

FIRST RESULTS OF THE CRFQ PROOF OF PRINCIPLE*

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Abstract

The Circular Radiofrequency Quadrupole (CRFQ) is a new concept of a storage and accelerator ring for intense beams of light and heavy ions, protons and electrons. It is basically a Linear Radiofrequency Quadrupole completely bent on a circle. The advantages, which are expected to be the same performance features of a linear RFQ, would be smaller overall dimension with respect to accelerators with comparable beam intensity and emittance [1]. The prototype design is based on a 4-rods scheme and have a linear sector followed by a 45-degree curved sector. In this paper the first power and beam tests of the linear sector are presented.

INTRODUCTION

A collaboration between University of Naples, University of Sannio, INFN and Brookhaven National Lab was set up at the end of 2002 with the aim of the proof of the bending principle of the CRFQ [2].

A 30-keV prototype, with a linear RFQ matching section and the first curved sector, is being presently manufactured for testing of the fundamental principles in the *Laboratorio dell'acceleratore* of Dipartimento di Scienze Fisiche in Naples, Italy. They are fed by a RF *Frank James* power amplifier, available as a loan from CERN.

The proof of principle will go through several phases [3] and we are at the first one at present, aiming to demonstrate the curvature effect of the quadrupolar rfq field on the proton beam. This phase includes the design, realization and tests of the first curved sector and of a linear rfq with no beam acceleration, i.e. no rods modulation. A schematic layout is shown in fig. 1. The linear sector is a matching section for the proton beam and is needed to verify the adopted solutions about radiofrequency and mechanical alignment.

DESCRIPTION

The beam parameters have been chosen in order to minimize cost and the impact of the RF requirements of the first phase. Computer simulations of the motion of protons in the linear and curved RFQ sectors has been made at Brookhaven, leading to the input beam parameters of table 1 where the RF and the main geometrical parameters

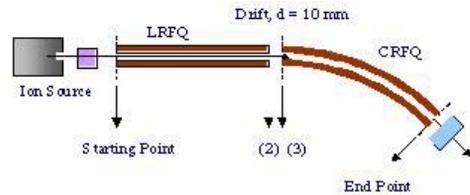


Figure 1: Schematic layout of the first phase of the CRFQ proof of principle.

Table 1: Beam dynamic, RF and main geometrical design parameters of the linear and curved sectors.

Input Energy	30keV
Transverse Emittance	5π mm mrad
Beam Current	1mA
RF Frequency	202.56MHz
Power	20kW
Duty Cycle	0.2%
Transverse Shunt Impedance	33k Ω
Rods Peak Voltage	36kV
Field Flatness	bt 10%
Rods Diameter	10mm
Beam Gap Diameter	10mm
Sector Length	707mm

are presented too. It is worth noting that those parameters apply to both the linear and curved sectors.

The RF frequency and duty cycle are set by the available *Frank James* RF power amplifier, while the peak voltage and the longitudinal field flatness have been set by the particle beam dynamic calculations. Moreover, the dissipated peak power is intended as an upper limit to allow the feeding of both linear and curved sectors with one power amplifier at the same time. As a consequence, the transverse shunt impedance is intended to be a minimum goal. Finally, the low duty cycle implies a dissipated average power of 100W at worst, and no water cooling is planned.

About mechanical design, since the transverse shunt impedance and the field flatness requests are not prohibitive, the simplicity of construction, assembling and alignment of the curved sector has been used as the most important property. Therefore, a four rods design with double stems has been adopted for its compactness, robustness and intrinsic reduced sensitivity from dipole modes perturbation. Furthermore, the solutions adopted for the curved sector has been exported to the linear sector too. In fig. 2 a

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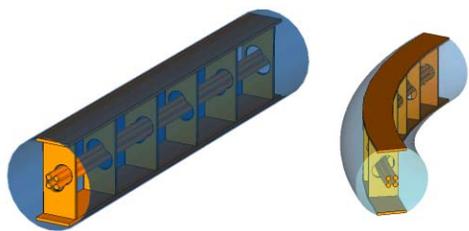


Figure 2: A sketch of the linear and curved sectors as represented by Microwave Studio.

representation by Microwave Studio of the two geometries is shown.

