RFQ-ACCELERATORS FOR RADIOACTIVE ION-BEAMS

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Abstract

For the REX-ISOLDE- Project at CERN a Four-Rod-λ/2-RFQ has been built up and is currently tested at Munich. This RFQ is similar to the GSI high-charge-state-RFQ and to the Heidelberg high-current-injector-RFQ. It operates at a resonant frequency of 101.28 MHz and will accelerate neutron rich ions with an A/q of 3 to 4.5 from 5 keV/u to 300 keV/u.
Parallel to the test of the REX-ISOLDE-RFQ, investigations with the code MAFIA are under progress on an IH-type RFQ for the planned fission-fragment-accelerator of the new Munich high-flux reactor FRM II [1]. The IH-RFQ will also operate at 101.28 MHz and accelerate ions with an A/q up to 6.3 from 3 keV/u to 300 keV/u. As a first step of development a 1 meter-model will be built to check the calculated resonator-parameters and to compare the model-measurements definetely with the parameters of the REX-RFQ. In this paper the status and the characteristics of the REX-ISOLDE 4-Rod-RFQ will be presented together with the results of the MAFIA-calculations for the fission-fragment-IH-RFQ.

1. DESIGN AND TEST OF A 4-ROD-RFQ FOR THE REX-ISOLDE-PROJECT AT CERN.

The LINAC of the planned REX-ISOLDE-experiment consists of a 4-Rod-RFQ and an interdigital-H drift-tube-accelerator, which are followed by three seven-gap resonators for energy variation from 1.1 MeV/u to 2.2 MeV/u [2].
The RFQ - which is together with the IH-structure assembled and tested at Munich - will accelerate the radioactive ions (design-ion: $^{36}Na^{8+}$) from the REX-ISOLDE mass-separator with an A/q of 3 - 4.5 from 5 keV/u to 300 keV/u. The according electrode-voltage is (max.) 42 kV, which will require an rf-power of about 44 kW. The RFQ has a total length of 3 m (18 stems) and operates at a resonant frequency of 101.28 MHz (duty-cycle: 10%). Due to the very low beam-currents (10000 particles per 100μs-EBIS-pulse), the transmission could be optimized by PARMTEQ calculations to 98%. Table 1. shows the design parameters of the REX-RFQ.

frequency	101.28 MHz
input energy	5 keV/u
final energy	300 keV/u
duty-cycle	10 %
q/A	1/3 - 1/4.5
input emittance	200 πmmmrad
phase	-90° bis -13°
electrode voltage	42 kV
rel. field deviation	< 1%
quality-factor Q_0	~ 4000
Rp-value	~ 130 kΩm
accelerator cells	232
electrode length	2920 mm
tank length	3000 mm
tank diameter	320 mm
stem height	189 mm
number of stems	18

Table 1: *Parameters of the REX-RFQ.*

To avoid particle losses during the beam transport from the RFQ to the IH-structure and generally to reduce the required field strength of the magnetic quadrupole-lenses, the electrode design of the REX-RFQ includes a so called ‘matching-out section’. Analogue to the matching-in section at the entrance, the focusing strength at the exit of the accelerator was reduced by iterative manipulation of the electrode parameters (aperture and modulation) in the last 10 cm.

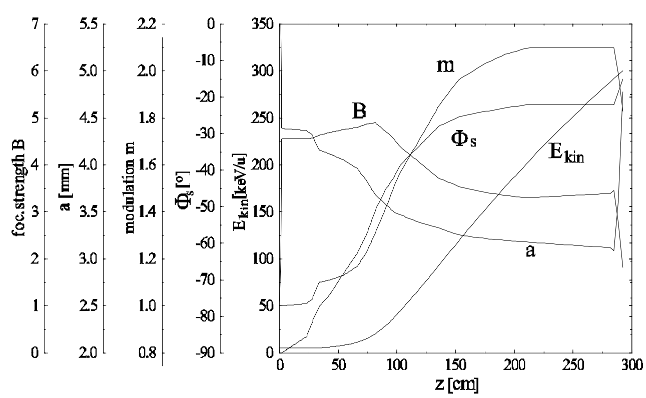

Fig. 1: *Electrode design.*

This produces a decreased divergence of the output-beam (at constant energy- and phase-spread) and thus facilitates the beam transport. In Fig. 1 the electrode-parameters are charted as a function of the accelerator-length. Fig. 2 shows the calculated output-emittances with (below) and without (above) matching-out section.

