DESIGN OF THE GSI 36 MHZ RFQ ACCELERATOR ON THE BASE OF MAFIA CALCULATIONS

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Abstract

The paper summarizes the studies and Mafia calculations for the rf design of the new GSI RFQ accelerating structure (H_{110}-mode resonator, tank diameter 0.762 m, length 9.4 m). When Mafia is applied to a tank of this size, the resolution of the Mafia mesh remains very poor even when a maximum number of mesh points is used. Comparing calculations for an accelerating structure with similar size and complexity (GSI Wideroe 2) showed that the Mafia results can agree extremly well with the data measured in this structure some 25 years ago. This justified the use of Mafia as the main base for the rf design of the new RFQ structure, without any further model measurments. Many problems could be investigated with a mesh resolution of 1 mm on short subsegments of the RFQ tank. For studies concerning the complete tank, a resolution of 4 mm has been used. Details of the design procedure, and the results are presented in the paper. The precision of the results is estimated to about 1 to 2%. Measures for correction of deviations of this order have been studied extensively.

1 INTRODUCTION

Since about 1994 the GSI accelerator complex is being upgraded for higher beam intensities. In this program, the present 27 MHz Wideroe prestripper section will be replaced by a 36 MHz section consisting of one RFQ and two interdigital H type accelerating tanks [1].

A schematic drawing of the RFQ accelerating section is given in Fig.1. The cylindrical tank with the two longitudinal supports and the RFQ electrodes installed in between form an H_{110}-mode resonator. The tank consists of 10 tank modules which are quasi identical except for the varying RFQ electrode structure and the end windows in the longitudinal supports. A cross section of the RFQ electrodes with the carrier rings for the opposite electrodes is shown in Fig.2. The technical design of the tank, and the RFQ electrode system have been mainly determined by technical and beam dynamic considerations.

The given RFQ electrode geometry [2] represents a z-dependent, high capacitive loading of the resonator. The resonant frequency, the outer tank diameter, and the distribution of the electric field along the accelerating axis are strongly dependent of this capacitive loading and also of the lengths Dht2 of the end windows. The interactions of all these parameters have been investigated and optimized on the base of Mafia calculations [3].

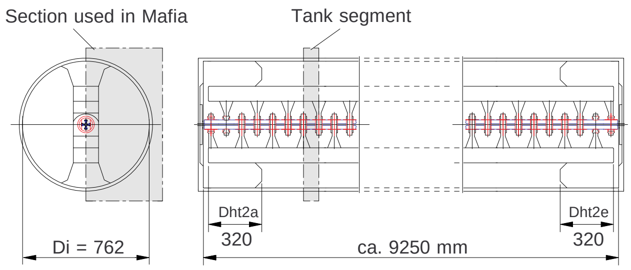

Fig.1: Schematic cross sections of the RFQ accelerator The shaded areas show the boundaries of Mafia mesh m1

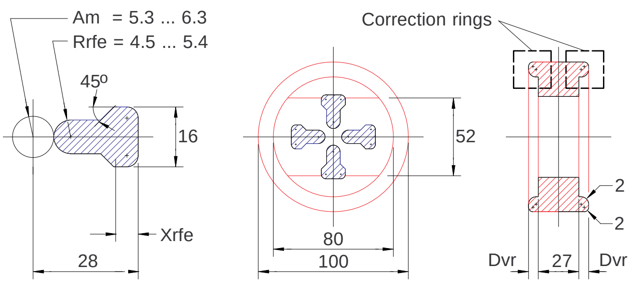

Fig.2: RFQ electrodes with carrier rings and correction elements for compensation of the capacity variations

2 GENERAL DESIGN STRATEGY

For field distribution calculations with Mafia, the geometry of the resonating structure has to be modelled in a 3-dimensional coordinate mesh. The maximum number of mesh points that can be handled on a workstation without exceeding 512 Mbytes of working memory, is in the order of 1 to 2 millions. As shown below, when the complete length of the RFQ tank is modelled with 1.2 million of mesh points, the best resolution obtained with an optimally designed Mafia mesh is about 4 mm. Compared with the about 5mm radius of the RFQ electrodes, this resolution seems extremely coarse and insufficient. The following strategy has been used.