As coarse frequency tuning system, copper tiles can be added to reduce the volume near the top and bottom bars, see fig. 2. As fine frequency tuning system, the linear rfq has end disk plates that can be moved in order to change the ends capacitances and to tune the resonant frequency within kHz precision.

The 1mA proton beam is provided by a reconditioned RF source. The performance of the source has been enhanced with an electrostatic acceleration in order to give the emittance and the energy requested by the beam dynamic. It is worth noting that the acceleration can provide a beam energy up to 40keV.

A ISO150 standard vacuum pipe has been used as outer cylinder of the linear sector. A custom 45 degree curved pipe will be used for the curved sector. The beam gap diameter is 10mm with circular 10mm diameters rods. Each sector is 707mm long. Each outer cylinders have one standard flange for vacuum pumping. In the linear rfq a $2 \cdot 10^{-7}$ mbar vacuum has been reached with a turbomolecular pump.

The RF coupler of the linear module is a magnetic loop and its magnetic flux area has been determined by means of a simple lumped model. The possibility to rotate the loop has been included in the mechanical design and an aluminium foil has been used as loop conductor, as it is shown in fig. 3. It is possible to make a low power network analyzer measurement to setup to the correct critical coupling.

A beam diagnostic box is going to be available in the near future. It is based on two electrical quadrupoles sections. Both of them makes use of rectangular plates coupled to eight 50Ω bnc connectors. They can be used to bend the beam in both horizontal and vertical planes and to pick up beam information at the same time. The measurements include standard beam diagnostic, as beam intensity and beam transverse position. Finally, three signal loops take place on each outer cylinders to monitor the RF field level.

RF EXCITATION DESIGN

The radiofrequency of the linear and curved sector for the CRFQ has been designed with a suitable use of Microwave Studio and of an equivalent circuit. The numerical

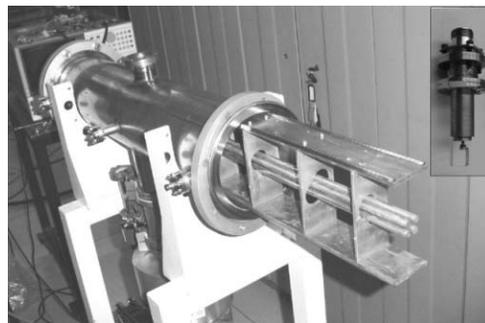


Figure 3: The linear rfq hot model and the power loop of the linear sector (up right corner).

code has been used to optimize the stems geometry with respect to the transverse shunt impedance. This study has led to stems with a very simple geometry: a rectangular transverse section and two cylindrical windows for the four rods. It is worth noting that the stems are machined from the same bar used for the top and bottom bars.

The equivalent circuit is based on a multilayer transmission line approach and transmission matrix representation of each block [4]. It gives the longitudinal profile of the rods potential as a function of the stems spacing and allows the study of the quadrupole mode and parasitic dipole modes as function of geometrical errors, as rods displacement. In this model, the four rods and the outer tube are represented as a five conductor transmission line, where the capacitances of the line can be calculated by solving a 2D electrostatic problem. Each couple of stems and the top and bottom bars represent two one-winding coil in parallel and they are represented by lumped inductances in the equivalent circuit. The equivalent circuit and the numerical simulations results have found confirmation in the cold model measurements [5].

LINEAR RFQ MEASUREMENTS

In the fig. 5 the linear rfq connected to the proton source is shown. The Frank James amplifier has been tested at first on a dummy load with a 48kW power deliverable. The maximum power deliverable to the LRFQ is 32kW and it is limited by the reflected power amplifier interlock, at present.

The linear rfq has been tested about resonant frequency tuning, quality factor and longitudinal electric field profile with bead pulling measurements. The RF coupling has been tuned with low power network analyzer measurements, leading to a -22dB reflected power.

