NUMERICAL SIMULATION OF IH ACCELERATORS WITH MAFIA AND RF MODEL MEASUREMENTS*

B. Krietenstein, T. Weiland, TH Darmstadt, Germany
U. Ratzinger, R. Tiede, GSI, Darmstadt, Germany
S. A. Minaev, MEPI, Moscow, Russia

Abstract

Two IH drift tube cavities will be part of the new pre-stripper LINAC for the beam intensity upgrade of the GSI accelerator facility in Darmstadt (Germany). A major part of the cavity design process consisted of numerical electromagnetic simulations using MAFIA[1]. The simulation method as well as the dependence of the field distribution on some key geometries are discussed. Based on these calculations the tanks are under construction and a 1:5.88 scaled RF model was built to compare the results and to determine the exact drift tube geometry. This paper describes the most important steps in the design process and presents results for the simulation and the measurement.

Introduction

The accelerator facility at GSI basically consists of a heavy ion linear accelerator (UNILAC), a heavy ion synchrotron (SIS) and a heavy ion storage ring (ESR). To be able to fill the SIS up to its space charge limit, the first (pre-stripper) part has to be replaced. Two IH drift tube linacs (IH1) and (IH2) will be part of the new UNILAC. They are designed to provide an effective voltage gain of 40.8 MV (IH1) and 42.4 MV (IH2) at a resonance frequency of 36.136 MHz (see also [7], [3]).

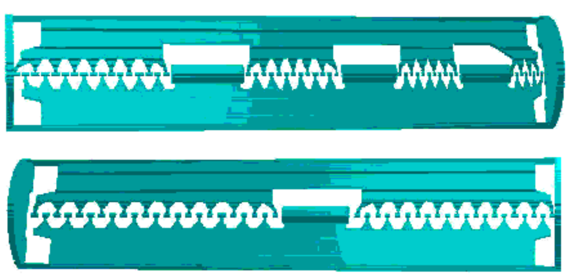

Figure 1: Layout of IH1 and IH2 after the optimization with MAFIA.

Unlike earlier designs, the IH-cavities were planned to be cylinders with circular cross sections, in order to provide better mechanical stability against gravitational and vacuum forces. Thus it was no more possible to measure and to tune the cavities during the production. As tuning elements reduce the reliability of such a structure, the parameters for the geometry had to be determined in advance as good as possible. This was performed by numerical field calculations. The eigenmode solver of MAFIA [1] was used to calculate the electromagnetic field distrubution and the resonance frequencies of both cavities.

[1] Solution of **M**axwell's equations using a **F**inite **I**ntegration **A**lgorithm

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Table 1: Main dimensions of IH1 and IH2.

	IH1	IH2
Radius [m]	0.915	1.017
Inner length [m]	8.995	10.175
Drift tubes	52	45
Input undercuts [m]	0.221	0.400
Output undercuts [m]	0.480	0.520
Gap quadrupole–girder	0.390	0.390

Simulation

Electromagnetic properties of IH-resonators

The most important parameters of an IH-cavity are the frequency of the acclerating mode and the gap voltage distribution. The basic relations for such a cavity operated in the H_{111}-mode are given in [4].

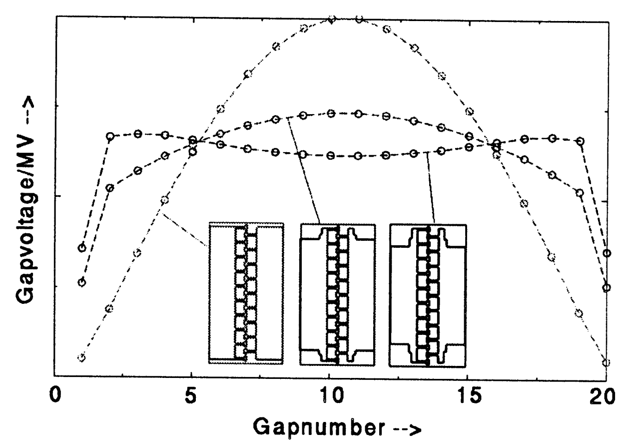

Figure 2: Voltage distribution for different depths of the undercuts in the girders.

