# THE CRYRING RFQ

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An RFQ is being built as an injector for the CRYRING project in Stockholm. It will accelerate ions with a specific charge q/u ≥ 0.25 from 10 keV/u to 300 keV/u. The 4-Rod RFQ developed in Frankfurt is used together with an improved electrode design leading to a short and efficient RFQ structure with good emittance and transmission. With help of an additional debuncher the energy spread will be below 1%. The status of the project and first results will be presented.

## INTRODUCTION

At the Manne Siegbahn Institute of Physics 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 will deliver pulses of highly charged ions e.g. $Ar^{18+}$, $Kr^{34+}$ and $Xe^{44+}$. The RFQ accelerates the ions from 10 keV/u to 300 keV/u and is designed to accept ions with charge to mass ratio greater than 0.25. The ring 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[3] has been chosen as accelerating structure as it 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 moderate voltage platform (50 kV) instead of the huge and unpractical 1.2 MV platform needed for electrostatic acceleration to 300 keV/u. We have decided to build a 4-Rod RFQ (fig. 2) of the kind developed in Frankfurt[4]. It is well suited for low current, heavy ion acceleration, where a rather low frequency of around 100 MHz has to be chosen.

Design features are small size (tank diameter 35 cm, length 160 cm), good RF efficiency and relatively modest mechanical tolerances. The injection into the ring [5] requires a small energy spread of less than 1 %. To obtain this energy spread, a separate debuncher will be placed 1 meter after the RFQ. Due to the very high vacuum in the ring, attempts have been made to obtain a good vacuum in the RFQ. This has lead to a design with metals seals and the unit can be moderately "baked" to $150^0$ C.

