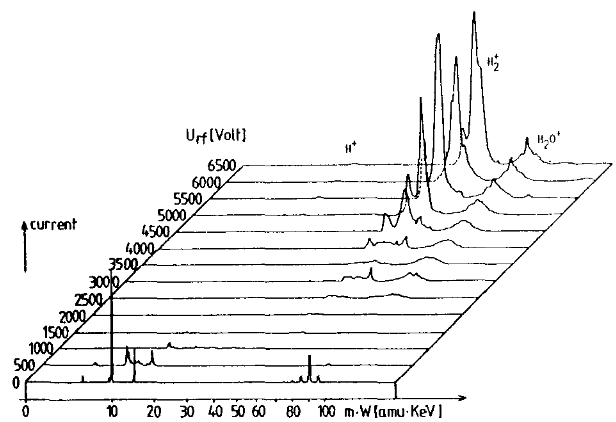

Fig. 2 Energy spectrum behind section 2 of the proton model

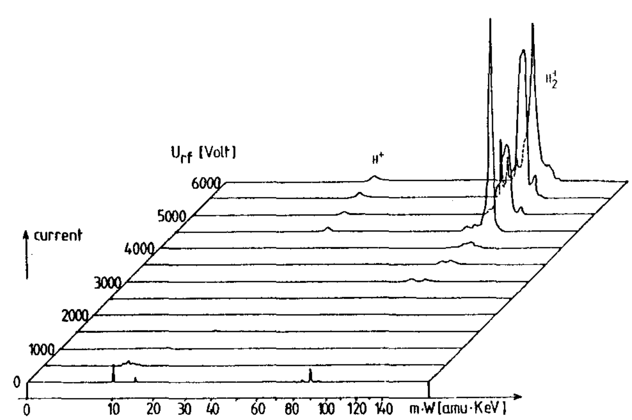

Fig. 3 Energy spectrum behind section 3 of the proton model

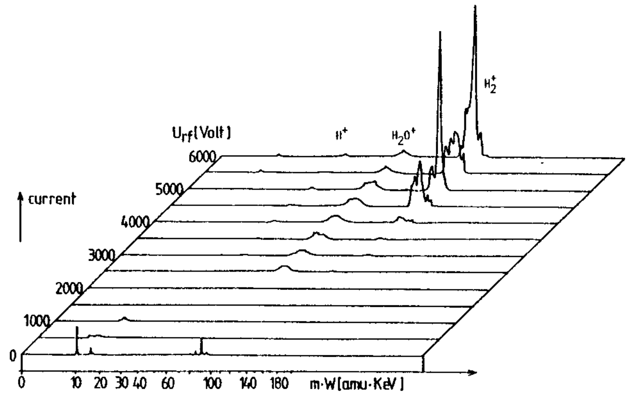

Fig. 4 Energy spectrum behind section 4 of the proton model

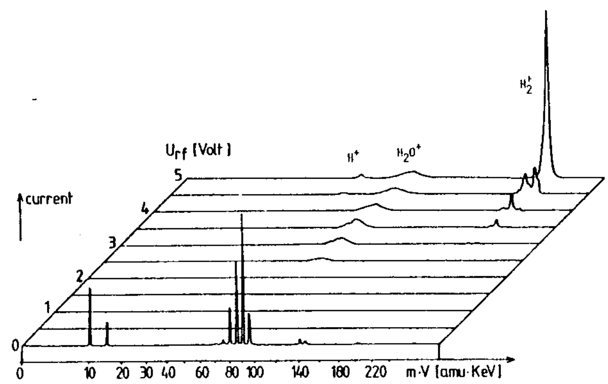

Fig. 5 Energy spectrum behind section 5 of the proton model

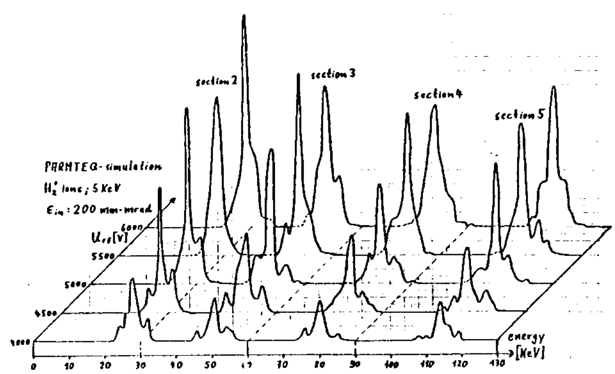

Fig. 6 Energy spectra behind different sections of the proton model

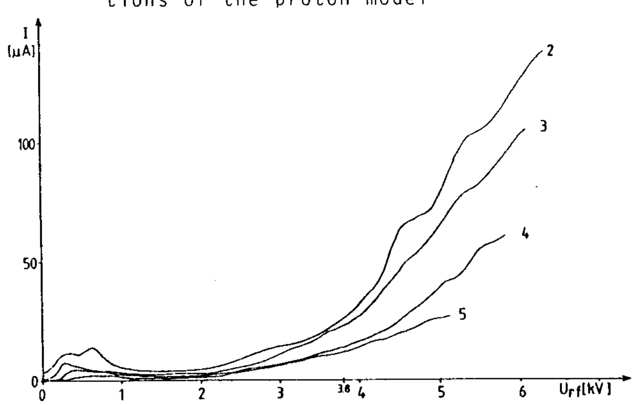

