TUNER DESIGN FOR HIGH POWER 4-ROD-RFQs*

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Abstract

The performance of high power RFQ linacs, as used in spallations sources and proposed for projects like ADxy, IFMIF or high duty factor drivers for RIB application are limited by beam dynamic properties as well as technical limits like sparking, power density, cooling and thermal stresses. A "one piece structure" even possible in theory has to have means for tuning the real fields like exchangable or moving tuners. Tuner design features will be discussed and results will be presented.

INTRODUCTION

The low energy section of a modern ion linac consist of an RFQ-DTL combination in which the beam from the ion source is shaped to match the experiment or the following accelerator, an high energy linear or circular accelerator.

The beam dynamics and rf-structure designs for moderate beam currents and pulsed structures are proven and there is a lot of experience and tools to match and shape for different special requirements.

For high average beam power and e.g. cw-operation of linacs the freedom of parameter is limited and the interference of beam dynamics with rf-design and mechanical engineering is much stronger.

There are high duty factor heavy ion machines and some experience with cw high current RFQ prototypes but new projects like the IFMIF / XADS [1] type of projects require new parameter ranges which cannot be achieved by just extrapolating low power structures.

The succesful tests of the LEDA RFQ with 100mA cw proton beam illustrates the magnitude of problems to be solved [2].

One important point is the tuning of a long structure. Starting from designs for an ideal cavity the frequency of the resulting structure can be determined in the order of some percents precision. The more homogenous the structure the more precise the simulation can be. But, e.g. with the modulation of the RFQ electrodes structure and by this varying capacity along the RFQ the simulation are less precise and in addition some design ask for a tilted field distribution, while in the normal designs the field amplitude is just a constant factor.

Tilted field designs are even more difficult to simulate and mechanical tolerances bring unavoidable field and frequency errors.

One point which brought some reduction in length sensitivity was the development of resonantly coupled sections and distributed rf-feeds and vacuum pumping ports. Still the LEDA-RFQ has 132 tuners to compensate for discontinuities and field balance.

The 4-rod-RFQ-structure is less sensitive to mechanical asymmetries, a typical number is 10 tuners for a 4 m long RFQ at 200 MHz. There are two kind of tuners: static ones to tune the frequency and dynamic ones to compensate for temperature changes. For lower average rf-powers this is no real problem. 30A/cm scale down to average currents of less than 1A/cm and rather low power losses on the contacts between tuner blocks and the tank base, which can be simple spring fingers, special developed finger stock like for tunable cyclotrons or metal vacuum seals.

We have made an attempt to investigate these problems, because for possible application of the 4-Rod as cw structure the straightforward finger stock material used so far is at its limits.

RFQ TUNER

The 4-Rod-RFQ consists of a chain of interlaced $\lambda/2$ resonators operating in π0-mode, generating the homogenous quarupole voltage distribution along the RFQ electrodes. Basicly the capacitively loaded stem structure is a loaded chain of strongly coupled resonators. The frequency of theses resonators should be identical, then the fields will be constant along the RFQ. Mechanical inhomogeneities, ports etc. and the varying electrode shape detune the chain.

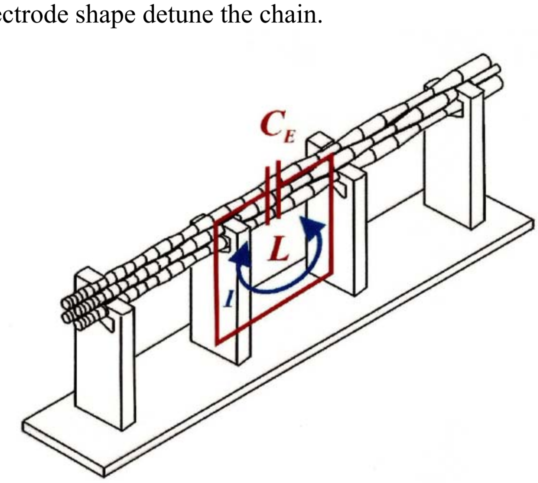

Figure 1: Basic 4-Rod-RFQ cell.

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Small changes can be achieved by bringing in copper cups, which perturb the magnetic field, raising the frequency of the pertubated cell and by coupling also of the chain of cells and such compensating thermal changes in operation, where these tuners serve in a feedback loop. Typically for a 4-Rod structure of 2 m length one tuner is sufficient.

