SCALE ROOM TEMPERATURE MODEL OF THE SUPERCONDUCTING RFQ1 FOR THE PIAVE LINAC

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Abstract

The new injector PIAVE (Positive Ion Accelerator for Very low Energy) will use two bulk niobium (Nb) superconducting RFQs (SRFQ1 and SRFQ2), which will be operated at 80 MHz. The electrode length of SRFQ1 is about twice as long as the being built SRFQ2 thus requiring an EBW vacuum chamber larger than the previously available one. A principal decision was hence taken to split the electrodes and the tank into two parts. A half-scale room temperature model was built at LNL in order to test RF characteristics of the structure and to determine its exact dimensions. Results of the model measurements and M.A.F.I.A. code simulations are presented.

1 INTRODUCTION

PIAVE injector is now under construction at LNL for the superconducting (SC) linac ALPI. The beam, generated by an ECR source, will be bunched by a three harmonic buncher and accelerated by two SC RFQs, followed by eight SC QWRs, for an equivalent voltage of 8 MV (U^{+28} beam) [1]. The cavity design of both SRFQ1 and SRFQ2 is based on the 4-rod structure with 90^{o}-apart-stem arrangement [2]. The components of the cavities will be manufactured from 3 mm thick niobium (Nb) sheet and will be assembled by electron beam welding (EBW). SRFQ2 is being already manufactured in LNL [3]. A design of SRFQ1 was done based on the M.A.F.I.A. code simulation for the case of unmodulated electrodes [4]. Since SRFQ1 electrodes are about twice as long as those of SRFQ2, it is impossible to weld them in the EBW vacuum chamber used for SRFQ2. We decided to split the vanes and the tank into two parts. Finally the two tanks will be welded by EBW into a single cavity. The cutting point of the unmodulated electrodes should be at the center between the stems (the point of zero longitudinal current) in order to minimize the field disturbance of the gaps. However, for modulated electrodes, the point should be slightly shifted to the position of electric field minimum closest to the position of zero longitudinal current. Since the welding of the electrode tips is technically impossible, a 1 mm gap between electrode parts is foreseen. RF contact between them will be provided by welding only proper Nb strips to avoid mode disturbance.

A half scale aluminum model of SRFQ1 with modulated electrodes was constructed having the goal:

1) to determine the tank diameter for the required resonant frequency;

2) to optimize the stem position in order to obtain proper field distribution;

3) to test the effect of the vane cutting and the strip connecting the gap;

4) to determine alignment error tolerance.

2 ALUMINUM MODEL DESIGN

The model (Fig.1) allowed easy access to the central part of the structure and hence proper alignment of the electrodes.

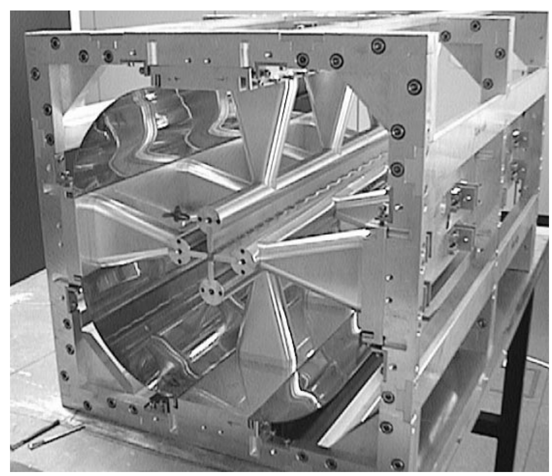

Figure 1: View of the half scale model of SRFQ1 (end flanges and one of the shells are not installed)

It is first assembled in 4 parts by means of longitudinal and transverse aluminum bars. The assembling procedure of the structure was the following.

At first each 1/4 structure was assembled independently: four stems, supporting the split (with 0.5 mm gap) electrode were installed onto the longitudinal bar and fixed. Then four such parts were assembled with respect to an external frame and aligned. After that four copper cavity shells were slided into proper slits with good RF contact. Finally two end flanges closed the structure. The first alignment procedure was the longitudinal positioning of the electrodes. Transverse positioning of the electrodes was obtained with respect to reference planes manufactured on each electrode.

Positioning of the electrodes was provided with an accuracy of $\pm$ 25 μm.

3 RESULTS OF MEASUREMENTS

3.1 Resonant frequency, Q-factor and mode separation

A comparison between M.A.F.I.A. simulations, performed using unmodulated electrode because of mesh number constraints, and measurements (modulated electrodes) is shown in Table 1.