Fig. 7 Transmitted current behind sections 2 - 5 of the proton model as a function of RF voltage

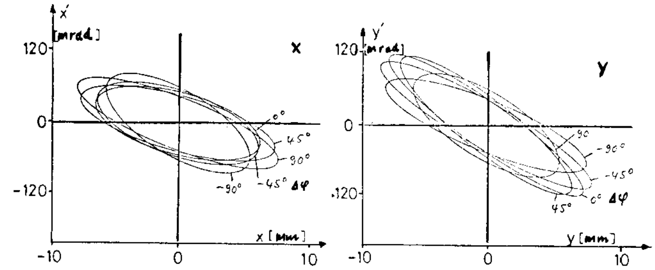

Fig. 8 Transverse acceptances of the MAXILAC-RFQ. Ar^+-ions, 90 keV, α=360 mm mrad

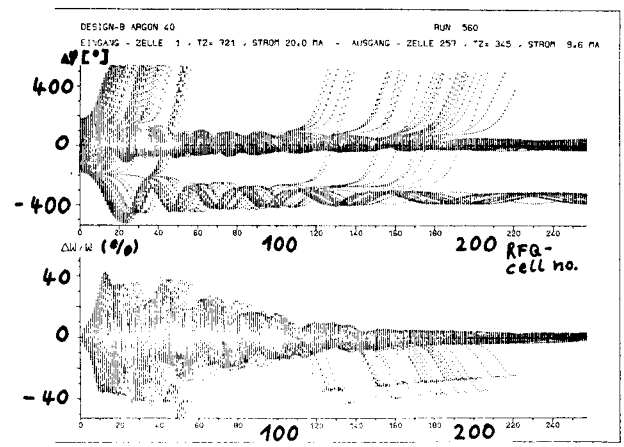

Fig. 9 Particle oscillations in MAXILAC-RFQ Ar^+-ions, 90 keV, transmitted current: 9.6 mA

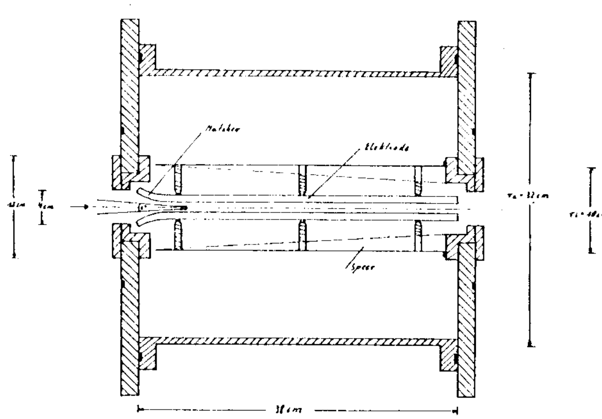

Fig. 10 Cross section of SCR for high current beam transport

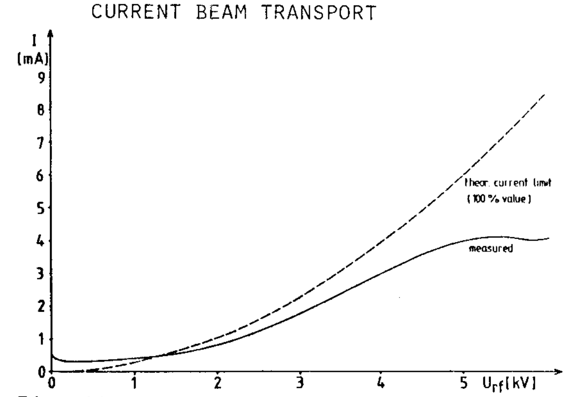

Fig. 11 SCR beam transport: Theoretical current limit and experimental result as a function of RF voltage