A contact to the cavity is not necassary, unlike tuners like for a spiral cavity which act capacitively and add capacity to the tank outside. There is a net current flow over the tuner stem to the tank, requiring a good sliding contact at the base.

Tuners in e.g. reentrant cavities and Alvarez structures tune the magnetic fields (change of the net volume of the tank) and they change the current path. They need a contact between tank and tuner if their change of the field distribution should be small. Simple and mostly used solution is a deep slot, which brings the net current flow on the contact down to a very small rest.

As indicated in the scheme of the basic cell of a 4-rod RFQ in fig.1 the cross section of the current loop is prop.. to the inductivity and making this loop smaller, e.g. by introducing some (copper) material on the base plate, will raise the frequency. Fig. 2 show the structure used in the following examples (stem distance 77 mm, stem height 95mm) together with calculated currents in the middle of the base plate and E-fields resp. voltages between the electrodes in the middle between the stems.

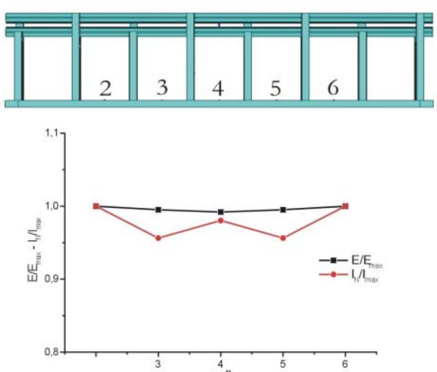

Figure 2: Voltages and currents in the cell centers between the stems along a short 8-stem 4-Rod RFQ.

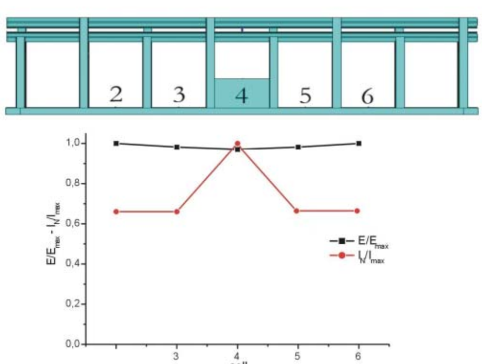

Figure 3: Voltages and currents along a short 8-stem 4-Rod RFQ with a central tuning block (Δf=2%).

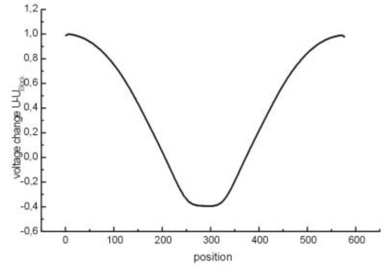

Figure 4: Electrode field changes induced by the central tuning block.

Introducing a tuning block (height 40mm) in the central cell will raise the frequency by 2%, lower the field in the middle cell and increase the current in the middle cell as shown in Fig. 3. Such an current increase of about 50% [3] can lead to overload of these contacts between stems and tuning block.

The variation of the E-field along the electrodes is localised around the tuned cell as shown in fig. 4.

The current distribution with a tuning block is investigated in more detail in figs. 5-8, where the current across the RFQ cell is plotted for different paths, showing that the full current is in the slot.

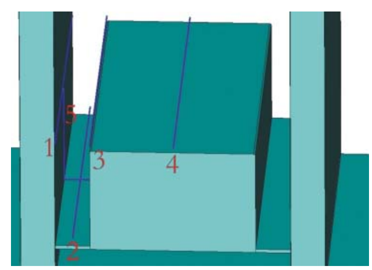

Figure 5: RFQ tuning block between stems with slots.

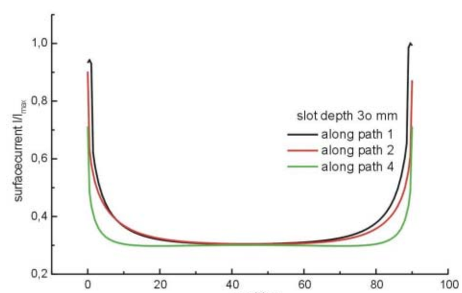

Figure 6: current distribution across the RFQ-cell at different points.

