CONSTRUCTION AND COMMISSIONING OF THE RFQ FOR THE CERN LEAD-ION FACILITY

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Abstract

The first accelerator of the CERN Heavy Ion Facility is an RFQ designed, built and commissioned by INFN-LNL in collaboration with CERN and with the involvement of Italian industries.

The beam dynamics specifications have been chosen to accelerate a 80 μA $^{208}Pb^{25+}$ beam from 2.5 to 250 keV/u. The resonant frequency of the structure is 101.28 MHz, with a repetition rate of 10 Hz and a duty cycle of 0.4%.

The RFQ structure is of a "four rod" type with symmetrical supports and vane-like electrodes.

The problems encountered in the construction phase are reviewed and the results of the RF and beam commissioning are presented.

Introduction

In the framework of the CERN Lead Ion Facility collaboration, the Laboratori Nazionali di Legnaro (LNL) designed and constructed the low energy part of the linac. This includes the Low Energy Beam Transport line (LEBT) [1], the RFQ and the Medium Energy Beam Transport line (MEBT) [2]. The main effort has been put in the design and the construction of the RFQ which is described in this paper.

The RFQ construction has been assigned to the LNL in September 1991, after a series of meetings to decide the beam specifications. The final conceptual design is the result of a close collaboration between CERN and LNL on all the aspects of the accelerator, as beam dynamics, RF cavity and mechanics. The construction drawings and the production of this RFQ is the result of the common work of these two laboratories and the Italian industries, under the supervision of LNL.

The most difficult task has been the construction of the electrodes. Their modulation has been checked at CERN, and they have been afterwards assembled in Italy with a tolerance of ± 0.03 mm along the whole structure.

The RFQ has been delivered to CERN in April 1994. After some RF measurements in Italy aiming at the adjustment of the resonant frequency and of the field distribution, more RF measurements, mainly to finalize the tuning and to check for possible transport damages, have been performed at CERN with positive results.

After the installation on the beam line, the calibration of the rf connection and an easy conditioning at high power, on May 3 the first 70 μA beam has been measured downstream of the MEBT. Since then the RFQ has been operational.

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Beam Dynamics

The specifications require an acceleration from 2.5 to 250 keV/u of a $^{208}Pb^{25+}$ beam with a transmission larger than 90% and a transverse normalized acceptance larger than 0.8 π mm mrad. The duty cycle is 0.4% at the repetition rate of 10 Hz.

To meet the specifications with a structure as compact as possible, a novel design procedure, inspired by the work of S. Yamada [3], has been adopted [4]. The structure is divided in six logical sections: radial matching section, shaper, prebuncher (where fast phase compression is performed at constant bucket area), adiabatic buncher [5], booster (fast rise of the acceleration) and accelerating section. The optimization of the parameters of the above sections led to a compact structure of 2.5 m total length.

Particular care has been put in the analysis of the effects on the beam dynamics of the input and output gaps between the electrodes and the external walls, taking into account the asymmetries in the vane potential peculiar to RF structures like the one chosen [6].

RF Design

The resonant frequency chosen for the low energy part of the lead linac is 101.28 MHz. For this frequency, the most convenient RF structure is the "4-rod" resonator. For the lead RFQ a "4-rod-like" resonator in which the rods are replaced by "vane-like" electrodes, has been adopted to facilitate the mechanical construction and alignment. Moreover, a symmetrical support has been preferred in order to have a structure that guarantees a dipole-free electric field distribution [7].

The resonator geometry has been defined by aiming to an optimization of the shunt impedance. Using 3D simulations with MAFIA codes [8], a triangular stem shape has been chosen, that gave shunt impedances higher than 200 kΩ·m [7]. The final structure, shown in Fig. 1, has a computed shunt impedance of 222 kΩ·m. In order to have a goc l mesh definition, only half of the structure has been simulated and a mirror plane has been used in the middle of the structure. In fig.1 is also shown one of the two adjustable piston tuners.

