Comparison Study of RFQ Structures for the Lead Ion Linac at CERN

A. Lombardi, G. Parisi
INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro (PD), Italy
M. Vretenar
CERN, PS Division, CH-1211 Geneva 23, Switzerland

Abstract

The low-energy section of the new CERN lead injector, between the ECR source and the main linac, will be built at the Laboratori Nazionali di Legnaro, Italy. The most important part of this section is a Radio Frequency Quadrupole, 2.5 m long, accelerating from 2.5 keV/u up to 250 keV/u and operating at a frequency of 101.28 MHz.

In order to define a satisfactory geometrical configuration for the RF resonator, both from the RF and from the mechanical point of view, different designs have been analysed and compared, starting from the classical "4-rod" Frankfurt-type structure, up to the "double parallel stems" and the "90°-apart stems" structures.

Results of 3D simulations on cold models are presented here, together with the proposed layout of the lead RFQ.

1 DESIGN CRITERIA

The beam dynamics analysis of the Pb-RFQ led to the definition of the geometrical parameters of Table 1 [1]. These determine the region around the beam axis, and the aim of this study was to find a suitable resonator which could be "built around" them.

Electrodes length	2.50 m
Electrodes transverse radius	4.05 mm
Average aperture	4.50 mm

Tab. 1: Geometrical parameters of the Pb-RFQ electrodes

As a starting design principle, the choice of a "4-rod"-like resonator was quite natural [2]; clear advantages of this structure, when compared to a design of the "4-vane" type, are its compactness at the low frequencies required for ion acceleration and its reduced sensitivity to perturbing modes which compensates for its lower shunt impedance.

Nevertheless, two main changes have been considered necessary with respect to the standard design. First, a double support design has been chosen in order to guarantee the resonator absolute freedom from unwanted dipole components [3]. Note that this feature does not affect the shunt impedance. Second, "vane-like" shaped electrodes (as in Fig. 1) have been chosen in preference to circular rods [4]; this allows the very precise machining of the modulation on a computer-controlled milling machine and gives, opposite to the electrode tip, a well-defined reference plane for the positioning in the tank. The drawback of the vane-like shape is the higher inter-electrode capacitance, which reduces the efficiency (by 20 ÷ 45% depending on the electrode cross-section). However, a careful optimization of the resonator can compensate for this.

In addition, designs allowing as many brazed and welded contacts as possible have been selected in order to avoid problems of mechanical stability and of vacuum due to movable connections in high current regions.

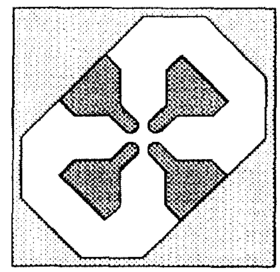

Fig. 1: Connecting frame and electrodes cross-section

2 COMPARISON OF STRUCTURES

Applying the above criteria, three structures have been selected for further investigation, differing in the shape and position of the supports.

Using the MAFIA code [5], each design has been studied with regards to its frequency dependance, Q-value and shunt impedance, Z_{sh}, for a single cell. The goal was to optimize Z_{sh} and therefore the power efficiency.

The computations were later extended to more than one cell, up to the limit allowed by the number of mesh points that could be treated by the available installation of MAFIA (about 80,000), in order to study the end effects and the overall field symmetry.

Three cold aluminium models, without modulation of the electrodes, have been built at LNL according to the computed dimensions. Each model comprises a few cells up to a length of about 1 m. Frequency and field symmetry have been measured on the models to verify the MAFIA results and to analyse end effects and sensitivity to mechanical misalignments. This provided valuable experience for the design of the final RFQ.

Note that all three structures have the same geometry in the central region (Fig. 1) in order to get comparable sets of data. The electrode cross-section has been studied to increase its mechanical rigidity and to give a large surface for the high longitudinal current. Opposite pairs of electrodes are connected to frames that force them to the same potential by acting as "Vane Coupling Rings". Furthermore, each frame is connected to two supports.

