THE LINAC OF THE MUNICH ACCELERATOR FOR FISSION FRAGMENTS (MAFF)

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Abstract

A linear accelerator for the new Munich high flux reactor FRM-II is under design [1,2]. This LINAC will be able to deliver intense beams of very neutron rich fission fragments from a target ion source located inside a through going reactor tube for the production of very heavy elements [3]. In order to obtain an efficient acceleration in the LINAC, charge breeding of the 1+ ion beam from the reactor to a q/A > 0.16 is required. The LINAC will work with 10% duty cycle with a final energy between 3.7 and 5.9 MeV/u. The LINAC of the Munich Accelerator for Fission Fragments (MAFF) will consist of an Radio Frequency Quadrupole (RFQ) accelerator, three interdigital H-type (IH) structures similar to the lead LINAC at CERN and two seven-gap IH-resonators for the adjustment of the final energy of the ions. In the present paper the concept, particle dynamics calculations and first cavity design calculations with MAFIA will be presented.

1 INTRODUCTION

Advanced radioactive nuclear beam facilities have a strong scientific case which is centered in three areas of basic science, namely Nuclear physics, Nuclear Astrophysics and the limits of the Standard Model. This physics and the application of neutron-rich fission fragment beams were discussed in [4]. With the ISOL (Isotope Separation On-line) technique intense high quality beams of radioactive ions can be supplied using very different reactions for the production: i) high energy protons, ii) fast neutrons and iii) thermal neutrons. The high neutron flux of a reactor and the high cross section of U^{235} for thermal fission (580b) allows to produce beam intensities comparable to those of stable beams which are used at GSI for the production of superheavy elements (SHE). The MAFF-Project at the new high flux reactor FRM-II at Garching will be the only facility world wide which uses this concept. A first realization of this concept was studied in the PIAFE project [5], which was stopped at 1. July 1998 for political reasons.

Compared to other radioactive beam accelerators under construction the MAFF project expects beam intensities (10^{11}/s) of fission fragments which are typically larger by a factor of 1000. Very intense neutron-rich ion beams accelerated to energies at the Coulomb barrier are of special interest for the production of very heavy elements. Fig.1 shows the calculated lifetimes for the elements Z=104 to Z=114 in dependence on the number of neutrons in the nuclei. The calculations are compared to measurements, which fit very well to the theoretical values.

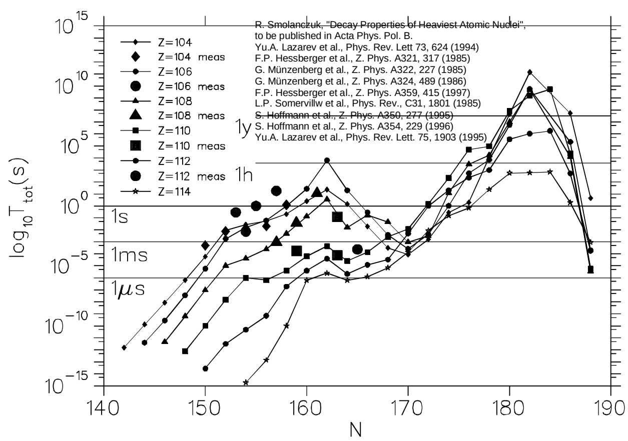

Figure 1: Calculated half-lifetimes for the elements Z=104 -114 in comparison to measurements [6].

In fig.1 is shown with very neutron rich isotopes as projectiles and implanted in a target very heavy elements with higher neutron numbers (165-180) can be produced, which lifetimes are extended to minutes and hours compared to the fusion products produced at GSI. The peak at lower neutron numbers (N=162) is derived from effects of magic shell closure.

2 ACCELERATION CONCEPT AND BEAM DYNAMICS

To achieve adequate final energies close to the Coulomb barrier several acceleration schemes have been proposed [2,7]. For MAFF the singly charged ions out of the reactor source will be injected into a high charge state ion source, presumably an electron cyclotron resonance ion source (ECRIS) and charge bred to an A/q < 6.3. The LINAC of MAFF is sketched in fig.2. The key parameters of the LINAC are shown in Table1.

2.1 The resonant structures

The LINAC consists on an RFQ which accelerates the ions from 2.5 keV/u to 300 keV/u which requires a rod voltage of 59 kV for the present design which is similar to the REX-ISOLDE RFQ. First examination have been carried out [8] to use a quadrupole structure which is driven by an IH-resonator. Such an RFQ will be used for the high current injector at GSI. The booster LINAC consists of three IH-cavities where a jump in frequency is done at the second tank to reduce the length of the accelerator [2].

