RF EXCITATION OF LINEAR AND CURVED SECTIONS OF THE CRFQ PROJECT*

D.Davino†, Università degli studi del Sannio, Benevento, I-82100, Italy
L.Campajola, V.G.Vaccaro, Università di Napoli, Napoli, I-80126, Italy
A.G.Ruggiero, Brookhaven National Laboratory, Upton, NY, USA
M.R.Masullo, INFN Sezione di Napoli, Napoli, I-80126, Italy

Abstract

The design criteria of the linear and first curved sectors of the Circular Radiofrequency Quadrupole (CRFQ) proof of principle are presented in this paper. Radiofrequency measurements on a cold model of the linear sector and comparisons with numerical simulations are presented too.

INTRODUCTION

In December 2002, a collaboration was setup between Brookhaven National Laboratory, University of Naples, University of Sannio and INFN-Sezione di Napoli in order to develop a proof of principle (PoP) of the CRFQ.

The Circular Radiofrequency Quadrupole is a new concept of a storage and accelerator ring for intense beams of light and heavy ions, protons and electrons[1, 2]. It is basically a linear Radiofrequency Quadrupole completely bent on a circle. The advantages, that 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. A 30-keV prototype, with a linear RFQ matching section and the first curved sector, is being presently designed and manufactured for testing of the fundamental principles in the *Laboratorio dell'acceleratore* of Dipartimento di Scienze Fisiche in Napoli. They will be powered by a RF *Frank James* power amplifier, available as a loan from CERN.

It is worth mention that the proof of principle will go through several phases [1]. We are at the first one that is mainly aimed to demonstrate the curvature effect of the quadrupolar rfq field on the proton beam. This phase includes the design, realization and tests of a linear rfq with no beam acceleration and of the first curved sector. A schematic layout is shown in fig. 1. The linear sector acts as matching section for the proton beam and helps to verify the adopted solutions about radiofrequency and mechanical alignement.

DESIGN CRITERIA

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 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 *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 eventually 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, 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 figure 2 a representation by Microwave Studio of the two geometries is shown.

A ISO150 standard vacuum pipe will be used as outer cylinder of the linear sector. A custom 45 degree curved pipe will be used for the curved sector. The outer cylinders will have one standard flange for the connection to a vacuum pump. The RF power loops will be placed in the geometrical center and are presently under design. They will make use of a standard 1 5/8" EIA connections. Three signal loops will take place on each outer cylinders to mon-

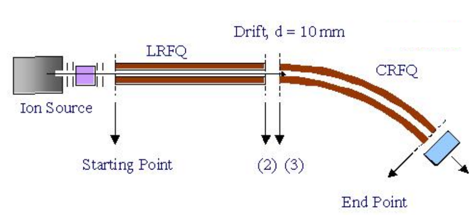

Figure 1: Schematic layout of the first phase of the CRFQ proof of principle.

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† davino@unisannio.it

itor the field level. As coarse frequency tuning system, it is foreseen the possibility to change the volume near the top and bottom bars, see fig. 2, where magnetic field is strong.

The proton beam is provided by an 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.

RF Excitation Design

Linear four rods rfqs have been designed and built starting from '80s and since then several approach have been proposed to explain the electromagnetic behaviour and to help the design. Some researchers have used a lumped elements circuit representation [3], others have used a single trasmission line periodically loaded [4], others have used a five conductors trasmission line approach [5]. All the proposed models showed the robustness of four rods rfqs design, because of its *lumped circuit like* behaviour. On the other hand, the use of an electromagnetic simulator has always been considered important to evaluate the effect of small details on the relevant parameters as resonant frequency, quality factor, field flatness and shunt impedances.

The radiofrequency of the linear and curved sector for the CRFQ PoP has been designed with a suitable use of Microwave Studio and of an equivalent circuit. The numerical 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, namely 5×60mm.

The equivalent circuit is based on a multiline trasmission line approach and trasmission matrix representation of each block [6]. 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 trasmission 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.

Table 1: Beam dynamic, RF and main geometrical 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	33kΩ
Rods Peak Voltage	36kV
Field Flatness	bt 10%
Rods Diameter	10mm
Beam Gap Diameter	10mm
Sector Length	707mm

Cold Model RF Measurement

A cold model of the linear sector with five stems has been built in order to check RF solutions and to measure the relevant parameters. The rods are 585mm long and are placed in a 600mm long outer cylinder. During the assembling, it is possible to change the longitudinal position of all the stems, except the central one. The rods are kept in place by elastic hollow cylinder placed on the beam axis near each stem, as it is shown in fig. 3.

