RF DESIGN OF THE MAFF IH-RFQ*

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Abstract

The low energy part of the LINAC of the MAFF facility will be an IH-RFQ cavity with 101.28 MHz resonance frequency. The RFQ is designed to deliver ions of A/q = 6.3 up to 300 keV/u to be injected into the following LINAC. The structure chosen was an IH type of resonator since it was demonstrated to have a better shunt impedance [1]. The required maximum voltage between the electrodes is 70 kV and the operation mode is pulsed with a duty cycle of 10%. The structure will be made out from bulk copper in order to improve the shunt impedance and hence to allow not direct cooling on the electrodes. A detailed description of the resonator as well as simulation results will be presented in this paper.

INTRODUCTION

The driver for the production of exotic isotopes of the Munich Accelerator for Fission Fragments (MAFF) [2], the research reactor FRM-II in Garching (Germany), has been commissioned successfully. The first acceleration stage for the radioactive ions has been funded. The first part of the acceleration chain consists in an IH-type of Radio Frequency Quadrupole (RFQ) at 101.28 MHz, running at 10 % of duty cycle. As the maximum intensity of exotic beams from the MAFF target ion source is about $10^{10} - 10^{12}$ ion/sec. a high transmission and low emittance growth are required. Therefore the rod voltage and thus the focusing strength have been raised, which influence the RF layout. Details about the optics and the beam dynamics choices of the accelerator can be found in [3]. The overall length of the resonator is 2894 mm with the electrode length equal to 2810 mm. The equivalent effective voltage gain is 1.871 MV with a peak power dissipation of 78 kW. The maximum duty cycle is 10% so the average power dissipation is 2.6 kW/m which can be cooled easily. The structure is modular in order to facilitate the construction: there are five identical central-modules whose length is 400 mm and two end-modules whose length is 425 mm. The modular concept does not spoil the RF properties of the resonator since the longitudinal surface current are negligible.

RF COMPUTER SIMULATION

The design of the resonator was performed with the code `CST MICROWAVE Studio` [4]. As first design step a single cell model and a central module model were simulated and optimized with respect the shunt impedance and the Q-value of the resonator. Many parameters were studied already in [1] and the current design uses some optimization found in it. Particular care was given to the meshing procedure, since the automatic mesh algorithm was not able to converge in to a definite solution. In details, we have simulated a complete central module with an increasing number of meshes until the frequency error was converging to be less than 0.1% for several runs. This technique is applicable only an a short structure, otherwise the computing time and the memory requirements exceeds the one available in our department. Once the supposed correct frequency was found, we have studied a different mesh with much less mesh-cells that can reproduce the same results. In this way for the single module we where able to reduce the mesh-cells from 3 millions to 4 hundred thousand, more then a factor of 7 less, with a great impact on the computing time. With this method the critical regions where most of the field is concentrated were identified and proper mesh was given, while for the other regions the meshing was done by the automatic procedure.

In Fig. 1 is shown the results of the calculation for the surface current in the central module, the value of the electric and magnetic fields and hence the currents are normalized to a total energy of 1 J. A calculation of the power dissipation shows that 52 % of the power is dissipated in the cylinder walls together with the ridges, 34 % is dissipated in the stems and only 14 % in the electrodes.

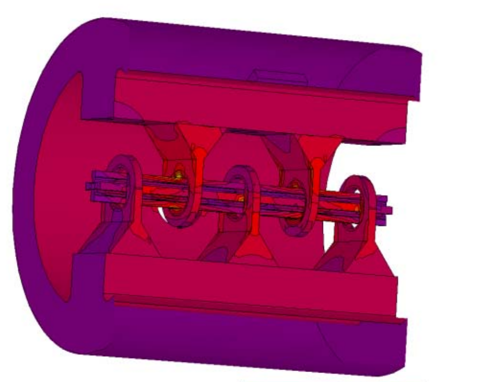

Figure 1: Simulation results for the surface currents in one of the central modules. The field and currents are normalized to a total energy of 1 J.