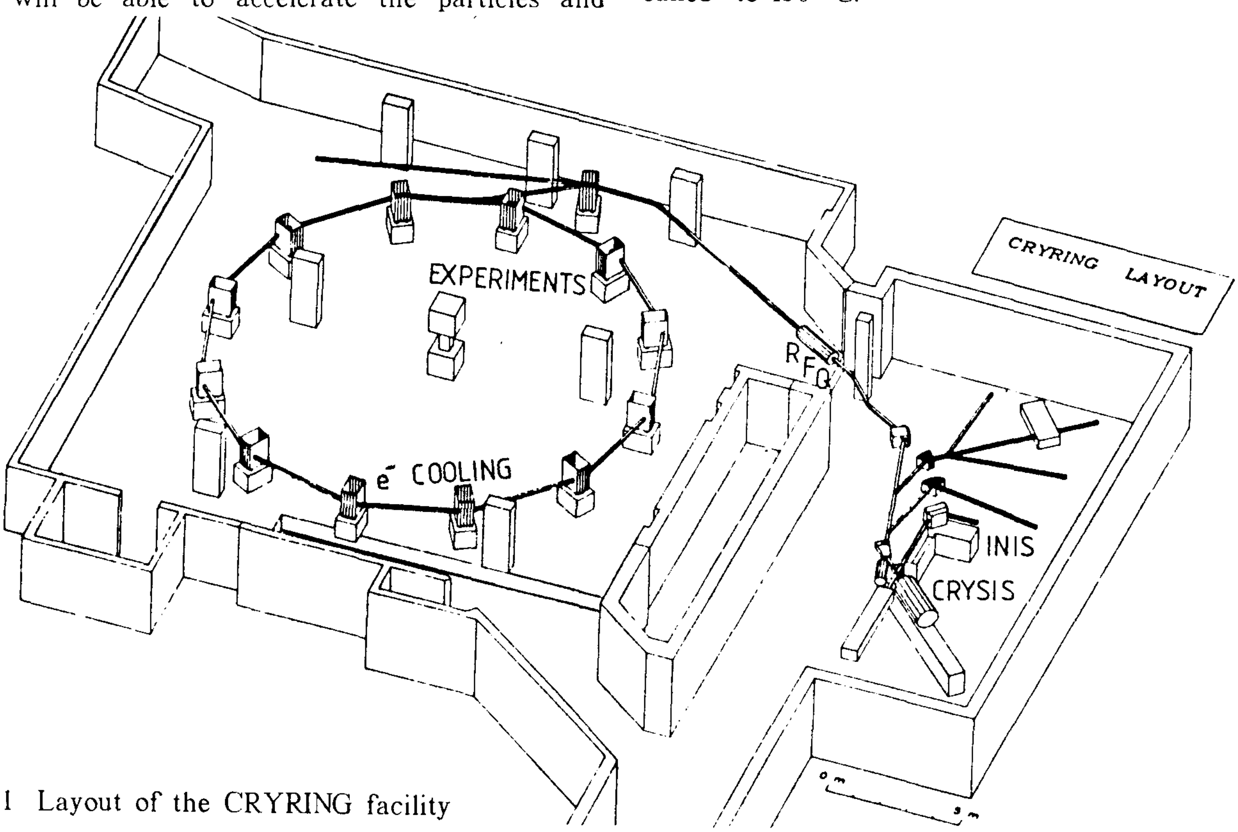


Fig. 1 Layout of the CRYRING facility

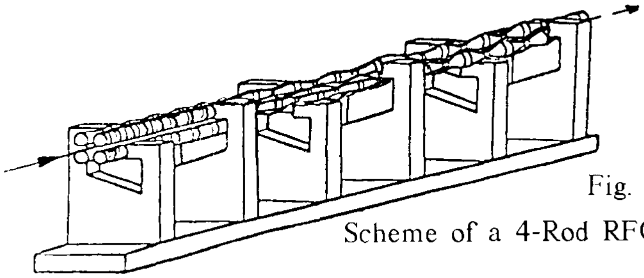

Fig. 2
Scheme of a 4-Rod RFQ

## BEAM DYNAMICS

The normal way of designing the parameters of an RFQ as originally done in Los Alamos[6] with a gentle bunching of the beam would in our case lead to an RFQ, which is more than 2 meters long. This length would cause manufacturing problems and too much rf power would be needed. To make a shorter RFQ we have used a novel design procedure[7]. At first, there is a prebuncher, consisting of four cells with a small modulation followed by a 12 cm long drift section without modulation. The prebuncher enables the following rapid increase in synchronous phase $\varphi_0$, and modulation m from $90^0$ to $50^0$ and 1.0 to 1.6 respectively, without increased particle losses. The increase in $\varphi_0$ and m takes place in only 25 cells (21 cm). Then follows a slower linear increase to the final values $\varphi_0 = 25^0$ and m = 2.0 that are reached near the end. Fig. 3 shows a comparison between the two ways of designing an RFQ. The prebuncher also reduces the energy spread of the beam, as most of the particles are near the synchronous phase during the rapid increase of the longitudinal field, which introduces much of the energy spread. In fig. 4 plots of the beam in the transversal and longitudinal phase spaces according to the PARMTEQ calculations are shown. The new design increases the smallest distance between the rods, which normally is found where the final values of $\varphi_0$ and m are reached. Thus an increased voltage can be applied between the rods and also the current handling capability is increased.

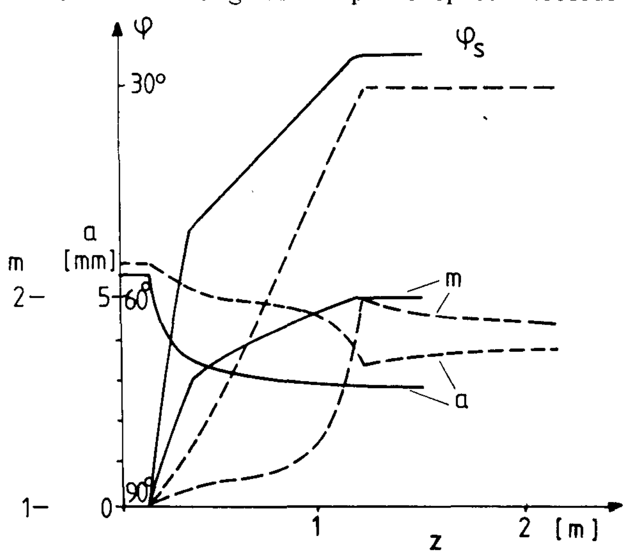


Fig. 3 The variation of the electrode parameters synchronous phase $\varphi_S$, modulation m, and aperture a along the z-axis. The dashed lines correspond to the standard method of RFQ design and the solid lines to the new method used in our design.

Our RFQ is designed for a voltage of 70 kV between the rods, which would be needed for ions with q/A = 0.25. This voltage corresponds to a surface electric field of approximately 1.6 times the Kilpatrick limit for sparking[8], which should be safe for the short RF pulses of less than 1 ms and give a possibility to increase the voltage and accept ions with lower charges. Some parameters of the RFQ are given in table 1.

## RESONATOR DESIGN

The 4-Rod RFQ is named after the electrodes, which are rods with conically varying diameter. In the first order approximation the variation of the electrical field on the axis is the same as that of the modulation. While in the design work and in RFQ resonators with vane-shaped electrodes the field can be derived from a two term potential, for the conical electrodes higher order terms have to be considered. Thorough investigations have shown,

Table 1 Parameters of the CRYRING RFQ

| | |
|---|---|
| Charge (q/A) | ≥ 0.25 |
| Input energy (keV/u) | 10 |
| Output energy (keV/u) | 300 |
| Electrode voltage (kV) | 70 |
| Synchronous phase $\varphi_0$ | $90^0 - 25^0$ |
| Maximum modulation | 2 |
| Number of cells | 103 |
| Length (m) | 1.54 |
| Aperture radius (mm) | 5.5 – 3.0 |
| Frequency (MHz) | 108.48 |