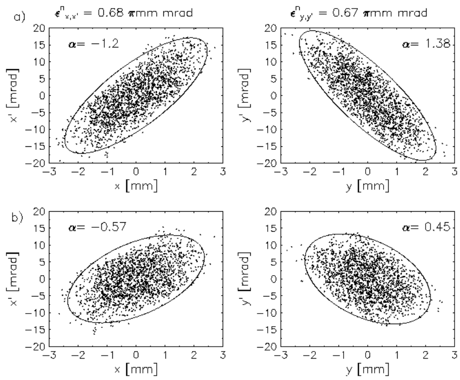

Fig. 2: *Output-emittances.*

Regarding the mechanical properties of the REX-RFQ, a new stem design - developed for the Heidelberg high-current-injector-RFQ - was chosen for the water supply of the rods. Figure 3. shows that the cooling water channels are completely drilled inside, what leads to easier manufacturable stems with an overall plain surface. This design avoids the (former used) little tubes on the outside, which turned out to be sensitive to corrosion and mechanical resonances. A disadvantage of the new stems might be, that the electrode alignment is at least only possible in a range of a few 1/10 mm, what on the other hand is sufficient, if the given tolerances of some 1/100 mm are kept while manufacturing the accelerator components.

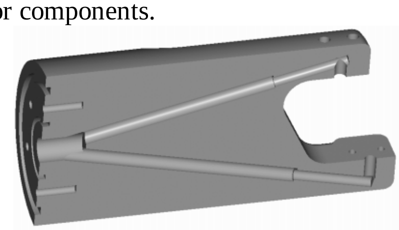

Fig. 3: *Waterleading-stem used in the REX-RFQ.*

After a first assembly, the measurement of the characteristic resonator-parameters resulted in a resonant frequency of 101.17 MHz, a quality-factor of 3600 and an Rp-value of about 120 kΩm. The relative voltage deviation could (after mounting of the tuning-plates) be reduced from 20% to 3%.

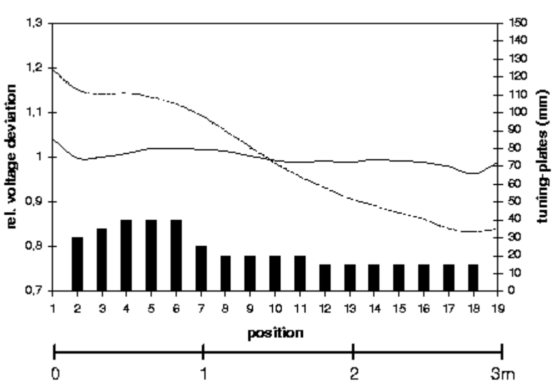

Fig. 4: *Voltage distribution of the REX-RFQ before (dotted line) and after (solid line) a first Flatness-tuning*

With the final frequency tuning, electrode alignment and final assembly of the resonator (with piston tuners etc.), we are optimistic to reach the specified values: Q=4000 and Rp=130 kΩm. The 'Unflatness' is expected to be 1%.

2. MAFIA-COMPUTATIONS FOR AN IH-RFQ-RESONATOR AT 101.28 MHz.

An IH-RFQ consists basically of a cavity (excited in the TE_{111} Mode) with two opposite vanes carrying the interdigital holders on which the electrodes are fixed (see Fig. 6). One example for an existing IH-RFQ is the first module of the new GSI high-current injector (diameter=76 cm, f=36 MHz, Rp=620 kΩm, Q=13000) [3].