Reference voltage distributions for IH1 and IH2 were derived earlier from LORASR beam dynamics calculations and from experience with respect to high shunt impedance values. They are plotted in figures 7 and 8. There are two very effective principles to tune the gap voltage distribution:

- Variation of the ratio g/L of drift tube gap to period length. A reduction of the capacity per length induces a reduction of the gap voltage and vice versa [5].

- Undercuts at the girder ends rise the gap voltage in the region of the tank ends (see [6] and figure 2).

In contrast to earlier designs the voluminous quadrupoles will be mounted on the girders. Using such an array, the local capacity rises and tends to detune the structure locally. To compensate the resulting increase of the gap voltage, the lens support was elongated and the distance to the opposite girder was enlarged (see figure3).

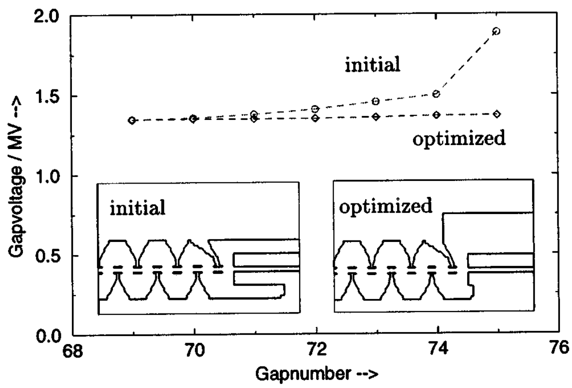

Figure 3: Optimization of the arrangement around the quadrupole lenses. The distance to the opposite girder was enlarged and the lens support was elongated.

Procedure for the Simulation

In comparison to the complete IH-cavities, the drift tube geometry represents a rather close-meshed structure. A discretization of the real drift tubes with an acceptable resolution would lead to a tremendously large number of meshpoints.

Thus, the main problem was to find an appropriate approximation for the real drift tube geometry. An octagonal cross-section was chosen, that can be modeled with very few mesh-steps (see figure 4). Detailed simulations had to be perfomed in order to match the capacities of the real drift tubes and their substitutes. In spite of the rather coarse discretization, about $40\,000$ meshpoints were necessary to model a slice with one gap, resulting in $3\,000\,000$ meshpoints for IH1 and $2\,000\,000$ for IH2.

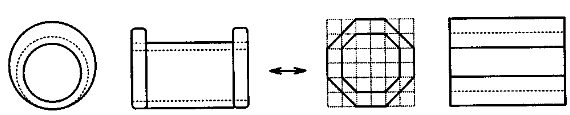

Figure 4: The real drift tube and its substitute. The octogonal cross-section can be discretized with only 3 cells along the radius.

Table 2: Some data concerning the simulations.

Smallest mesh step:	3 mm
Biggest mesh step:	30 mm
Number of mesh points:	2-3 million
CPU-time:	36 hours
Machine:	IBM RS-6000 590

To locally optimize the voltage distribution, a detached simulation of shorter sections is possible. Some cross-sections of the cavities exist, on which the magnetic field is perpendicular. The cavities can be split at these points, if magnetic boundary conditions are applied.

The arrangement around the quadrupole lenses was optimized, using such a short section. A comparison of the resonance frequencies of single sections also gives a first impression of the total voltage distribution. Sections with higher frequencies will have lower gap voltages and vice versa.

As a last step, after the voltage distribution was optimized, the exact cavity radius r_{cav} was determined in order to match the nominal frequency f_n. This can be done with sufficient accuracy, using the simple relation

$$r_{cav} = \frac{f}{f_n} \cdot r \qquad (1)$$

with r and f being the radius and the frequency from the last calculation.

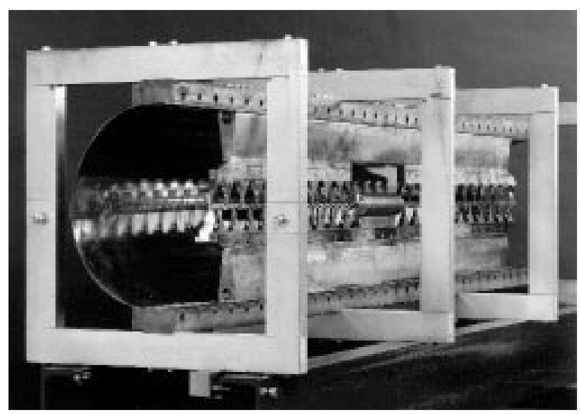

Figure 5: The 1:5.88 model for cavity IH2 (Photo: A. Zschau, GSI).