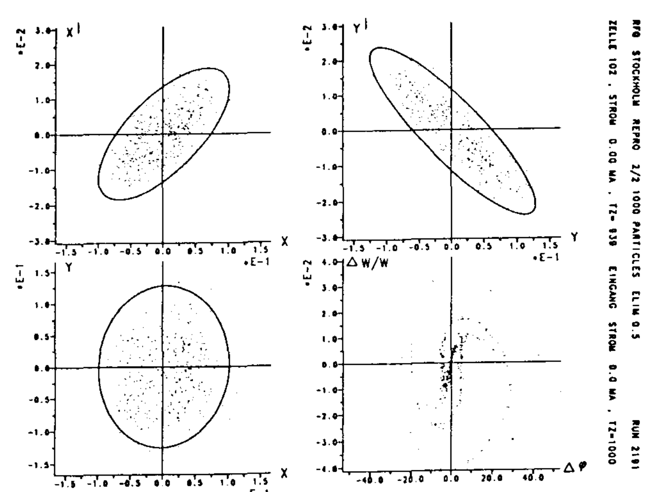

Fig. 4 Calculated phase space plots for the beam after the RFQ

however, that the higher harmonics are not important, if the aperture is not fully used. Stepwise appropximations of the ideal sinusoidal modulation has been done for the 4-Rod RFQ tested at DESY, has shown little influence on beam quality[4]

The rf resonator driving the electrodes consists of a chain of coupled $\lambda/2$ transmission line resonators. The 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 has two important consequences. Firstly, the tank has practically no influence on the resonant frequency, secondly, all parts of the resonant copper structure can easily be cooled efficiently by water-flowing through bores in the stems and thick wall tube electrodes. The electrodes are made on a lathe and brazed to the stems. Alignment of the electrodes and a rough frequency tuning of the structure is done outside the vacuum tank. The tuning is done with copper inserts in the end cells. The number of stems and the size and shape of the stems determine the frequency and the efficiency of the resonator.

The shunt impedance $R_p$, which is a measure of the efficiency, is defined as $R_p = U^2 L_c / N$, where U is the electrode voltage and N is the rf power for the RFQ cavity of length $L_c$ . In fig. 5 calculations of $R_p$ as a function of the number of stems and the diameter of the stems are shown. Assuming 60 % of these values as a conservative estimate, 60 kW of RF power is needed for the design voltage of 70 kV. Due to a very low duty cycle of less than 0.1 % the average power level is very low. Figure 6 shows a cross section of the 4-Rod resonator. Figure 7 shows a view of the rod assembly during tuning.

## STATUS OF THE PROJECT

The design of the RFQ has been completed and the beam dynamics parameters have been fixed. The tank has been manufactured and will be copper-plated at GSI in October. The RFQ will be assembled and tuned in Frankfurt. We hope to make first rf tests in December and to have the whole unit ready in the end of 1988.

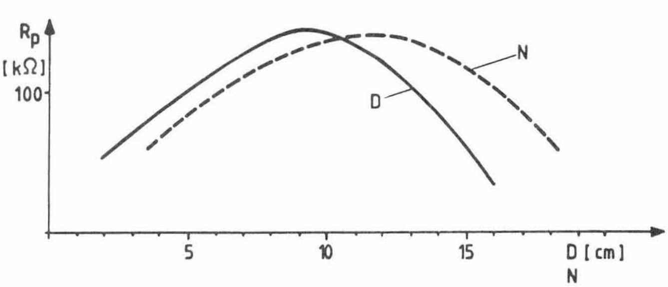


Fig. 5 Calculated $R_p$ values vs. stem diameter D and number of stems N

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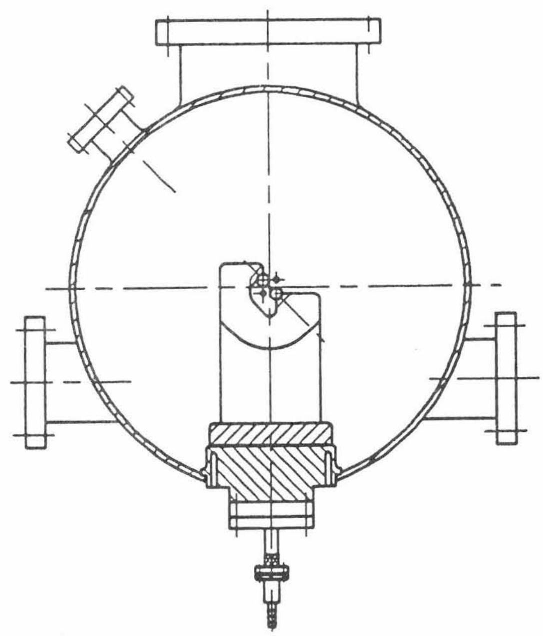

Fig. 6 Cross section of the 4-Rod RFQ

Fig. 7 View of the 4-Rod insert during assembly