THE CRYRING RFQ FOR HEAVY ION ACCELERATION

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Abstract

An RFQ has been built for heavy ions (specific charge $q/A \geq 0.25$, energy 10 - 300 keV/u) for the storage ring CRYRING at the MSI Stockholm. The 4-Rod RFQ resonator has been designed, built, and tested in Frankfurt and is now installed at the injector beam line at MSI. The properties of this RFQ and first experimental results will be described.

Introduction

At the Manne Siegbahn Institute of Physics (MSI) the CRYRING facility is being built for atomic, molecular and nuclear physics [1,2]. The layout of CRYRING is shown in Fig. 1. It consists of a cryogenic electron beam ion source (CRYSIS), a radio frequency quadrupole (RFQ) and a synchrotron/storage ring. CRYSIS. built in close cooperation with the Institute de Physique Nuclaire in Orsay[3], delivers pulses of highly charged ions e.g. Ar^{18+}, Kr^{34+} and Xe^{44+}.

The RFQ accelerator is used as injector to the ring. It accelerates the ions from 10 keV/u to 300 keV/u and is designed to accept ions with charge q to atomic mass A ratio of $q/A \geq 0.25$. The ring (circumference 51.6m) will be able to accelerate the particles and store them at energies from 24 MeV/u (for $q/A = 0.5$) down to at least 100 keV/u. An RFQ[4] is a compact and efficient unit for accelerating low-energy ions and it introduces minimum emittance growth. It allows CRYSIS to be put on a platform with a moderate voltage of 50kV.

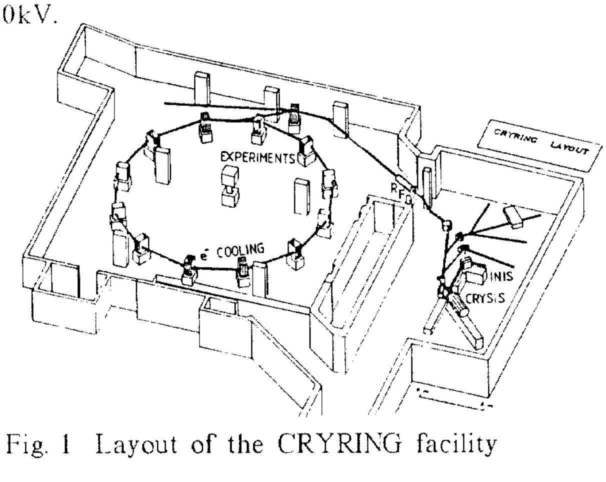

Fig. 1 Layout of the CRYRING facility

The RFQ is of the 4-Rod type shown schematicly in fig. 2, the structure developed in Frankfurt[5,6]. A rather low frequency of 108.5 MHz had been chosen to get an RFQ design with modest field strengthes allowing stable operation and also future extensions to lower charge to mass ratios.

Design features are a small size (tank diameter 35 cm, length 1.6 m), a good rf efficiency and modest mechanical tolerances. The injection into the ring requires an energy spread of less than 1 %. To obtain this small energy spread, a separate debuncher is placed 1 meter behind the RFQ.

RFQ beam dynamics

A new method of designing the electrode parameters along the RFQ has been applied for the first time. The advantage over the standard method with shaper, gentle buncher, and accelerator sections is a significantly shorter RFQ structure which saves costs and rf power without drawbacks in beam quality[7,8].

A special feature of the CRYRING RFQ is a prebuncher, consisting of four cells followed by a 12 cm long drift section without modulation. The prebuncher enables the following rapid increase in synchronous phase φ_0, and modulation factor m from 90° to 50° and 1.0 to 1.6 respectively. This change in φ_0 and m takes place in only 25 cells (21 cm). Then follows a slower linear increase to the final values $\varphi_0 = 25^\circ$ and $m = 2.0$.

