The 0-mode RFQ consists of 4 trapezoidally modulated electrodes, manufactured on a lathe and periodically supported by radial stems. This resonator is excited in \( n \cdot u \)-mode forming an RF field, which is highly stable against tolerances and dipole-modes. A compact proton accelerator (10 - 300 keV, 108 MHz) with high duty cycle has been built and RF properties and first beam measurements are presented. New sparking experiments and results of high power tests with a 18 MHz spiral-RFQ are discussed.

Introduction

The 0-mode RFQ structure has been investigated as part of a program for the development of high current heavy ion accelerators. It might be used as an integral part of the RFQ cell of a resonator accelerator to existing heavy ion machines or as a small flexible accelerator following the new ion sources for highly charged heavy ions. Such accelerators must be operated at low frequencies and for some applications with a high duty cycle. General properties being the low injection energies, possible adiabatic bunching, and a high transmission for high current beams. The development of RFQ structures has been pushed forward by the Los Alamos group introducing a number of RFQ features now generally adopted in a number of laboratories. Especially for the low frequency heavy ion application a TE-type cavity - like those used in Los Alamos - seems too big. The goal of our development is the construction of a compact, efficient, low frequency RFQ. The 0-mode - \( \Lambda / 2 \)-RFQ seems to be an appropriate solution.

The \( \Lambda / 2 \)-RFQ Structure

The basic cell of the \( \Lambda / 2 \)-RFQ structure can be considered as two coupled \( \Lambda / 2 \) transmission lines excited in transverse \( \Lambda / 2 \)-mode. The capacitance coupling via the RFQ electrodes and the inductive coupling formed by the current loops of the radial stems form a very compact, efficient and flexible RF structure. For frequencies of about 100 MHz the tank diameter might be as small as 20 cm, RF cell length being between 15 and 20 cm. The RFQ resonator consists of a chain of strongly coupled cells driven in axial 0-mode.

Fig. 1 shows two such \( \Lambda / 2 \) cells, the arrows indicating the current flow. One electrode pair is supported by a common leg, so dipole-modes being a problem in \( E_{\lambda \rho \phi} \)-cavities, are very unlikely. In principle any kind of electrodes (e.g. vanes) can be inserted into this RF arrangement. Even multibeam electrode systems have been tested. We use circular electrodes machined with trapezoidal profile. Besides simple machining these tubes can be coated version efficiently with direct water flow via the radial stems allowing high duty cycle operation.

Abstract

The 0-mode RFQ consists of 4 trapezoidally modulated electrodes, manufactured on a lathe and periodically supported by radial stems. This resonator is excited in \( n \cdot u \)-mode forming an RF field, which is highly stable against tolerances and dipole-modes. A compact proton accelerator (10 - 300 keV, 108 MHz) with high duty cycle has been built and RF properties and first beam measurements are presented. New sparking experiments and results of high power tests with a 18 MHz spiral-RFQ are discussed.

Proton Accelerator

Our prototype accelerator was first designed to accelerate protons from the ion source (10 keV extraction potential) to 360 keV. First successful operation has been in October 1982, which had been proving that the accelerator principle was well suited: Compact tank (diameter 35 cm, length 120 cm); the RFQ is built in a cage for simple tuning, repair and control of the RF structure; the electrodes are made out of conical sleeves soldered on a tube. To improve the proton current, which was less than 1 mA, we remodeled the RFQ structure. Now we used electrodes machined from a thick wall tube. At the entrance a radial matching section and at the end a 21 cm long transport section (unmodulated electrodes) to fit into the outer tank have been brazed directly onto the prototype resistor, which were designed to accelerate protons up to 300 keV with a constant cost of the particles. The parameters of the proton accelerator are summarized in Table 1. Fig. 2 shows the test arrangement. Fig. 3 gives a view of the resonator. Tuning to the proper frequency of 108.6 MHz is done with the shortening bars between radial stems. The radial matching section can be seen, which consists of 20 mm long Cu-rods. This resonator has been tested with RF power of up to 15 kW (cw operation) and up to 55 kW (10 % duty cycle). For the design value of 28 keV electrode voltage only 7.5 kW RF power is needed.