Table 1 : RF parameters of the model

	M.A.F.I.A. simulations	Measurements
Frequency of quadrupole mode [MHz]	158.038	158.546
Q-factor	7400	3700
Frequencies of dipole modes [MHz]	181.169	178.197 179.440
Capacitance [pF/m]	141	_

As it can be seen from Table 1 simulated value of the quadrupole mode frequency for unmodulated electrodes is slightly lower than measured one with modulated electrodes, but it should be higher since the modulation results in lowering resonant frequency. It means that the simulation underestimated the frequency value mainly because of the unavoidable roughness of the mesh size in the simulation, especially around the vane tips. The modulation of the electrodes can result also in tilt of the longitudinal inter-electrode voltage distribution due to a change of inter-electrode capacitance, since modulation factor changes from 1.2 to 2.8. Instead of direct simulation of the version with modulated electrodes we calculate the capacitance variation along the regular channel of the structure for several cells by means of M.A.F.I.A. static solver. The input geometry used for calculation included one cell with vane tip and cilindrical part of the electrode. Figure 2 shows results of the calculations.

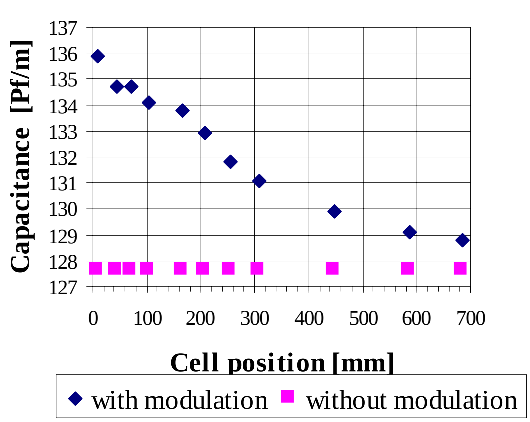

Figure 2. Inter-electrode capacitance variation

The effect of frequency shift due to the modulation was estimated to be 2.7 MHz ($\delta f = (f*\delta C)/(2*C_t)$, where C_t - total capacitance of the RFQ, and δC is change of it.

Measured frequencies of the dipole modes are split owing both to electrode modulation and to not ideal alignment. The frequency separation between the qudrupole mode and dipole ones is about 20 MHz. For 80 MHz Nb SRFQ1 it will be 10MHz, but it is enough to prevent the mode mixing. Measured Q value is also lower than simulated one due to not ideal RF joints.

3.2 Field distribution measurements

Measurements of the fields were carried out by means of standard bead-pull technique. We used for transverse field measurements a plexiglas bead (6 mm in diameter) and for longitudinal ones an aluminium cylindrical rod (1 mm in diameter and 3 mm in length). The inter-electrode voltage distribution (transverse E) along the structure was measured for each pair of neighbouring electrodes. To reduce effects of the modulation, the bead was pulled between electrode cylindrical parts at a distance of 30 mm from the beam axis. The results of field measurements were obtained after averaging 8 runs for each position. Standard deviation was 0.5%.

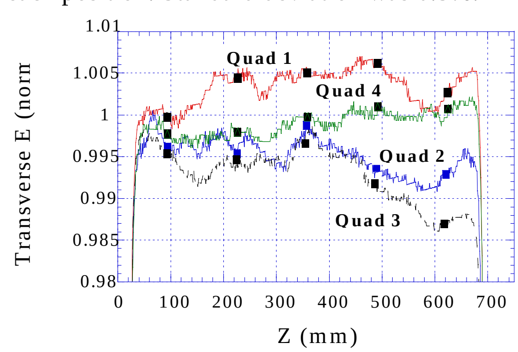

Figure 3: Close view of normalized transverse electric field distribution for 4 quadrants

As can be seen from figure 3 electric field unbalance among four qudrants is within ± 1%. Upper curves correspond to quadrants in which the distance between electrodes at the exit of the structure. is slightly smaller (~0.02 mm) than in the other two. The tilt of electric field distribution less 1% and no correction of the stems position is hence required. Electric field distribution at the beam axis is shown in figure 4.

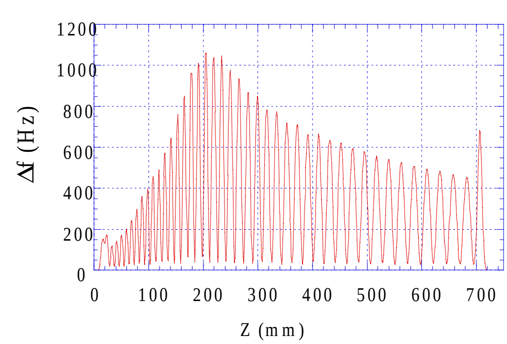

Figure 4: Δf ($\propto E_z^2$) distribution at beam axis

The increase of E_z^2 in the initial part (0-200 mm) of the structure is due to the change of the modulation factor

(m) from 1.2 to 2.8 The behaviour of the rest of the curve is explained by the constant value of m. More detailed distribution (E_z^2) in the 8 mm long gaps between the end flanges and the electrodes are shown in figure 5 (a, b). Like all 4-rod structures a voltage difference exists in the gap between end flanges and ends of the electrodes. The effect of the exit gap voltage is used here in order to create an additional accelerating cell [5]. The different shapes of the electric field distribution in the input and output gaps are due to the termination of the electrodes (SRFQ1 adopts a half cell termination at the end) and the positioning of the stems.