In the fig. 6, the bead pulling measurements for the four sector is presented. The electric field longitudinal distribution is flat within $\pm 8\%$, while the transverse dipole modes are within $\pm 1\%$ of the quadrupole amplitude. About proton beam measurements, the fig. 4 shows the oscilloscope screenshot with persistence option for increasing input power to the LRFQ (from 4.5kW to 15kW). It is clear

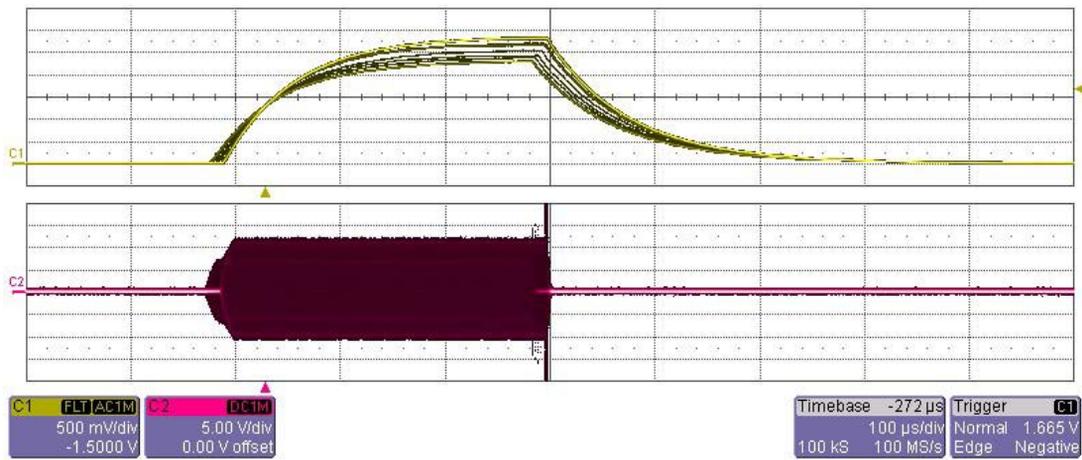


Figure 4: Faraday's cup signals (up) and RF signals in the cavity (down).

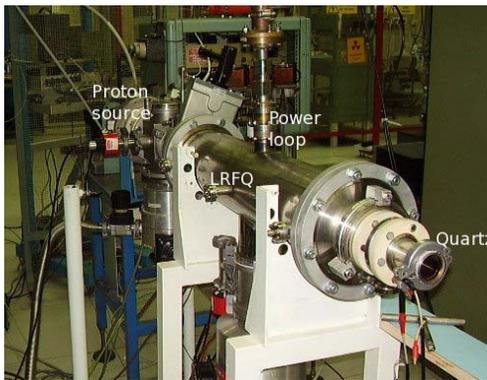


Figure 5: The Linear RFQ ready for tests.

CONCLUSIONS

The first high power and beam tests of the linear RFQ of the CRFQ proof of principle has been presented in this paper. The RF power tests are within specifications with a maximum deliverable power of 32kW and a sufficiently flat longitudinal electric field distribution. Up to now, only Faraday's cup for intensity beam measurements have been performed, showing the focusing rfq effect. In the next months, a measurement campaign with the available diagnostic box is foreseen and the construction of the curved sector will start.

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REFERENCES

- [1] A.G. Ruggiero, The circular Radio-Frequency Quadrupole Storage and Accelerator Ring, C-A/AP/65, Brookhaven National Laboratory, October 2001.
- [2] CRFQ02 workshop final relation, Benevento, Italy, October 2002
- [3] A.G. Ruggiero et al., MOPLT171, Proceedings of the EPAC 2004 conference, Luzern, Switzerland.
- [4] M. Caprioli, Progettazione di un quadrupolo a radiofrequenza, Graduation Thesis (in Italian), March 2004, University of Naples, Italy.
- [5] D. Davino et al., MOPLT055, Proceedings of the EPAC 2004 conference, Luzern, Switzerland.

that the focusing effect increases the beam intensity signal on the Faraday's cup.

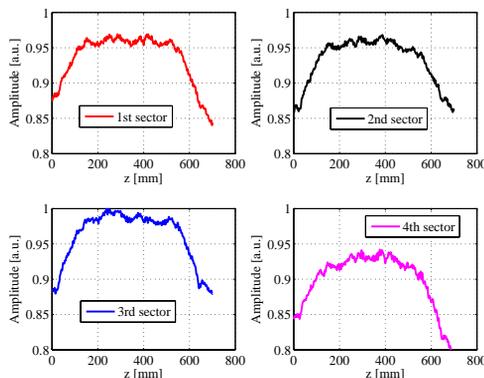


Figure 6: Bead pulling measurements of the four sectors. The field is flat within $\pm 8\%$ and the dipole modes are within $\pm 1\%$.