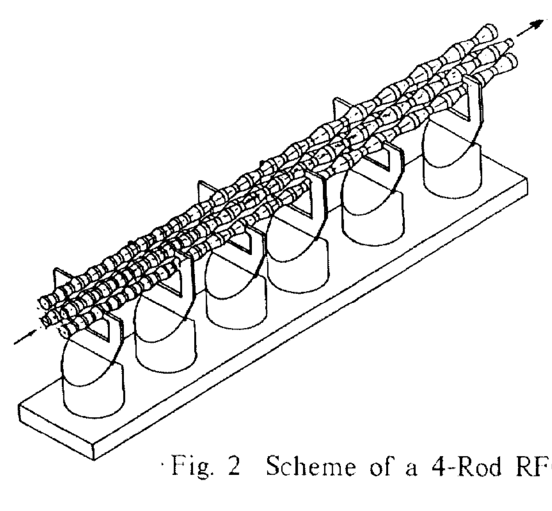

Fig. 2 Scheme of a 4-Rod RFQ

Additionally the special design increases the smallest distance between the rods. Thus an increased voltage can be applied between the rods without sparking. The design voltage of 70 kV between the rods (for q/A = 0.25) corresponds to a surface electric field of approximately 1.6 times the Kilpatrick limit for sparking[9], which is very safe for the short rf-pulses of less than 1 ms and gives a possibility to increase the voltage and accept ions with lower charge to mass ratios.

RFQ resonator design

In the design work and in RFQ resonators with vane-shaped electrodes the field can be derived from a two term potential. For cylindrical electrodes the higher order modes occur, but they are not important, if the aperture is not fully used. Experiments with approximations of the ideal sinusoidal modulation, with a nearly constant electrode cross section by conical and cylindrical parts with varying cross sections, because of the machining on a lathe, had shown little influence on beam quality[10]. Therefore for the CRYRING RFQ with sinusoidal variation of radii no problems were envisaged.
The rf resonator driving the electrodes consists of a chain of coupled $\lambda/2$-transmission line resonators. Four $\lambda/2$ cells resp. twelve supporting stems, which correspond to the inductivities, are arranged linearly on a common base plate. In this arrangement currents are confined in the resonant stem-electrode structure, which allows cooling of the resonant copper structure by water-flowing through bores in the stems. Fig. 3 shows a view of the CRYRING RFQ.