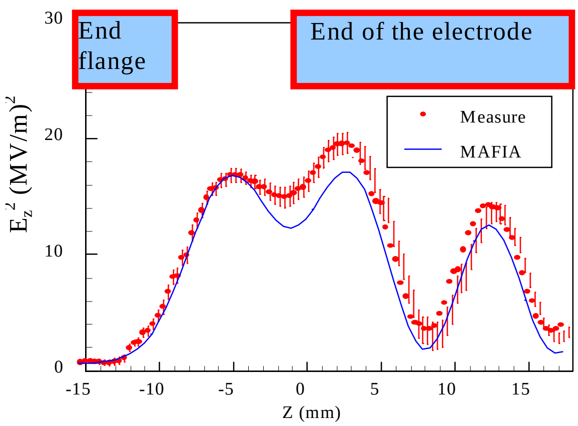

Figure 5 a): E_z^2 distribution at the entrance of the RFQ

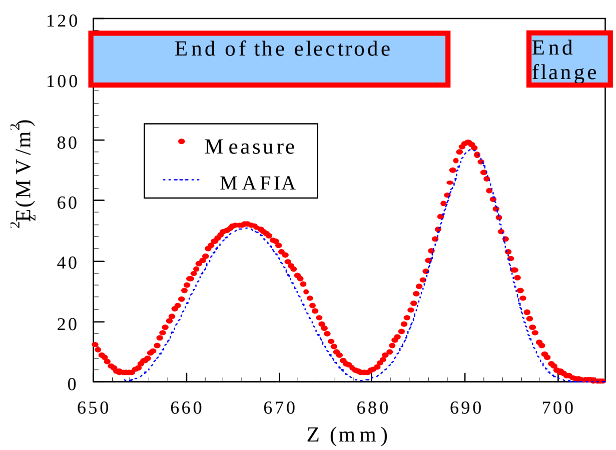

Figure 5 b) E_z^2 distribution at the exit of the RFQ

Field measurement were carried out along the beam axis near the electrode spliting points to observe effect of the split electrodes when RF strips were installed. M.A.F.I.A. static solver simulation predicted very small (~0.2%) field drop. No effect was consistently observed on the 0.5 mm gap with measurement accuracy. In order to estimate sensitivity to alignment errors the upper electrode was moved downwards by 0.1 mm. The resonant frequency of quadrupole mode was decreased by 257 kHz as a consequence. The measured transverse electric field distribution for the 4 quadrants is shown in figure 6.

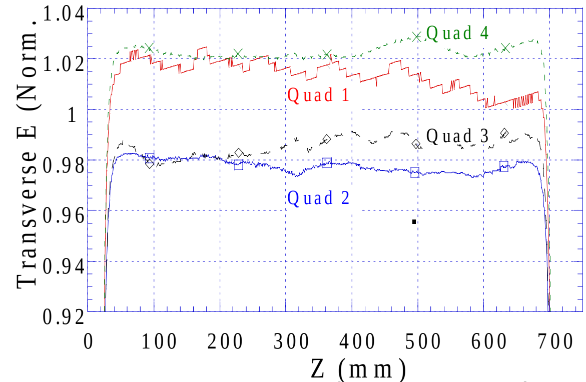

Figure 6. Normalized electric field distribution for the 4 quadrants after 0.1 mm misalignment of one of them

As it is shown by figure 6, transverse electric field in the upper quadrants (1 and 4) were increased and in lower ones (2 and 3) reduced. Total unbalance between the quadrants of the RFQ does not exceed ± 2% (i.e . ± 1% in the full-scale 80 MHz Nb structure).

4 CONCLUSION

Cold model measurements allowed to answer all the questions and to get results which will be a guideline in the construction of the full scale Nb SRFQ1.

Tank diameter for required resonant frequency was determined. Tolerance for the electrode misalignment should not exceed ± 0.1 mm in the 80 MHz SRFQ1.

A 1 mm gap between split electrodes parts will not affect the field distribution appreciably.

M.A.F.I.A. static solver simulations and experimental results obtained for E_z^2 distribution on the beam axis are in very good agreement.

5 REFERENCES

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