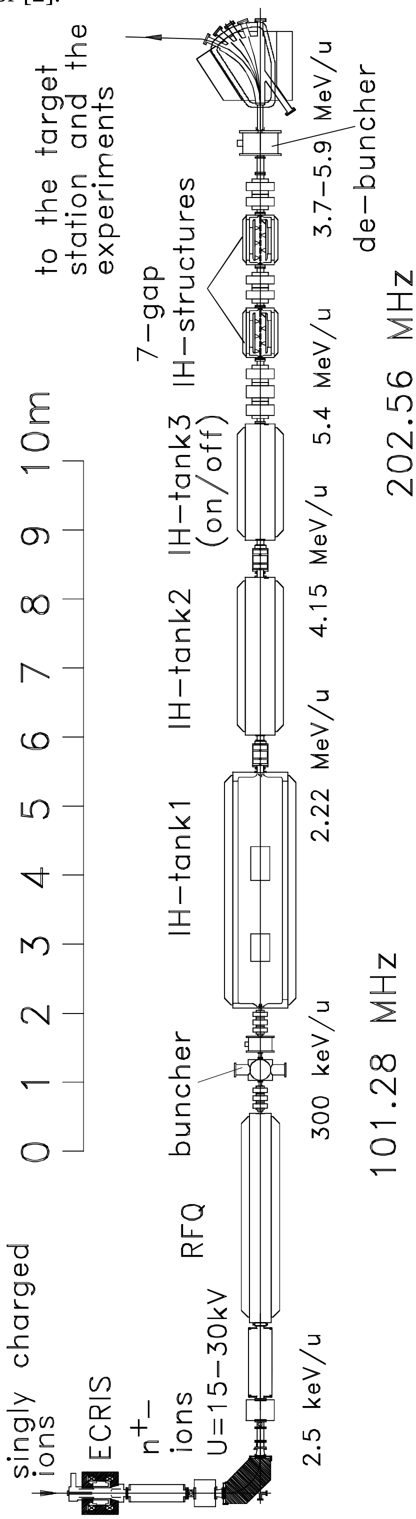

Figure 2: Lay-out of the MAFF LINAC.

Table 1: Key parameters of the MAFF LINAC

resonance frequency	101.28 / 202.56 MHz
injection energy	2.5 keV/u
final energy	3.7 - 5.9 MeV/u
A/q	< 6.3
max. duty cycle	10%
required energy spread at the target	<0.2 %
beam intensities	$4*10^{11}$ ions/s (^{91}Kr)
mass range (A)	75 -150
elements (Z)	Ni - Eu (28 - 63)

2.2 *Variation of the final energy*

The variation of the final energy over the large range of 2.2 MeV/u is done by using two 7-gap resonators and the tank 3 of the booster LINAC. So deceleration and acceleration is done at two different injection energies with the same 7-gap accelerators at 4.15 and 5.4 MeV/u. The 7-gap resonators of the MAFF-LINAC are IH-cavities in order to reach higher resonator voltages (2.1 MV) in comparison to the cavities used for REX-ISOLDE [9]. The 0^o-synchronous particle structure is used in the beam dynamics, which means that the mean particle of the bunch will reach the center gap at 0^o phase of the RF. The voltage of tank3 of the booster LINAC must be twice the effective voltage of the 7-gap resonators. In order to achieve the required low energy spread de-buncher is required after the second 7-gap cavity.

2.3 *Beam dynamics*

Beam dynamics calculations have been carried out to prove the possibility of the energy adjustment with only two 7-gap resonators.

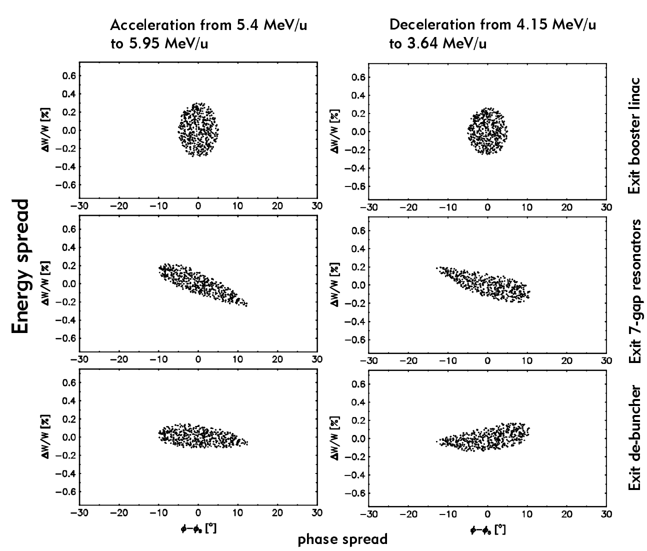

Figure 3: Development of the longitudinal phase space for the minimum and maximum energy of the MAFF LINAC