With the reduced mesh we are now able to simulate half of the structure, (the other half is symmetric) and in Table 1 we report the dimension of the more important parameters which gives a resonant frequency close to 101.28 MHz. An important parameter of for the RFQ is the flatness of the voltage along the electrodes. From beam dynamics reason the maximum oscillation between the minimum and max-

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Table 1: Geometric parameters of the resonator and computed r.f. figures.

Inner radius	151.5	mm
Axis to pole-tip distance	4	mm
Pole-tip radius	3.5	mm
Radius ring	25	mm
Distance between stems	80	mm
Number of stems	35	#
Axis to ridge distance	80	mm
Undercut width	90	mm
Width of the ridge	80	mm
Length of the tank	2894	mm
Frequency	101.349584	MHz
Shunt Impedance	183	kΩm
Q-value	7877	
Max power density	2.5	W/cm^2

imum value of the voltage should not exceed 2% of the average voltage. Fig. 2 shows the computed voltage distribution along the electrodes for half of the resonator. The vertical electrodes have a global offset in voltage of around 2%. This difference is due to the fact that the current path for the vertical electrodes is different, while for the horizontal ones the path is the same. In order to minimize this effect, one solution could be to have a slightly different geometry between the vertical electrodes, as, for example, a different height of the electrode shoulder. Unfortunately the variation of geometry is too small to be computed correctly, so any variation of the geometry will be prototyped and measured in a cold model

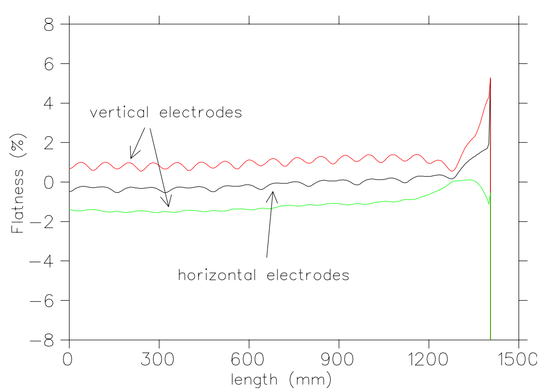

Figure 2: Voltage distribution along the electrodes. The red and the green traces represents the distribution of the vertical electrodes, while the black one represent the distribution of the horizontal electrode which is takes as a reference.

COLD MODEL

The construction of the cold model was suggested in order to verify the frequency calculation for a complicate structure such as an IH-RFQ. Fig. 3 shows the cold model that has been fabricated at the workshop of the department. The model will be used for benchmark the tuning procedure for the voltage distribution, the frequency tuning and the alignment of the electrodes. First preliminary measurements were done with a c-shaped thick-plate tuner, and that gave us an idea about the frequency range and the tuning sensitivity. The resonant frequency calculated for one given geometry was measured compatible with an error of 0.5%.

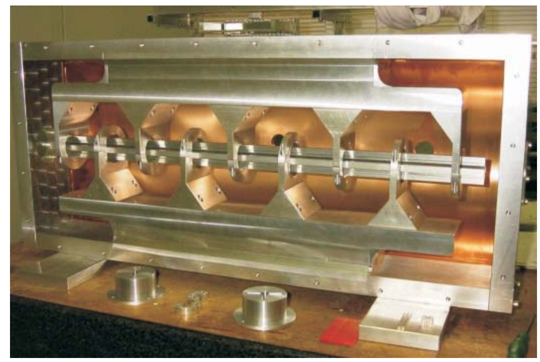

Figure 3: Cold model for the IH-RFQ. The transverse dimension of the model is the same as for the full power resonator, only the length is 750 mm.

Fig 4 shows a preliminary measurements of the tuning frequency range for different undercut length. As one can see clearly, the effect of the different length of the undercut is just a global frequency variation, while the effective tuning range is the one that is very close to the electrodes region.