It is worth mention that, having fixed the outer tube diameter, it is not possible to get a satisfactory field flatness and the goal resonant frequency at the same time with only five stems and shorter rods. Nevertheless, the goal of the cold model measurements is to check the confidence with numerical simulations. In this paper we present the results of two particular configurations. For the first one, the measured resonant frequency is 202MHz with a quality factor of 1000, which is due to screws bad contact. The electric field longitudinal distribution is flat within $\pm 16\%$ and is in agreement with Microwave Studio results, as shown in fig. 5. The numerical calculation gave a resonant frequency and a quality factor of 200MHz and 4000, respectively. In the fig. 6, it is presented the comparison between the cold model measurement and the result from the equivalent model with transmission lines and lumped inductances.

It is known that the field flatness can be improved by changing the end-cell spacing [7]. This has been done with the second configuration where the stems have been equally spaced. In this case, the resonant frequency was 185MHz, but the field flatness was $\pm 1.5\%$, as it is shown in fig. 7. The transverse dipole modes were within 2% of the quadrupole amplitude for both configurations.

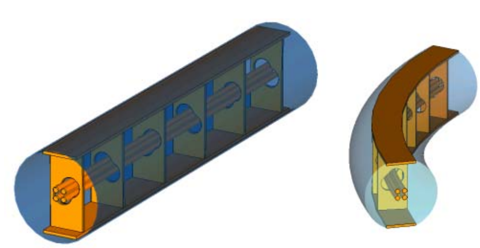

Figure 2: A sketch of the linear and curved sectors as represented by Microwave Studio.

Figure 3: The cold model of the linear sector without outer cylinder.

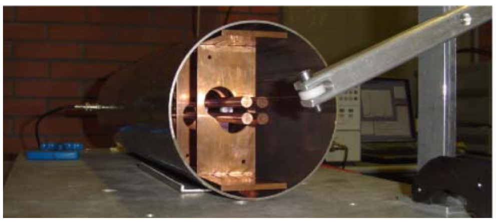

Figure 4: The cold model of the linear sector under bead pulling measurement.

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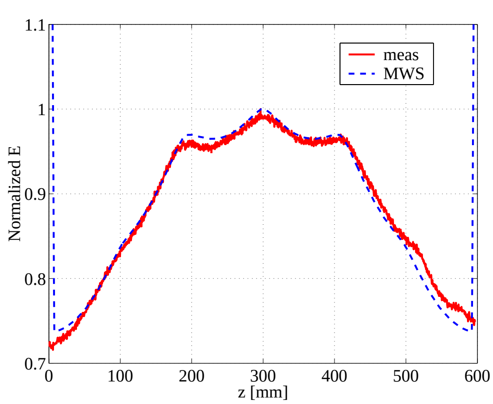

Figure 5: Field flatness comparison between the cold model measurement and a Microwave Studio simulation.

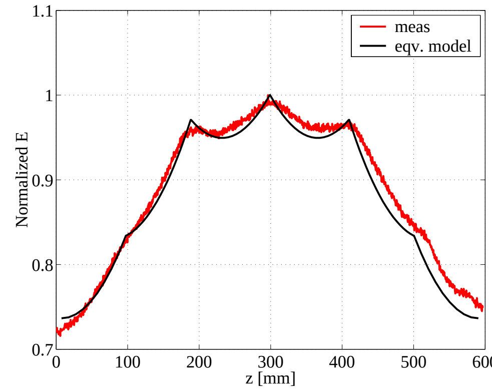

Figure 6: Field flatness comparison between the cold model measurement and the transmission line model result.

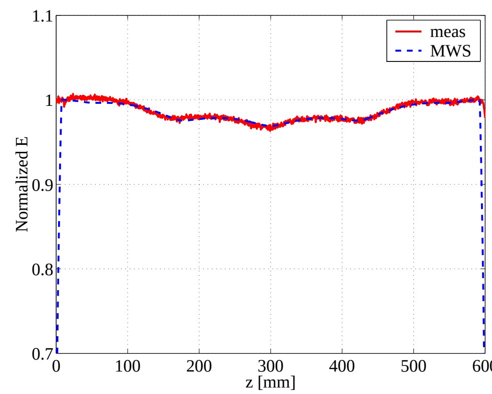

Figure 7: Field flatness comparison between the cold model measurement and a Microwave Studio simulation for a equally spaced stems configuration.

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