The whole resonator has been designed using the program MAFIA. In particular, this program has been used

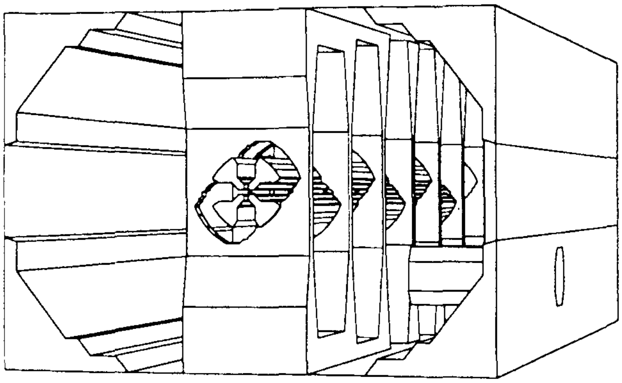

Figure 1: RFQ structure in a MAFIA plot

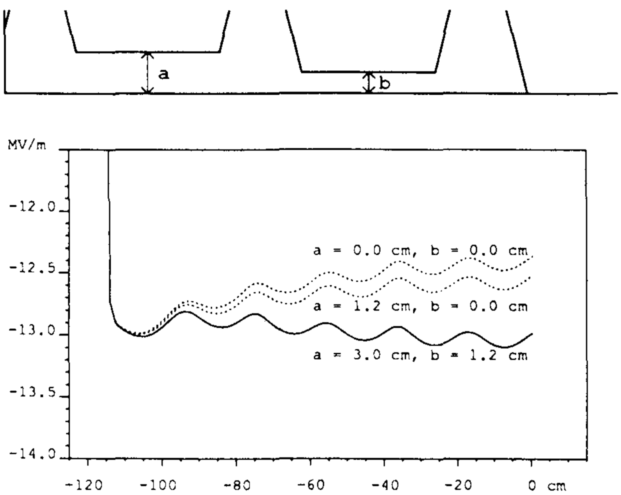

Figure 2: Simulated Electrical Field distribution with different volumes in the terminal cells

to determine the shape of the cells at the two ends of the structure, which have a smaller volume in order to obtain field flatness along the RFQ. Fig. 2 shows some computed field distribution for different end cell geometries.

In order to compensate for the variation of the inter-electrode capacitance due to vane modulation, some additional capacitances have been added in the high energy half of the RFQ. Following an idea proposed by W. Pirkl, the capacitances consisted of small, "L-shaped" conductors screwed on the support stems and facing the back of the electrodes.

The tuning system is made of two adjustable inductive tuners placed towards the low energy end of the structure. The final position of the tuners has been chosen among five possibilities in order to minimize the remaining E-field tilt, that was not compensated by the additional capacitances. Finally, the field tilt has been contained within $\pm 1.7\%$ (Fig. 3).