Fig. 3 shows calculations of the development of the longitudinal phase space of the beam from the exit of tank3 of the booster to the exit of the de-buncher. Table 2 summarizes the energies which can be achieved by deceleration and acceleration with both 7-gap cavities.

For the transverse emittances, the typical emittance of an ECRIS of about 0.6 π mm mrad (normalized) has been assumed. For the longitudinal phase space at the exit of the booster a phase spread of $\pm 5^{\circ}$ and an energy spread of +0.2% have been taken into account. From fig. 3 it can be seen that even in the worst case of maximum deceleration at lower starting energy the low energy spread at the exit can be provided.

Table 2: Achievable energies using the two 7-gap IH-resonators for deceleration and post acceleration.

E_{inj} [MeV/u]	E_{min} [MeV/u]	E_{max} [MeV/u]
4.15	3.64	4.77
5.4	4.78	5.94

3 CAVITY DESIGN AND MAFIA CALCULATIONS

The structures which will be examined first are the IH-RFQ and the 7-gap-IH-resonators. In order to get some cavity characteristics both resonator types have been examined by MAFIA calculations.

3.1 The IH-RFQ

The investigation of an IH-type RFQ at frequencies around 100 MHz is motivated by a higher shunt impedance compared to a 4-rod RFQ and that a direct rod cooling is not required due to a higher number of stems and herewith lower electrode currents. Fig.4 shows the 3m MAFIA model of the IH-RFQ. The parameters determined with MAFIA [8] are an R_p-value of 288 kΩm, a quality factor of 11657 at a frequency of 93.5 MHz, concerning a stem distance of 8 cm.

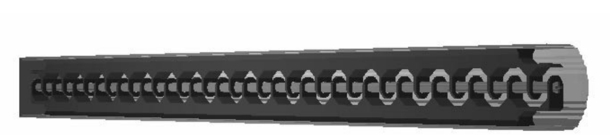

Figure 4: MAFIA model of the 3m IH-RFQ for the MAFF LINAC.

3.2 The 7-gap IH-resonator

The central issue of the MAFF-LINAC are the 7-gap IH-cavities. For the beam dynamics calculations a total resonator voltage of 2.1 MV have been assumed. For an incoupled power of 80 kW a shunt impedance of 110 MΩ/m is required to fulfill these requirements. Fig.5 shows the MAFIA model of one half of the 7-gap-IH-cavity. The cell length is 74 mm, the drift tube length 50 mm. The half shell radius is about 135 mm. The calculated quality factor is 15000, the shunt impedance about 300 MΩ/m. The calculated resonance frequency of the cavity was 225 MHz. Model measurements will done soon to prove the MAFIA calculations of the IH-RFQ and of the 7-gap cavity. Assuming the calculated values, the maximum resonator voltage of 2.1 MV can reached with low rf-power of about 50 kW.

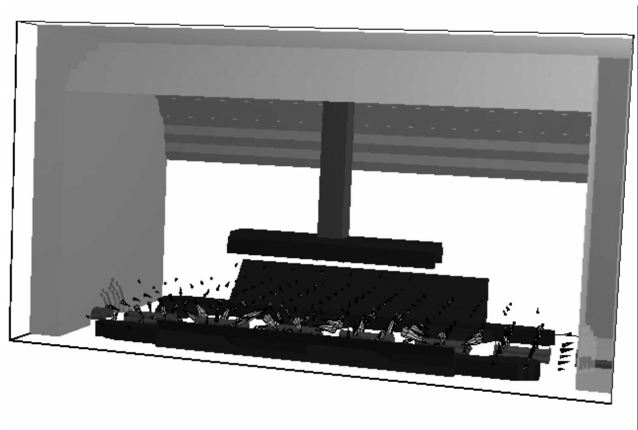

Figure 5: MAFIA model of one half of the 0.55m IH-7-gap resonator for the MAFF LINAC. Shown is the electric field of the TE_{111} mode.

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