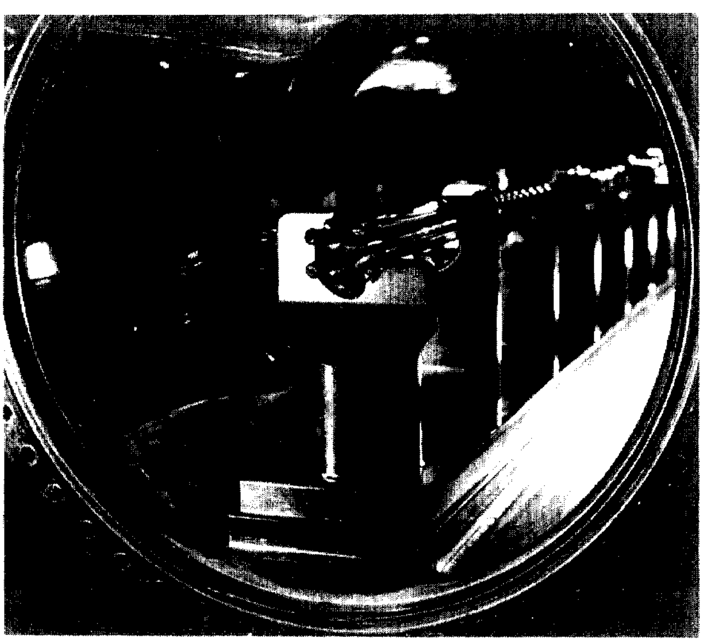

Fig.3 View of the CRYRING RFQ

Experimental results

The 4-Rod RFQ has been assembled and tuned in Frankfurt. The Q-Value of the resonator was Q=3500 the shunt impedance R_p ($R_p = U^2 L_c/N$, U electrode voltage, N rf power, L_c cavity length) was as high as 215 kΩm. Thus, much less power than anticipated is needed. First rf-tests showed no multipacting and very stable operation up to the maximum power level of 85 kW (2% duty cycle) which corresponds to an electrode voltage of U=110kV. There was no sparking at all.
Beam tests were done using a set up of a duoplasmatron with an einzellens for matching, injecting directly into the RFQ and a system of analyzing magnet and our slit/grid emittance measurement device[11]. Fig. 4 shows an energy spectrum in comparison with theoretical values[12]. The value of the final energy is T_f = 310 keV/u, the energy spread $\Delta T/T$ only 3.5keV (FWHM). Fig.5 shows the result of an emittance measurement. Fig.6 shows for comparison calculations using the

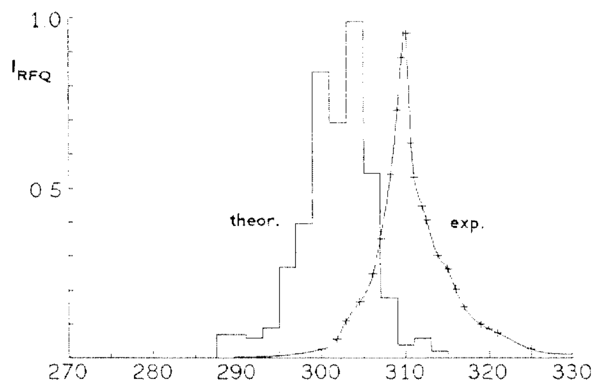

Fig. 4 Ion energy spectra

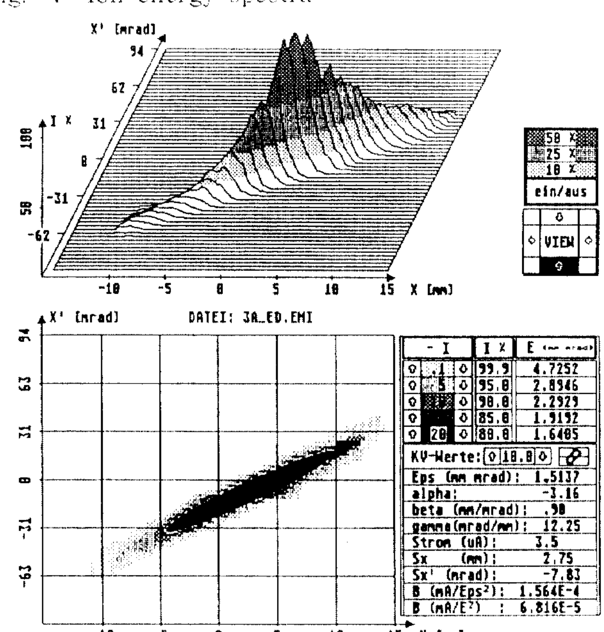

Fig. 5 Measured radial beam emittance

data of the ion source and the injection system, which are in good agreement and indicate very small emittance growth.
After these successful tests, the RFQ has been transported to MSI Stockholm, assembled and operated at the CRYRING injection line.
To be independant from CRYSIS, a separate ion source, similar to the Danfysik type 910 source[13], on a 50kV platform has been set up for beam tests of the RFQ and the injection into the ring. The beam is matched and transported to the RFQ with two electrostatic triplet lenses as indicated in Fig. 7. The rf-transmitter consists of two parallel stages (Itelco FM) which are combined for the design value 100kW pulse power as indicated in Fig. 8. Beam tests were done with P, H_2^+ and $^3He^+$ beams. A Si detector measured the energy of ions scattered on a gold foil behind the RFQ. An example is shown in Fig.9.