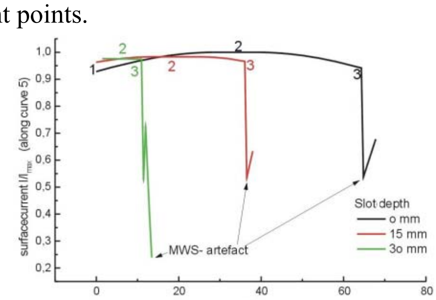

Figure 7: Current distribution along the cell center at different points (parameter: slot depth).

Figs. 9-12 show the same for a partial slot of only 30 mm length. There the current in the slot is strongly reduced. MWS has limited precision at sharp corners, resp. we must use higher resolution for more details. But the present results show clearly the current paths and magnitudes in the different cases, where contacts have to be placed.

Fig.11 and 12 show ALGOR calculations of the temperature distribution in a 4-Rod cell. In this example a constant power load per area and only cooling of the base plate and the electrodes are assumed.

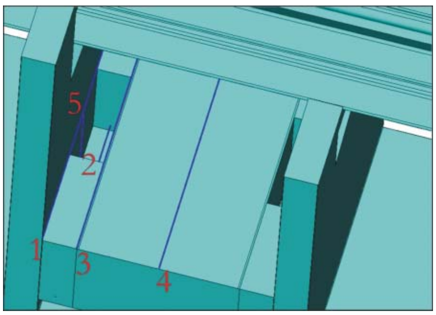

Figure 8: RFQ tuning block between stems with a short central slot (30mm).

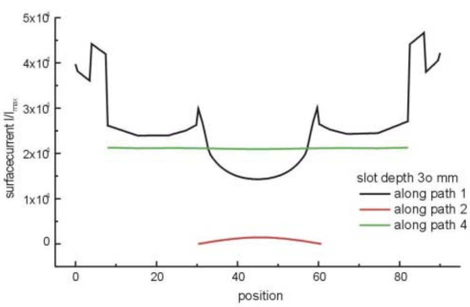

Figure 9: Current distribution across the RFQ-cell at different paths.

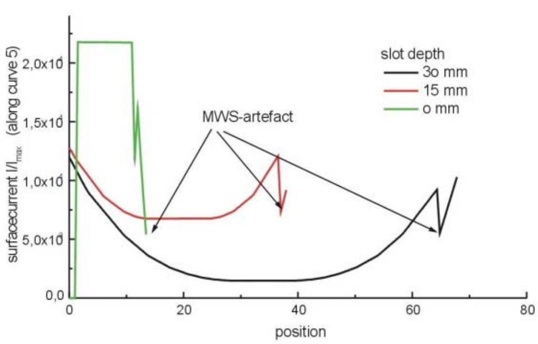

Figure 10: Current distribution along the cell center, (parameter: slot depth).

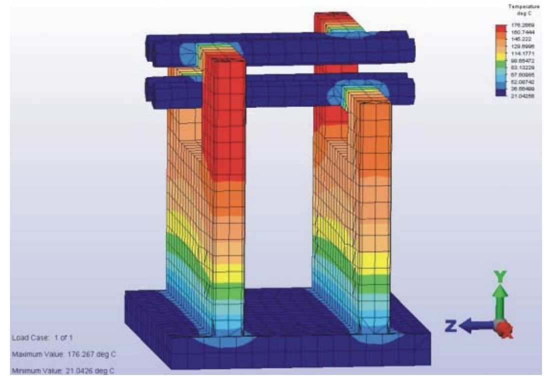

Figure 11: Simulation of temperature distribution of one RFQ cell with constant power/area. Base plate and electrodes cooled.

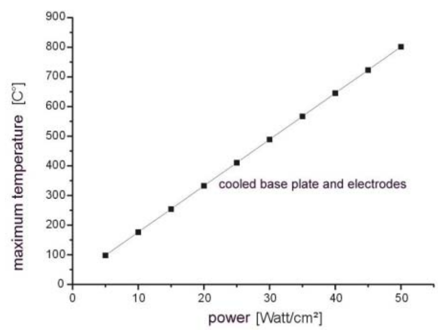

Figure 12: Maximum temperature in a RFQ cell with constant power/area. Base plate and electrodes are cooled.

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[3] H. Liebermann, Int. Note 03