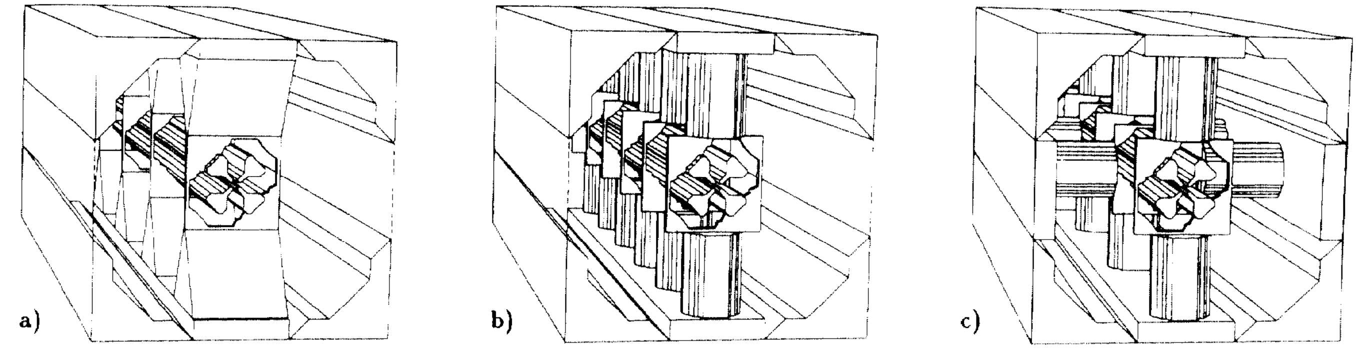

Fig. 2: MAFIA plot of the three structures

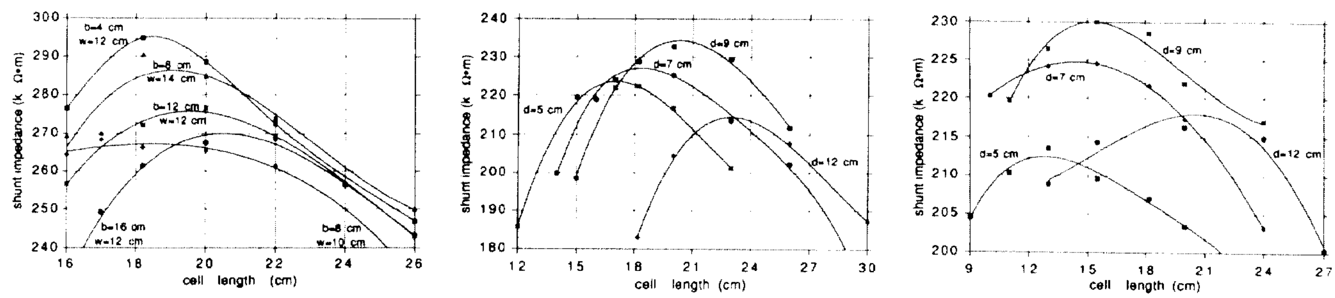

Fig. 3: Z_{sh} of the three structures

The first structure (Fig. 2 a) comprises a sequence of cells with "triangular" supporting stems. These allow a homogeneous distribution of the current in the stem and therefore a reduction of current density and power losses. At the same time, the large stem base guarantees good mechanical stability.

The second structure (Fig. 2 b) has cylindrical ("double parallel") stems.

The third structure, proposed by V. Andreev from ITEP, (Fig. 2 c) also has cylindrical stems, but alternately placed orthogonal to each other and to the beam direction ("90°-apart" type). A version of this structure having the electrodes connected directly to the stems (without frames) was also analysed, and it was built at ITEP giving analogous results [6].

3 STRUCTURE OPTIMIZATION

A complete set of curves, giving $Z_{sh} = (U_0^2/P) \cdot l_{cell}$ as a function of the geometrical parameters, has been computed for each structure (Fig. 3). In the computations, the tank radius was adjusted to keep the single cell resonant frequency at the design value.

A common feature of all the curves is the fact that, for each stem geometry, there is an optimum cell length which minimizes the losses. For short cells, the tank diameter has to be increased to maintain the resonant frequency, thus increasing the current path and the power losses. For long cells, it is the losses in the electrodes, where the current density is high, which dominate.

Together with the cell length, the support geometry has been varied (base width w and length b for the triangular stems, diameter d for the cylindrical ones, see Fig. 3). Fig. 4 shows, on the same scale for ease of comparison, the best Z_{sh} curves obtained for the three structures.

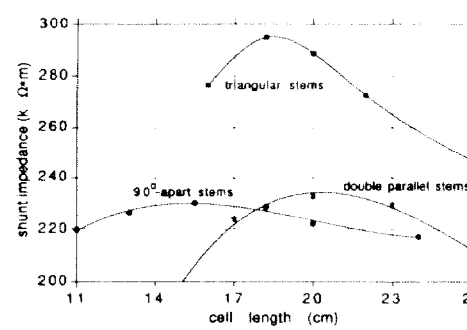

Fig. 4: Z_{sh} comparison

4 MODEL MEASUREMENTS

The main parameters measured on the three models are summarized in Table 2 and compared with the results from MAFIA. A modular assembly technique was chosen in order to make use of the same electrodes, frames and tank for all models, so that no particular care was taken to get the same frequency for all of them. The measured frequencies are slightly different from the computed ones, mainly because the MAFIA approximation of the electrode tip was quite coarse, while the Q-values are poor due to bad contacts.