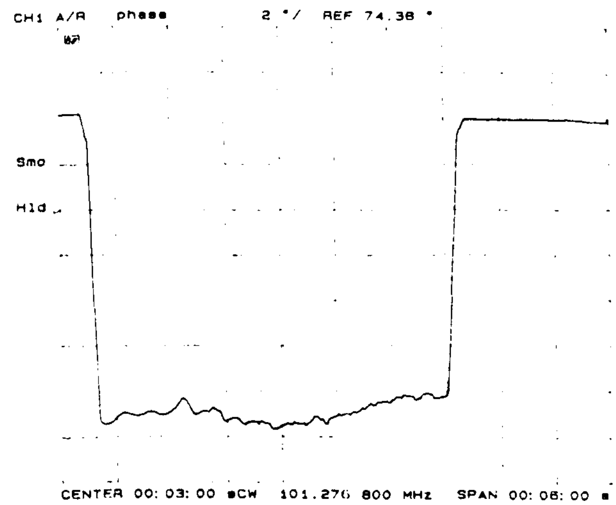

Figure 3: Measured Electrical Field distribution along the RFQ

Mechanical Features

The main characteristic of the mechanical structure of this resonator is its rigidity and the possibility of positioning the electrodes within the required tolerance of ± 0.03 mm over the whole length. The cavity is made of two parts. The bottom part, placed on three external supports, houses the electrodes with their supports, and contains the reference planes. Two alignment arms with targets for the positioning on the beam line are also mounted on this part. The top part is fixed on the main body by M10 screws and an aluminum joint insures the vacuum tightness. Pick up loops and tuners are mounted on this cover.

The resonator is made of copper plated mild steel,which was preferred to stainless steel for its higher thermal conductivity. Although the duty cycle of the RFQ is very low, precautions had to be taken in order to have a thermally stabilized structure. The elongation of the copper-chromium-zirconium alloy electrodes, which created forces in the relatively rigid supports, was minimized. Cooling channels were therefore made available inside the supports, to keep the maximum temperature difference between the bottom of the vanes and the base of the support below six degrees.

The electrodes have been positioned on the supports via copper spacers and stainless steel keys which allowed to reach the required tolerances. The RF contacts have been decoupled from the mechanical connections and realized by flexible copper strips with finger contacts, screwed into the bottom of the vanes on one side and into the support on the other.

The electrodes have been machined in Italy and controlled at CERN. Their correct positioning has been achieved in a very short time taking advantage of the connecting system described above. The beam transmission of more than 90% proved the correct assembly of the RFQ elements.

RF Measurements

Resonant frequency, tuning range, quality factor and voltage distribution along the RFQ have been checked first at LNL, and then at CERN. The results, compared with the MAFIA simulations, are shown in Table 1.

TABLE 1
Theoretical and measured RFQ parameters

	Computed	Measured	
Resonant Frequency	101.29	101.17	MHz
Tuning range	176	153	kHz
Q	10760	4344	
Total E-field tilt	0.	3.5	%
E-field ripple	1.	2.3	%

The relatively large difference between the theoretical and the measured values of the quality factor is mainly due to the rf contacts between electrodes and supports, that were not taken into account in the simulations.

The E-field tilt is due to the electrode modulation and has been minimized using the capacitive tuners already mentioned.

The voltage distribution along the structure has been measured using a bead-pulling technique. A dielectric bead touching two adjacent electrodes on their external part was moved along the RFQ. During the measurements at LNL, a Phase Locked Loop circuit was used to measure the frequency shift due to the perturbator. The data acquisition and the stepping motor control has been made via PC. For the measurements at CERN, the phase shift due to the perturbator has been directly measured by a Network Analyzer. A typical measurement is shown in Fig. 3, where a "ripple" of the field due to the presence of the supports, typical for this type of resonators can be seen. The RF power conditioning of the RFQ has been straightforward, taking about two days to reach a power level of 140 kW.

Beam Commissioning

The RFQ has been commissioned during the first two weeks in May 1994 and, since then, has been operational.

The commissioning has been performed in parallel with the commissioning of the MEBT [2], in order to compress the time schedule and meet the deadline for the injection into the Booster. The measurements lasted for two weeks and the results, presented in Table 2, are in very good agreement with the design values.

TABLE 2
RFQ output beam parameters

	Computed	Measured	
Transmission	90	>90	%
ε_x (rms)	4.2	3.8±.4	π mm mrad
ε_y (rms)	4.4	4.3±.2	π mm mrad
ε_{long}	40	30.2	π deg keV/u
Output Energy	250	250±2	keV/u

Conclusions

The construction and the commissioning of the first acceleration stage of the CERN Lead Injector, namely the RFQ and its matching lines, have been performed successfully.

The RFQ, which is the most important part of the LNL commitment, meets fully the specifications. It has been conceived, designed and constructed in three years by a close collaboration among LNL, CERN and italian industries.

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