Measurements

A 1:5.88 scaled model was built, which allowed to compare the numerical results with measurements. In addition, a conical geometry for the drift tubes facing the quadrupoles was designed and tested, which reduced the peak field strength on axis by ≈30%. Compared with the other gaps, the peak field still is at least 12% higher.

Furthermore, plungers with combined capacitive and inductive action for tuning the resonance frequency in the range of 0% to -0.5% were tested (see figure 6).

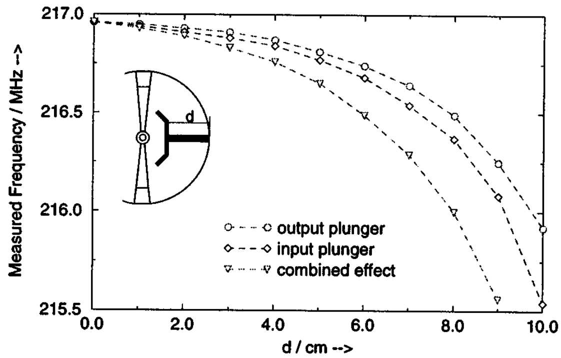

Figure 6: The LC-plunger and its effect on the resonance frequency.

Results

A comparison of calculated and measured voltage distribution for IH2 (figure 8) shows a good agreement. Even better and more important is the agreement in the resonance frequency (table 3), as a later tuning is only planned in the range of 0% to -0.5% (see figure 6). Figure 7 shows two different results in comparison with the reference after a first optimization of IH1 due to variation of the undercuts in the girders and the g/L-distribution.

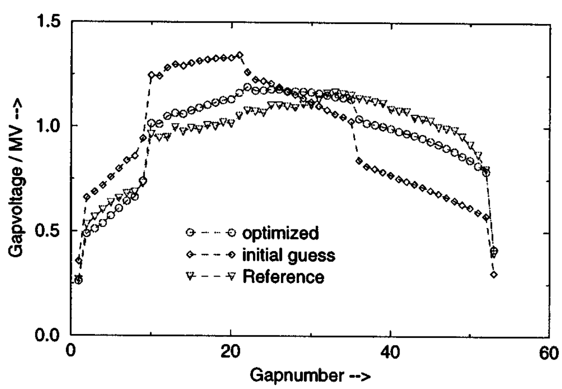

Figure 7: Calculated and reference voltage distributions in cavity IH1.

Table 3: Calculated and measured frequencies of the accelerating and higher modes for cavity IH2.

	Frequency of Modes [MHz]			
	1	2	3	4
MAFIA	36.275	37.962	42.208	47.570
Measurement	36.287	37.885	41.868	47.011

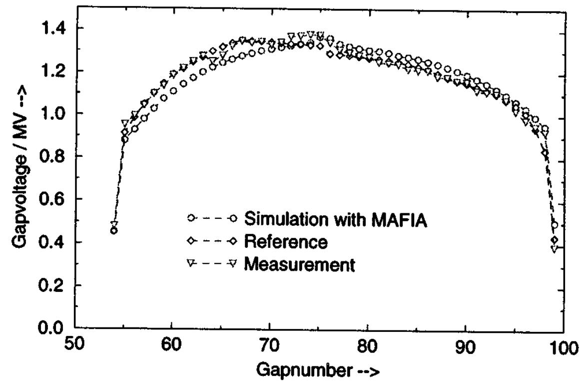

Figure 8: Calculated, measured and reference voltage distributions in cavity IH2.

Summary

With help of the calculations, the tanks for both cavities could be ordered, even though the exact drift tube distances in tank IH1 had not yet been optimized with respect to the reference voltage distribution. The main parameters to be determined were the tank radii and the dimensions of the undercuts in girders. Measurement and simulation showed a very good agreement.

References

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