As a preliminary study, the Mafia code was applied to an accelerating structure with very similar dimensions and complexity, GSI Wideroe tank 2. Some 25 years ago, this tank has been designed by extensive measurements in a half-scale model [4]. The data measured in the model as well as in the final tank represent a unique source to test the Mafia code. In spite of the very coarse mesh used, the data obtained with Mafia agree extremly well with the measurements [5].

The investigations for the new GSI RFQ structure have been split up into two steps. In the first step, short elementary slices of the structure (cf. Fig.1) have been studied with a fine Mafia mesh. This allowed to describe the RFQ electrode geometry and the mean aperture variations along the tank z-axis with a relatively high precision. The variations of capacitive loading along the z-axis were then compensated by introduction of correcting elements, such that a constant resonant frequency is realized over the full tank length. In the second step, a simplified cross section of the RFQ electrodes with the same frequency and a coarser mesh have been used for calculations concerning the complete tank length.

3 STUDIES ON SHORT TANK SLICES

Fig. 3 shows Mafia mesh m1 used in this case. The mesh density ranges from 1mm around the RFQ electrodes up to 10 mm for the outer tank regions. As far as possible, the mesh lines and/or the mesh diagonals have been chosen to coincide with the relevant physical edges of the structure. The longitudinal ondulation of the RFQ electrodes had to be neglected and was replaced by the geometric mean values. The mean electrode aperture varies in the range Am= 5.3...6.3 mm, the electrode radius is given by Rrfe = 0.85·Am. For the inner region of the RFQ electrodes, mesh m1 has been scaled proportionally with Am and Rrfe. In this region, the maximum deviations between the Mafia shapes used and the real electrodes could be kept below 0.15 mm.

The limiting z-planes of the short tank slices are treated as electric mirror planes in Mafia. The data calculated for the slices represent the z-dependent local properties of the corresponding RFQ structure. The local resonant frequency of mode 1 increases linearly by about 2% with the growing aperture of the RFQ electrodes. When the tank is assembled from the calculated elementary slices without any corrections, the voltage distribution along the tank axis decreases by about 20% towards the end of the tank. The required quasi constant voltage distribution can be realized only when the local resonant frequency is made constant over the entire tank length. One solution could be a variation of the tank outer diameter by about 16 mm. The following solution seemed more advantageous for many reasons.

The RFQ electrode and carrier ring units are the only removable parts of the given RFQ design. The required compensation of the local resonant frequency has been transferred to these parts by two measures (cf. Fig.2): First, the width Xrfe of the rear part of the RFQ electrodes has been chosen variable. Secondly, correction rings of width Dvr have been introduced on both sides of the RFQ carrier rings. In this way, the varying capacitive loading is compensated close to the place of origin.

The Xrfe and Dvr values have been derived from a large series of Mafia calculations on the base of short tank slices and partly by interpolation of the results. Xrfe is varied in the range from 4.5 to 10.5 mm, Dvr is varied between about 3 to 6 mm. With the fine mesh m1, the influences of some smaller details, like radii of the correcting rings, had to be neglected or estimated. The main advantage of the correcting rings is that they allow for corrections of the voltage distribution and/or the tank resonant frequency at the time of final assembly.

