The IH-7-Gap Resonators of the Munich Accelerator for Fission Fragments (MAFF) LINAC

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Abstract

The linear accelerator MAFF for the new Munich high flux reactor FRM II (Forschungsreaktor München II) which is under design [1,2] will deliver intense beams of very neutron rich fission fragments. Up to 10^{12} particles per second with final energies between 3.7 and 5.9 MeV/u are expected in order to perform experiments for the production of long living heavy elements [3]. Since the overall length of the accelerator is restricted to 20 m, charge breeding of the 1^+ ions from the reactor to q/A ~ 0.15 – 0.20 and bunching of the continuously produced radioactive ions according to the duty cycle of 10 % is required to obtain the necessary acceleration in such a short LINAC. Furthermore structures with high shunt impedances and high effective accelerating fields like the IH-structure will be used to reach energies at the Coulomb barrier. In order to obtain a high flexibility in the final energies with only two short cavities the properties of IH-7-gap structures are under examination at the Munich tandem laboratory and will be presented.

1 THE MAFF-LINAC

The MAFF-LINAC [4] is planned to accelerate heavy neutron rich fission fragments produced in an inpile target ion source at the FRM II. The available neutron flux of $1.5*10^{14}$ cm^{-2} s^{-1} results in a fission rate of 10^{14} s^{-1} where mass separated beams with intensities of up to 10^{12} /s can be expected. In fig.1 the overview of the MAFF LINAC is shown. The overall length of the LINAC is restricted to 20m, because the space of the experimental hall is limited by the reactor fence. Thus charge breeding of the intense radioactive ion beams in order to enhance the charge to mass ratio to q/A>0.16 and bunching of the continuous 30 keV beam from the in-pile source has to be done. The first acceleration stage is an IH-RFQ which accelerates the ions from 2.5 keV/u to 300 keV/u. The matching to the following drift tube LINAC is done by a magnetic quadrupole triplet lens and an RFQ buncher (super-lens) [5]. The booster LINAC consists of three IH cavities which will accelerate the ions up to 5.4 MeV/u. The two 7-gap IH-resonators will be able to vary the final energy between 3.7-5.9 MeV/u due to acceleration and deceleration at different injection energies.

The booster section consists of three IH-structures, which accelerate the beam from 300 keV/u to 4.15 or 5.40 MeV/u respectively which depends on the desired final energy and the mode of Tank 3 of the booster. Tank 1 operates at 101.28 MHz tank 2 and tank 3 at 202.56 MHz. The final energy variation is done by two IH-7-gap structures, which accelerate or decelerate the ion beam from the two different injection energies.

2 THE IH-7-GAP STRUCTURES

2.1 General

The energy variable section of the LINAC consists of two identical 7-gap structures that will be place after the booster and operated at 202.56 MHz. To increase the efficiency of the 7-gap structures compared to the split ring resonators used e.g. for REX-ISOLDE [6] the resonators are planned as IH structures.

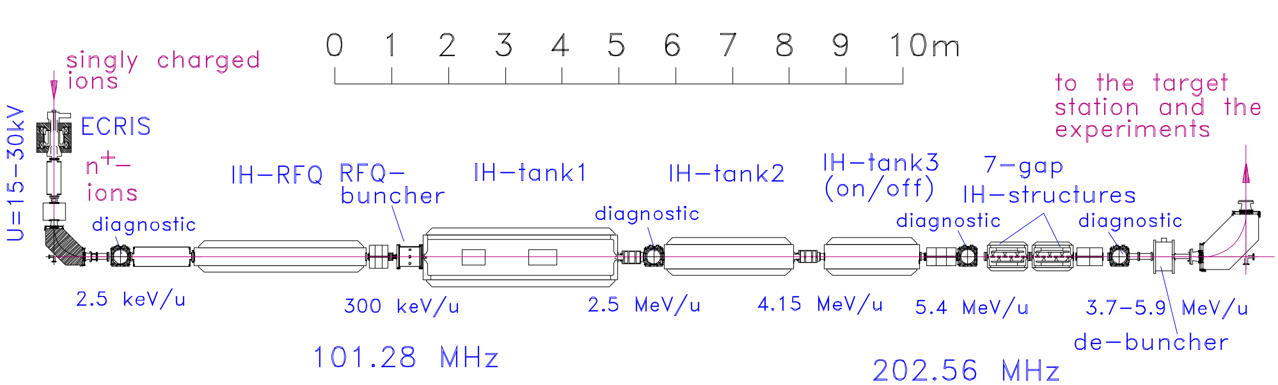

Figure 1: Layout of the MAFF LINAC. The overall length is limited to 20 m due to the experimental hall. The final energies can be varied between 3.7 MeV/u and 5.9 MeV/u via two 7-gap-IH resonators.

