NUMERICAL SIMULATION OF IH ACCELERATORS WITH MAFIA AND RF MODEL MEASUREMENTS

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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. 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]).

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 was used to calculate the electromagnetic field distribution and the resonance frequencies of both cavities.

Table 1: Main dimensions of IH1 and IH2.

<table>
<thead>
<tr>
<th></th>
<th>IH1</th>
<th>IH2</th>
</tr>
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<tbody>
<tr>
<td>Radius [m]</td>
<td>0.915</td>
<td>1.017</td>
</tr>
<tr>
<td>Inner length [m]</td>
<td>8.995</td>
<td>10.175</td>
</tr>
<tr>
<td>Drift tubes</td>
<td>52</td>
<td>45</td>
</tr>
<tr>
<td>Input undercuts [m]</td>
<td>0.221</td>
<td>0.400</td>
</tr>
<tr>
<td>Output undercuts [m]</td>
<td>0.480</td>
<td>0.520</td>
</tr>
<tr>
<td>Gap quadrupole-girder</td>
<td>0.390</td>
<td>0.390</td>
</tr>
</tbody>
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Electromagnetic properties of IH-resonators
The most important parameters of an IH-cavity are the frequency of the accelerating mode and the gap voltage distribution. The basic relations for such a cavity operated in the \( H_{111} \)-mode are given in [4].

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

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 figure 3).

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 $r_{\text{cav}}$ was determined in order to match the nominal frequency $f_n$. This can be done with sufficient accuracy, using the simple relation

$$r_{\text{cav}} = \frac{f}{f_n} \cdot r$$

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

Table 2: Some data concerning the simulations.

<p>| | |</p>
<table>
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<tr>
<td>Smallest mesh step:</td>
<td>3 mm</td>
</tr>
<tr>
<td>Biggest mesh step:</td>
<td>30 mm</td>
</tr>
<tr>
<td>Number of mesh points:</td>
<td>2-3 million</td>
</tr>
<tr>
<td>CPU-time:</td>
<td>36 hours</td>
</tr>
<tr>
<td>Machine:</td>
<td>IBM RS-6000 590</td>
</tr>
</tbody>
</table>

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 performed 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 octagonal cross-section can be discretized with only 3 cells along the radius.

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 $\approx 30\%$. 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.

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