The motivation to investigate IH-type RFQ's also at higher frequencies is given in several advantages these structures possibly have in comparison to the Four- Rod-RFQ. Our MAFIA-calculations for the 101 MHz IH-RFQ with a length of 3 m have shown, that - due to the higher number of electrode-holders (IH 1: 42 holders, IH 2: 36 holders) - the current and therewith the power dissipation on the quadrupole-electrodes is much lower than in the 4-Rod-RFQ.

	REX-RFQ	IH-RFQ1	IH-RFQ2
tank	7.2 %	43.5 %	41.1 %
stems/holders	59.8 %	38.3 %	39.1 %
ground-plate/frame	7.3 %	11.9 %	11.6 %
electrodes	25.7 %	6.3 %	8.2 %

Table 2: *Power dissipation at different accelerator-components calculated for the REX-RFQ and for the IH-RFQ with 6 cm (IH 1) and 7 cm (IH 2) holder distance.*

This allows on the one hand to cool the electrodes indirectly by the holders (without cooling-channels, seals, etc.) and should on the other hand increase the quality-factor and the efficiency (Rp-value) of these accelerators. Table 3. shows - corresponding to table 2. - the result of calculations for 3-ground-cell-segments cut out of an infinitely long resonator.

	REX-RFQ	IH-RFQ1	IH-RFQ2
frequency (MHz)	94	92.5	93.5
Rp-value (kΩm)	278	281	288
Quality-factor	7996	11874	11657

Table 3: *Resonator-parameters of the REX-RFQ and the two IH-RFQ's.*

As expected, the Quality-factor is about 1.5 times higher in the IH-RFQ, whereas the calculations show no significant difference in Rp-value. Since the efficiency of a resonator depends on the ratio of inductance and capacity, in the relative small IH-RFQ-cavity at 93 MHz the capacitive load of the numerous holders seems to compensate the advantage of the short electrode-length between the holders (this is also indicated by table 3: larger holder distance ⇒ higher Rp-value).

From earlier MAFIA-calculations for the REX-RFQ (compared to measurements) we have the experience, that the calculated quality factors and Rp-values are always more than a factor 2 too high. At least, only the measurements on the 0.75 m IH-RFQ-model, which will be built up, can show if this discrepancy is also valid for a cavity resonator, and thus, if 100 MHz are already beyond the limit of reasonable IH-RFQ operation.

Even if the absolute MAFIA-values do not exactly match the experiments, the relative values are a very helpful tool to optimize the IH-RFQ-structure (and the model seen in Fig. 6) in reference to the resonant frequency, maximum Rp-value, minimum dipole-quota and the flatness (tuned by variation of the magnetic flux inductors at the end of the vanes [4]). Concerning the dipole content, the figures below show the voltage distribution for three different IH-RFQ MAFIA-models. The electric field has been integrated between all neighbouring electrodes. The resulting voltages with the maximum difference have been plotted in the diagrams.