Due to the higher shunt impedance of IH structures a higher resonator voltage in combination with a very compact design can be achieved with the same rf-power. The booster injects the ions either at 4.15 or 5.40 MeV/u into the IH-7-gaps by switching tank 3 off or on (s. fig. 1). This beam is then accelerated or decelerated to the final energy. Therefore it is necessary that each of the two IH-7-gap structures is able to accelerate or decelerate over a range of at least ±0.31 MeV/u with a sufficient transit time factor. Furthermore in beam dynamics the combined 0°-synchronous particle structure is used. This means that the mean particle of the bunch will reach the center gap of each resonator at 0° phase of the incoupled rf. This results in an overall higher transit time factor over the whole energy range. The transverse focusing is done with magnetic quadrupole lenses in front and behind the two 7-gap resonators.

2.2 Design Layout

Since the resonators are used both for efficient acceleration and deceleration respectively, they are designed identically with constant cell and gap lengths. Based on the fact that the energy would be between 3.7 MeV/u and 5.9 MeV/u and the mass to charge ratio A/q is expected to be < 6.3 a cell length of 74 mm at 202.56 MHz was chosen, which corresponds to ß=0.1. This results in an overall length of each resonator of 518 mm. A drift tube length of 50 mm and an aperture of 20 mm were used in the first MAFIA calculation. To obtain the desired operation frequency of 202.56 MHz the tank was estimated to be 310 mm wide and 410 mm high.

In order to determine the values for the cavity characteristics, necessary to build a model of one of the resonators, extensive MAFIA calculations have been performed. These simulations of the model showed that a quality factor of 15 000 to 18 000 and a shunt impedance of ca. 150 MΩ/m can be expected for the real resonators. Calculation show that 2.8 MV total resonator voltage can be expected for the proposed IH-7-gap resonators at 150 MΩ/m shunt impedance, 100 kW generator power and 200 MHz resonator frequency. Therefore two resonators should be sufficient to cover the planned energy range.

2.3 Beam Dynamics

Depending on the differences between injection energy and exit energy of the ions, the phase of the bunch can vary significantly from gap to gap. Generally the phase switches its sign at the center gap. In fig.2 the phase variation of the center of the beam bunch in comparison to the synchronous particle is shown for the different modes of deceleration and post acceleration. The beam is always longitudinally defocused in either the first three gaps of each resonator or in the last three gaps depending on whether the ions are accelerated or decelerated. However, this defocusing effect is compensated by the fact that the beam will be focused in corresponding three gaps.

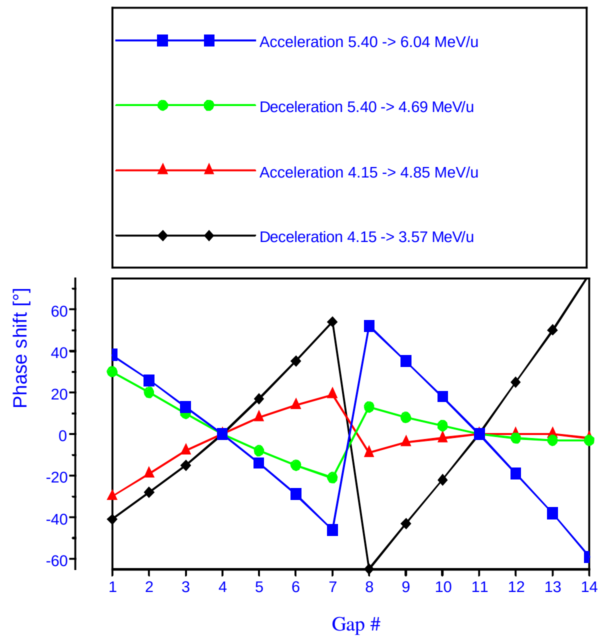

Figure 2: Phase shift of the ion bunch in relation to the synchronous particle

Simulations with LINAC code from Heidelberg showed that a total resonator voltage of 2.2 MV for each resonator is enough to cover the entire range of the proposed energy variation. Assuming 150 MΩ/m shunt impedance, this Voltage can be reached with a comparably low rf-power of 63 kW. Higher power would not result in significant more efficient acceleration due to extreme phase shifts (s. fig. 2).