Status

The CRYSIS ion source is working and will be used for atomic physics experiments.
The RFQ is operational. The installation of the debuncher, the completion of the injection line and first experiments with an injected beam into the ring will be the next steps. The ring itself is planned to be completed end of 1990 [14].

Acknowledgements

The authors thank all collegues for their help, especially G. Hausen, K. Küllenberg and I. Müller (Univ. Frankfurt). We thank the Swedish Telecommunication Department (Hörby) for helping to built the transmitter and GSI for copper plating the tank.
One of the authors (A. Sch.) has to give special credit for Swedish hospitality, confidence, patience, and taste.

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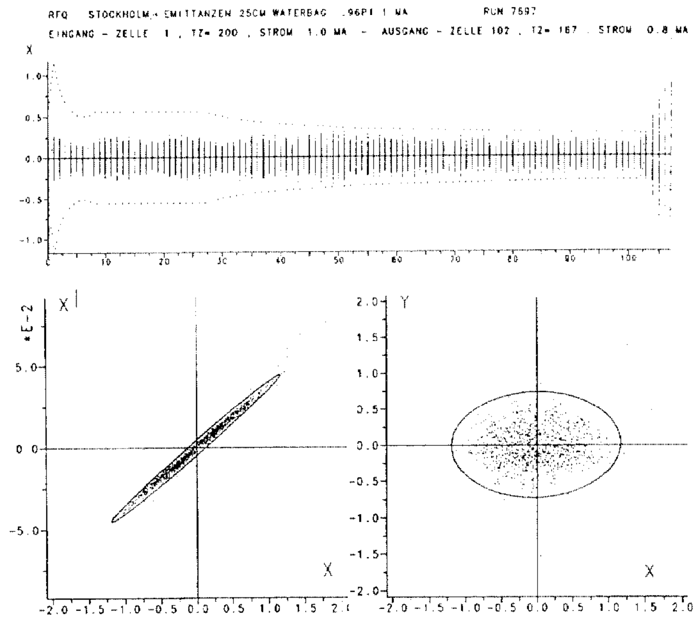

Fig. 6 Simulation of the output beam

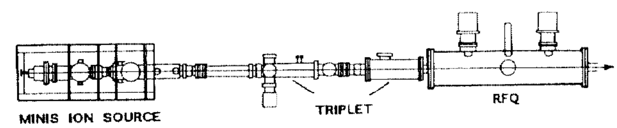

Fig. 7 Experimental set up at MSI

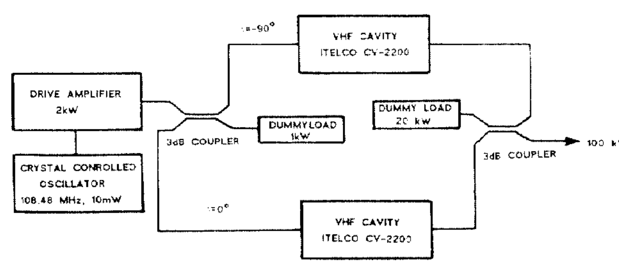

Fig. 8 Block diagram of the rf-transmitter

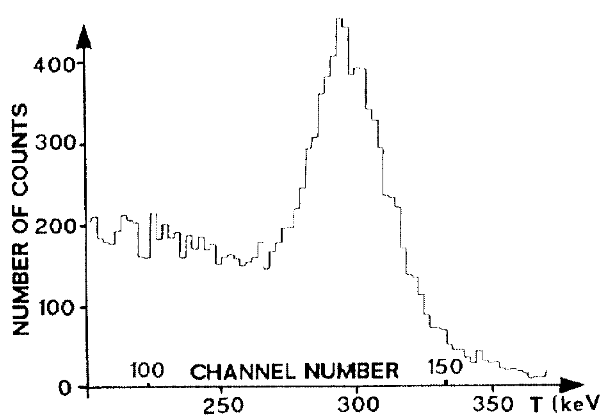

Fig. 9 Energy spectrum for protons