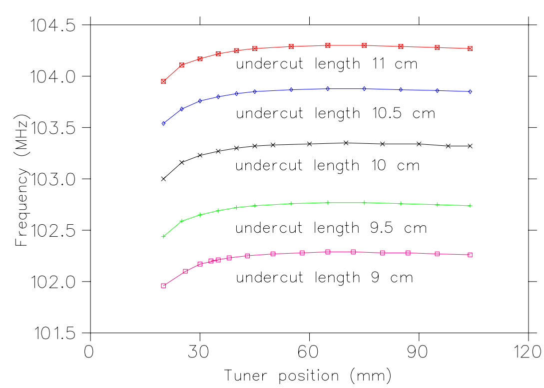

Figure 4: Plot of the tuning ranges for different undercut length. The plot shows that the sensitive area of tuning is just near the electrodes. The tuner position is read on a scale that printed on the shaft of the tuner itself.

Bead-pull measurement are carried out in order to determine the flatness of the rod voltages.

MECHANICAL CONSTRUCTION

As mentioned in the introduction the concept for the mechanical construction of the full power resonator foresees five identical central modules 400 mm long and two identical end modules 425 mm long which will be made out from bulk copper. Fig. 5 and Fig. 6 shows a 3D section of, respectively, central-module and end-module.

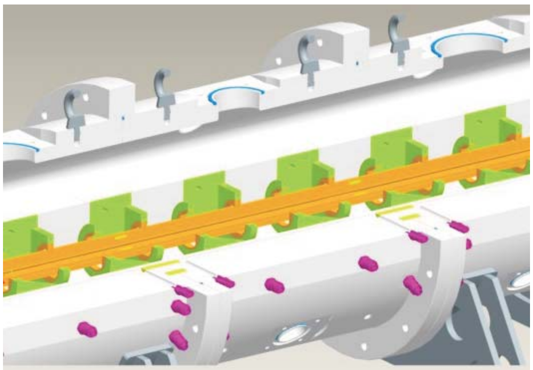

Figure 5: 3D image of one of the central modules.

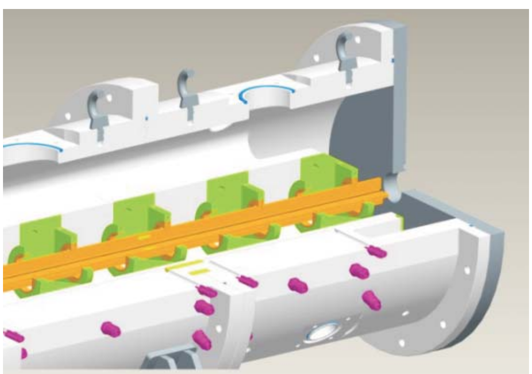

Figure 6: 3D image of one of the end modules.

This concept is based on the fact that there is virtually no longitudinal currents so any transverse cut does not interfere with the RF behavior of the cavity. The advantage of having such a concept is that the manufacturing of small pieces can be done with very high accuracy, so to meet the tolerances required from the beam dynamics. In fact since the alignment of the electrodes will be done on an external frame, it is mandatory to have the stems and the ridges where they are mounted as accurate as possible, so that the alignment can be preserved. The tolerance on the construction are tight: the error on the two planar surfaces of the ridges has to be within 50 μm. The electrical contact between the ridges and the stem is assured by gold foils. With this solution is possible to correct some construction errors since there are available commercially foils of different thickness. The correct connection between modules will be guaranteed by the use of pins which will be used as reference points,which define the axis..

Each module has four ports which are used as ports for the vacuum pumps, vacuum gauges, coupler and pick-up. The sealing will be done using Viton O rings. The vacuum requirements for highly charged ions demands for 10^{-8} mbar: only at this level in the first part of the RFQ the beam loss due the change of the charge state is negligible. Specifications about the vacuum system can be found in [5].

As for the cooling system, each stem has an independent cooling circuit, while the ridge is cooled by means of three independent channels which are running close to the flat ridge surface and to the conjunction with the main cylinder. The cooling channels on the stems have been designed to be very close to the electrodes connections, since the highest current density is located there. For the isolation between water and vacuum will be used small Viton O rings. The cylinder itself will be cooled externally with channels attached on each quadrant.

The modules are now being produced, see Fig. 7 and the delivery will be beginning of next year.

Figure 7: The picture shows the one of the central module after the first machining procedure.

ACKNOWLEDGMENTS

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