4 STUDIES FOR THE COMPLETE TANK LENGTH

The local frequency of the RFQ structure will be made constant as described above. For further calculations the cross section of the original RFQ electrodes has been replaced by a simplified geometry with the same resonant frequency, as shown in Fig.4.. With this geometry the number of mesh points in the radial plane can be reduced to the point that the complete tank length can be modelled with 1.2 million mesh points (Mafia mesh m4). On an

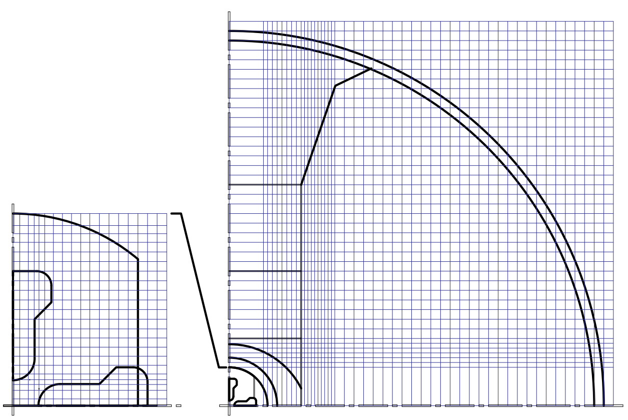

Fig.3: Mafia mesh m1, mesh densities from 1.0..10 mm RFQ electrode geometry used for investigation of short elementary tank slices. Mesh around the RFQ electrodes is shown only in the 5x enlarged part on the left side

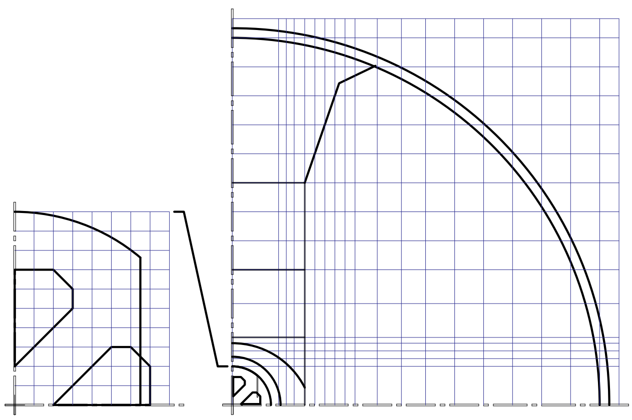

Fig.4: Mafia mesh m4, mesh densities from 4.0...30 mm Simplified RFQ electrode geometry and mesh used for calculations including the complete tank length. Mesh lines around the electrodes shown only in the left part.

IBM R6000/512 Mb workstation, the time for one run of Mafia module e320.D, with 6 modes and 4 iterations is about 8 cpu-hours.

Mesh m4 mesh was mainly used to calculate the voltage distribution between the RFQ electrodes along the accelerating axis and to optimize it by variation of the length Dht2 of the end windows. Fig.5 shows the distributions obtained with Dht2 = 319 ±27 mm. It must be emphasized that the flatness of the final voltage distribution will depend on the precision with which the local resonant frequency variations can be compensated.

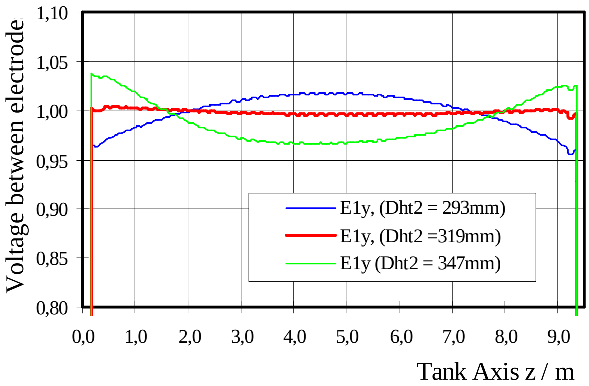

Fig.5: Voltage distribution vs. z-axis (x=2mm, y=4mm) Flat curve for optimum end window length Dht2=319mm

The calculations on the complete tank length revealed another important information. For short tank segments the higher resonant modes are by about a factor 8 above the fundamental mode. With the complete tank one finds mode F2 relatively close to mode F1 (F1=36.34 and F2=38.60 Mhz). The voltage distributions of the modes F2 and F3 are shown in Fig.6. They are very similar to the distributions in a quarterwave resonator with open ends.