Compared with the first beam tests an einzel lens 6 cm before the radial matching section has been installed to improve the radial matching. Fig. 4 shows analyzed proton spectra. Fig. 5 the total proton current as function of the electrode voltage. The current is now as high as 0.5 mA. The drop of the current with increasing voltage is indicating that space charge effects become effective. Another reason is the limited matching of the einzel lens, due to breakdown and electron loading.

The resonator worked very well. No RF detuning, no ponderomotoric effects and no thermal detuning or any sparking had been observed. All experiments have been done with 10 - 25 % duty cycle as well as in cw operation.

Sparking Experiments

Especially for heavy ions the maximum applicable electrode voltage determines the maximum beam currents in an RFQ. Sparking experiments have been done with RFQ cavities and with a coaxial resonator, in which tests with variable gap distances and electrode systems can easily be done. Experiments with Cs vapour load show significant smaller values for the breakdown voltages. New experiments with circular electrodes yield a higher breakdown voltage compared to plane electrodes. Fig. 6 shows experimental results. In Fig. 7 breakdown voltage is stated as a function of gap width for both plane and circular electrodes. Comparison with plane electrodes gives a significant improvement especially for small gap widths and,
as observed in all experiments, at small duty cycles respectively RF pulse lengths. Further experiments will be done in cw operation and the effect of surface treatment shall be studied.

*Spiral-λ/2-RFQ*

For lower frequencies the λ/2-RFQ principle has been used for a multichannel RFQ at 28 MHz (length 1.20 m, diameter 35 cm). Even lower frequencies can be obtained with a spiro-wound stem as used in our first RFQ studies and in Los Alamos. Spirals with high capacitive load and corresponding low resonance frequencies can be built very stable. Experiments on a cold model showed that with an antiparallel spiral arrangement highest Rp-values at lowest frequencies can be measured.

A high power structure with unmodulated electrodes was designed. As in the case of coupled spiral postaccelerator resonators, the spirals were brazed on a common bar. The tube length of the spirals was 165 cm, the pitch 15 mm (2.5 windings), the length of the electrode 45 cm, spiral distance 5 cm, distance between the two spiral pairs 35 cm. Because of the antiparallel arrangement identical spirals can be used and the cooling water for the electrodes is supplied via shortening rings.

On lower power level $f_e = 18.3$ MHz, $Q_0 = 1500$ and an extremely high Rp-value of 1.6 MΩ were measured with different methods. A computer code for coupled spirals with same drift tube capacity gave similar results; the high efficiency of the spiral-λ/2-RFQ is due to the large inductance of the spirals. So for an electrode voltage of 100 kV an RF power of only 6.3 kW is necessary. Fig. 8 shows a view of the spiral-λ/2-RFQ resonator.

In first high power tests up to 13.5 kW corresponding to 145 kV electrode voltage were applied in cw operation. In pulse operation (10 % dc) at 210 kV sparking (4 - 5 sparks/minute) started. This corresponds 3.2 times the Kilpatrick limit, which is a high factor, but the threshold is approximately 30 % lower. These first experiments indicate that the spiral-λ/2-RFQ can be a possible structure for low frequencies. Additional experiments will be made for improving mechanical stability at such high fields and preparing a resonator for beam tests with heavy ions.

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**Fig. 1** Scheme of the λ/2-RFQ resonator and electrode design

**Fig. 2** Proton RFQ test arrangement
Fig. 3 View of the λ/2-proton-RFQ

Fig. 4 Analyzed proton current

Fig. 5 Proton current as function of RFQ electrode voltage

Fig. 6 Breakdown voltage as function of pulse length; gap = 0.5 cm, pulse frequency = 45 Hz, f = 108.5 MHz

Fig. 7 Breakdown voltage as function of gap width, duty cycle = 5%

Fig. 8 View of the spiral-RFQ resonator