Using LORASR code (U. Ratzinger) to calculate the beam dynamics leads to even better results (decrease of emittance growth, more efficient acceleration, deceleration respectively). While the LINAC code simplifies the gap voltage distribution according to the distribution of split ring resonators to a ratio of 1:2:2:2:2:2:1, the LORASR code can use individual gap voltage values for each gap, which can be derived from measurements of the model.

One big advantage of IH-structures is that, depending on the undercut design, they do not have a flat gap voltage distribution like split ring structures of REX-ISOLDE have, but the gap voltage increases towards the center gap. The velocity of the bunch center is in normal operation mode of the cavities far away from the design velocity of 10% c. Thus a higher gap field in the center gap is an advantage, because the transit time factor is higher and the defocusing effects at the first and last gaps is reduced. Furthermore a undercut design with a non flat gap voltage distribution has an higher shunt impedances too.

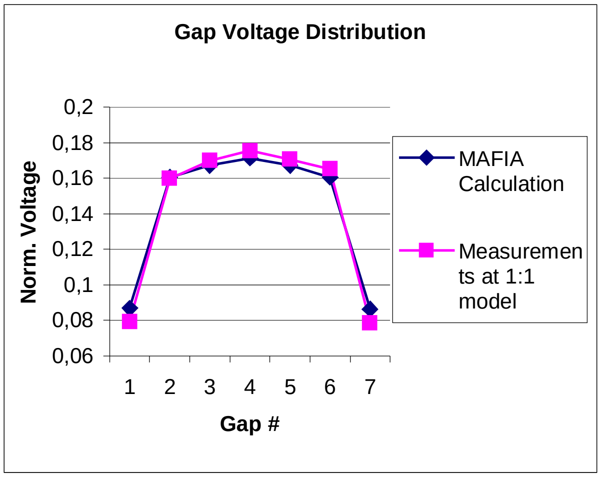

Figure 3: Comparison between MAFIA calculations and model measurements

2.4 Measurements

A 1:1 model is already build and used to optimise the design parameters and verify the MAFIA calculations. The model was built in such a way that the undercut lengths, height of the tank and the tuning plungers could easily be modified. In respect to resonance frequencies, resonant modes, dependency of the resonator characteristics on variation of the geometry the measurement and voltage distributions are in good agreement with the calculations.

Due to the fact that the flexible design of the model results in various effects which reduce the quality factor and the shunt impedance in comparison to a power resonator cavity, the realistic values could not be verified yet. Experience with similar models and IH-structures show that due to systematic error in MAFIA the values of these parameters are overestimated by 20 %.

2.5 Current Status

Design and Beam dynamic simulations with MAFIA, LINAC and LORASR have been performed and verified by measurements of the model. A 1:1 model of one of the resonator was built and the right undercut geometry was determined which gives optimum results in the particle dynamics. The real resonator is under design in Pro engineer and the first lay-out is shown in fig.4. Detailed drawings are in production. A test beam line for energy tests will be prepared at the Munich tandem laboratory.

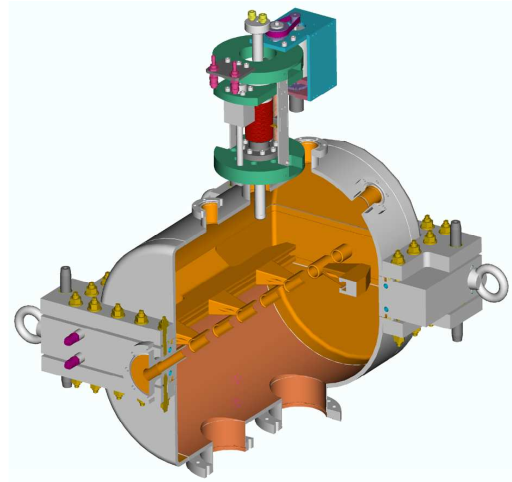

Figure 4: Design study of one of the real IH-7-gap resonators

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