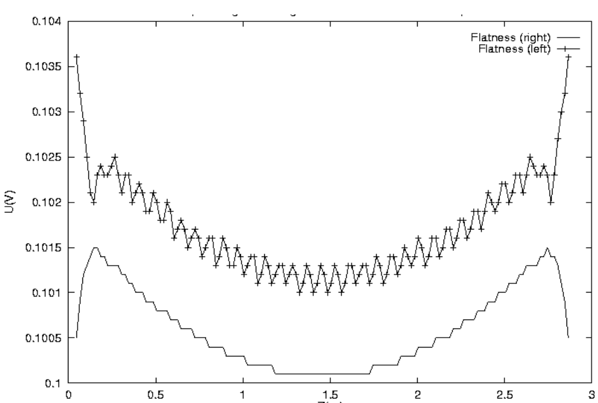

Fig. 5a: *Diagonal opposed electrodes, 42 holders.*

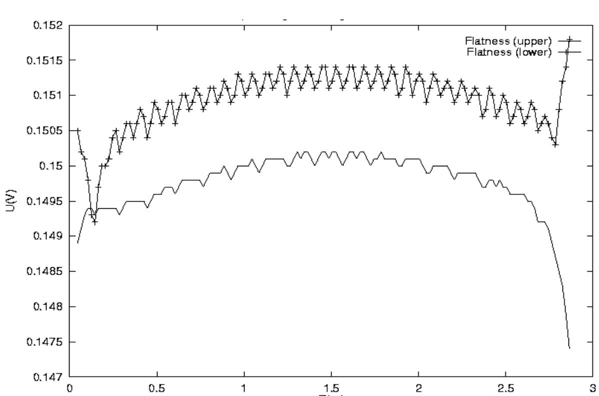

Fig. 5b: *Vertical/horizontal opposed electrodes, 42 holders.*

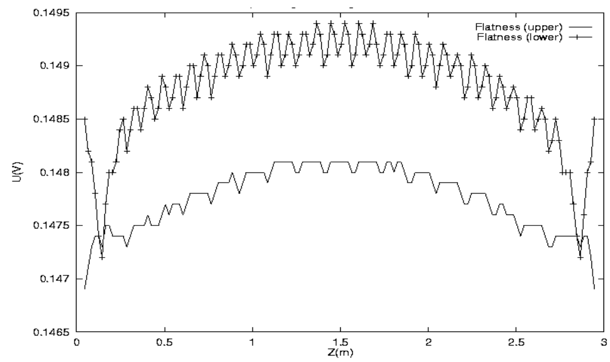

Fig. 5c: *Vertical/horizontal opposed electrodes, 37 holders.*

The calculations show, that all versions have comparable voltage differences in the middle section. The advantage of the IH-RFQ with vertical/horizontal opposed electrodes and an odd number of holders is, that the difference (1%) does not increase at the electrode-overhang at the ends of the resonator.

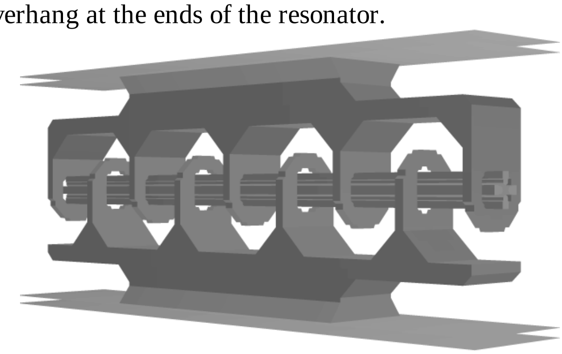

Fig. 6: *A possible design for the IH-RFQ-model (without half-shells). The parameters are: f=91MHz, Q=9164, Rp=236kΩm, length=0.75m, diameter=35cm, undercuts: length=16 cm, height=4.5cm.*

References

[1] O. Kester et al., „Fission Fragment Accelerators for the Grenoble and Munich High Flux Reactors“, Proc. ECAART-5, NIM B 139 (1998).

[2] D. Habs et al., „The REX-ISOLDE Project“, Proc. ECAART-5, NIM B 139 (1998).

[3] U. Ratzinger, K. Kaspar, E. Malwitz, S. Minaev, R. Tiede, „The 36 MHz high-current IH-type RFQ and HIIF relevant extensions“, NIM A (in press).

[4] K. Satoh et al., „ Exp. Studies on the Optimization of the Accelerating Field Distribution of IH Linacs“, NIM A 287 (1985), S. 7.

Acknowledgements

We like to thank Dr. M. Madert and Dr. R. von Hahn from the MPI-K Heidelberg for their friendly support during the assembly of the REX-RFQ.