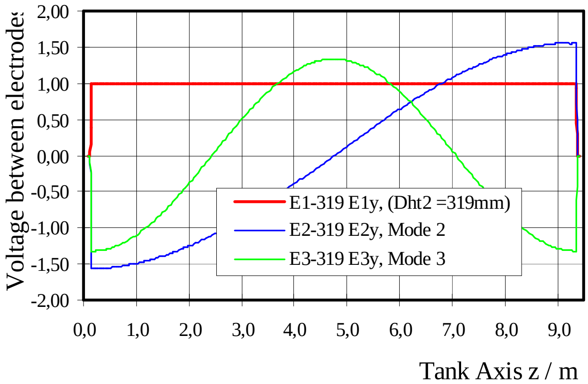

Fig.6: Voltage distributions vs. z-axis (x=2mm, y=4mm) Calculations for the lowest resonant modes F1, F2, F3.

5 ERROR ESTIMATIONS AND TUNING ELEMENTS

The geometric shapes used in the Mafia calculations are only a very coarse image of the geometry of interest. The precision of the calculated results is in the order of 10^{-5}. It is difficult to answer with which precision the results can be re-attributed to the original structure.

The RFQ aperture has been varied linearly over a certain range as discussed above. In the course of these studies parts of the electrode boundaries„jump“ from one mesh line to the next. The resulting resonant frequency deviations from linearity have been used to estimate the errors caused by these mesh imperfections. With mesh m1 one obtains an error in the order of ± 0.5% in this way.

Variations of the parameters Xrfe, Dvr, of the tank diameter etc. have been evaluated additionally to estimate the errors produced by neglecting structure details like rounded edges etc. It seems realistic to assume an overall error of the calculated data in the order of 1 to 2 %.

Several types of additional tuning elements that might be used to correct errors of this order of magnitude have been studied with Mafia as well. The results are outlined in Fig.7. The frequency variations given for the cases (A) and (B) have been obtained with one pair of tuners per tank module or a total of 20 tuners in the tank. Even with these extreme numbers of additional tuning elements, mode F2 does not move much closer to mode F1.

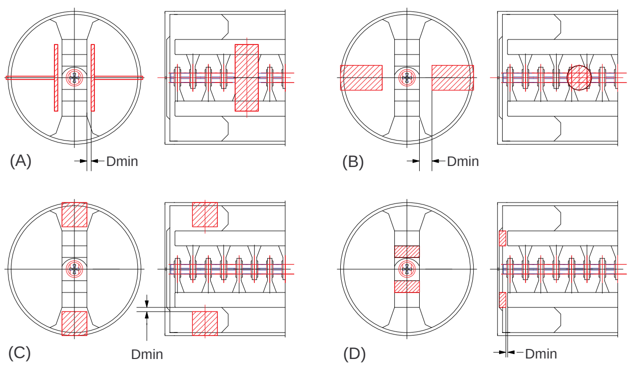

Fig.7: Tuning ranges of different tuning elements
(A) Capacitive plates, Dmin=20mm, dFmax/F=-2.2%
(B) Inductive tuners, Dmin=70mm, dFmax/F=+2.2%
(C) Window tuners, Dmin=30mm, dFmax/F=+0.4%
(D) Endflange tuners, Dmin=10mm, dFmax/F=-0.3%

REFERENCES

[1] U.Ratzinger, et al., The RFQ Section of the New UNILAC Prestripper Accelerator at GSI, See this Conference

[2] A. Schempp, Particle Dynamics of the U4+ High Current RFQ, Int.Rep.S-95-10, IAP Uni Frankfurt

[3] MAFIA Computer Code, Available from CST GmBH, Lauteschlägerstr.38, D-64289 Darmstadt, Germany

[4] K. Kaspar, Untersuchungen zur Dimensionierung eines Schwerionen-Linearbeschleunigers vom Wideröe Typ, 1973, GSI Report 73-10

[5] K. Kaspar, Comparison of MAFIA Calculations and Model Measurements for a Complex Drifttube Accelerating Structure, GSI Annual Report 1994