The electric field patterns between each pair of electrodes have been measured (without end plates) with a

	triangular stems		cylindrical stems		90°-apart stems		
	measured	simulated	measured	simulated	measured	simulated	
Frequency	73.6	75.7	106.1	111.6	101.1	104.7	MHz
Q-value	1.2	11.4	1.4	10.4	0.4	10.3	10^3
max. $\frac{\Delta E}{E}$	5	3.5	5	4	6	2.5	%
max. dipole comp.	3	0	5	0	6.5	0	%
Capacitance	152	129	170	141	168	140	pF/m
Shunt impedance	35	356	25	202	7	214	kΩ·m
Z_{sh} scaled	324	—	172	—	192	—	kΩ·m

Tab. 2: Measured and simulated (MAFIA) parameters for the three models

bead-pull technique; Fig. 5 shows those of the first model. All the measured fields display the characteristic ripple (less than 2%) caused by the supports, a residual bump due to end effects and some dipolar components from mechanical misalignments (see Fig. 6). The overall field asymmetry and the dipolar component measured for each model are given in Table 2.

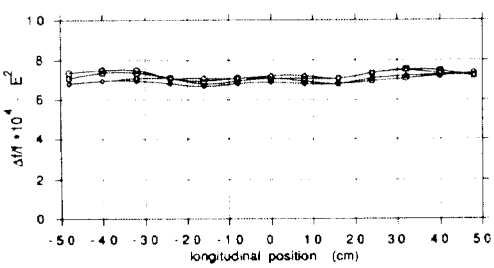

Fig. 5: Electric field patterns (first model)

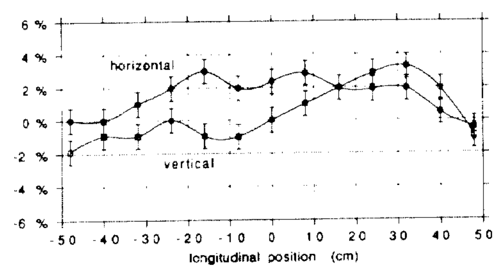

Fig. 6: Dipolar component (first model)

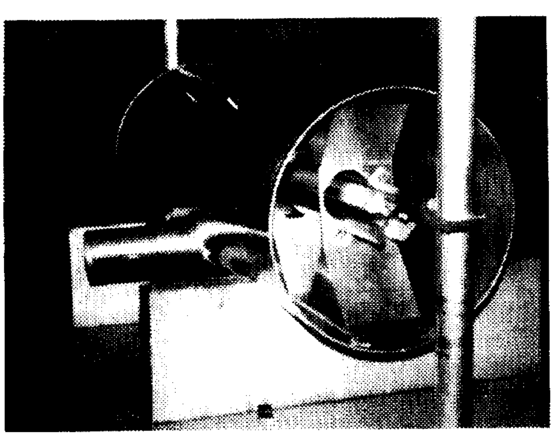

Fig. 7: The triangular stems model

For comparison, scaled Z_{sh} values have been computed using the measured capacitance and the MAFIA Q-value. Note that in the first model the shunt impedance is higher, due to a lower resonant frequency.

The first model is shown in Fig. 7.

5 CONCLUSIONS

The main result of this study is that the structure with triangular shaped stems appears the best, both in terms of Z_{sh} and of mechanical simplicity. A shunt impedance higher than 200 kΩ·m appears to be an achievable goal for the Pb-RFQ, even using vane-like shaped electrodes.

Furthermore, all three structures considered showed a satisfactory transverse field symmetry, while the required longitudinal field flatness has been easily obtained by tuning the end cells.

As for the design procedure, the MAFIA code gave results in good agreement with the measurements made, confirming that it is an essential tool in the design of complex resonators like RFQ's.

6 ACKNOWLEDGMENTS

The authors are very grateful to the LNL machine shop staff, particularly to S. Marigo and M. Lollo, for their essential help in the construction of the models.

7 REFERENCES

[1] G. Amendola, A. Pisent, J. Quesada, M. Weiss, "Beam Dynamics Studies for the CERN Lead-Ion RFQ", this Conf.

[2] A. Schempp, H. Deitinghoff, M. Ferch, P. Junior, H. Klein, "Four-Rod-λ/2-RFQ for Light Ion Acceleration", Nucl. Instr. and Meth. in Phys. Res., B10/11, 1985, pp. 831-834.

[3] A. Fabris, A. Massarotti, M. Vretenar, "A Model of Four-Rods RFQ", Seminar on New Techniques for Future Accelerators (Erice, 1986), New York: Plenum, pp. 265-269.

[4] M.J. Brownman, G. Spalek, P.B. Friedrichs, T.C. Barts, "Studies of the Four-Rod RFQ Using the MAFIA Codes", Proc. 1988 Linear Acc. Conf., Newport News, Virginia, October 1988, pp. 119-121.

[5] R. Klatt et al., "MAFIA – A Three-dimensional Electromagnetic CAD System for Magnets, RF Structures and Transient Wake-field Calculations", Proc. 1986 Linear Acc. Conf., Stanford, California, June 1986, pp. 276-278.

[6] V. Andreev, private communication.