Charge Breeding and Acceleration for MAFF

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In order to perform experiments with fission products at the Coulomb barrier post acceleration of the radioactive ions in a low β heavy ion LINAC is required. Several schemes of post acceleration can be considered [1]. For the Munich Accelerator for Fission Fragments (MAFF) [2,3], a compact linear accelerator is under design which accelerates highly-charged neutron rich ions from an injection energy of 2.5 keV/u to a final energy between 3.7 and 5.9 MeV/u. The LINAC will work with 10% duty cycle, a q/A>0.16 and a resonance frequency of 101.28 MHz and 202.56 MHz. For the charge breeding an ion source delivering highly charged ions like the Electron Beam Ion Source (EBIS) [4,5] or the Electron Cyclotron Resonance Ion Source (ECRIS) [5,6] is suitable.

Charge breeding experiments with an EBIS have been performed at Saclay and Stockholm [7,8]. Efficiencies of N^{7+} and Ar^{14+} of 30% and 9.4% respectively have been reached. The peak efficiency [n+]/[1+] for the ECRIS in the continuous charge breeding was about 10% for Ar^{8+}, Kr^{12+} and Xe^{14+} and about 5% for alkaline ions [9,10]. Using the ECRIS as a trap and a buncher, the efficiency for Rb^{15+} is about 2%, which can be improved in further studies [10]. The EBIS is however limited to 10^9 ions per accumulation cycle, due to space charge compensation of the electron beam. To increase the average current to up to 10^{11} ions per second, the repetition rate of the EBIS has to be as high as possible. Thus the charge breeding time of the EBIS is limited to less than 10 ms, which requires electron beam current densities of above 500 A/cm^2 especially for heavier radioactive ions. Due to the large plasma volume and the much higher ion density in the plasma the ECRIS is able to accept high intensities up to the required 10^{12} ions/s without problems.

EBIS and ECRIS can be used as an accumulator, breeder and buncher of the radioactive ions. The EBIS operates under ultra high vacuum conditions. The emittance and the time structure of the extracted ion beam pulses are well suited for the injection into a LINAC. The EBIS can be tuned simply to a different charge state by changing the confinement time. In case of the ECRIS the plasma has to be retuned (change of RF power, magnetic field, etc.) for changing the charge state. The ECRIS works with higher gas pressure of about 10^{-6} mbar. Thus fraction of the contaminant rest gas ions in the spectra of the radioactive ions is much higher compared to the EBIS, which makes the mass separation more difficult. The HT platform of the EBIS can be ramped to a different voltage during the breeding cycle, thus allowing a complete decoupling of the potentials of the ISOL part and the accelerator. For any charge breeder using an ECRIS an energy matching section has to be introduced between the n+ source and the main accelerator. This problem can be solved favorably with a small one gap cavity.

The LINAC will consists of several structures, a Radio Frequency Quadrupole (RFQ) accelerator, three IH-cavities similar to the CERN "lead-LINAC" and two seven-gap (IH)-resonators which are used to vary the final energy. The energy width of the final beam has to be smaller than 1 MeV to fit the requirements of the very narrow excitation function for the production of very heavy elements via fusion reactions. The first structure is a radio frequency quadrupole (RFQ) accelerator, which is driven by a cavity working in the TE111 (transverse electric) resonant mode and will accelerate the ions to a final energy of about 300 keV/u [11]. After acceleration to 2.1 MeV/u with the first tank, a jump to a higher frequency of 202.56 MHz is required to reduce the size of the following structures and to increase the effective acceleration voltage to 6 MV/m. Tank2 leads to the main energy gain with an exit energy of 4.15 MeV/u.

The variation of the final energy is done by switching tank3 of the booster LINAC on and off and by acceleration or deceleration via the two seven-gap IH-resonators. Thus tank3 has to have twice the effective voltage of both 7-gap resonators. The 7-gap IH-cavities will operate at 202.56 MHz eigenfrequency and with a 0^o-synchronous particle structure. A total resonator voltage of 2.1 MV at 80 kW incoupled rf-power is expected. The drift tube structure of a 7-gap structure is optimized to a certain particle velocity. Here the particle velocity varies between $\beta = 8.9\%$ and 11.3%, hence a design value of $\beta = 10\%$ or 4.6 MeV per nucleon is chosen for both resonators in order to get the highest possible transit time factors in both energy ranges. The gap length should be 2.5 cm in order to stay below 150 kV/cm which corresponds to the maximum Kilpatrick field strength [12] at 202.56 MHz. Thus a safety margin of 400 kV per gap is realistic. Particle dynamics calculations show that a continuous variation of the output energy from 3.64 to 5.94 MeV$\cdot A$ is possible. A higher resonator voltage may even increase the range. From MAFIA calculations a much higher shunt impedance of the 7-gap IH-resonators of about 300 MΩ/m is expected, which could reduce either the required rf-power or could increase the total resonator voltage.

References

[1] U. Köster, O. Kester and D. Habs, Rev. Sci. Instr. **69** (1998) 1316
[2] O. Kester *et al.*, Nucl. Instr. and Meth. **B139** (1998) 28
[3] O. Kester *et al.*, proc. of the HIAT98, Argonne, Chicago, USA, October 5-9, 1998
[4] E. D. Donets, chapter 12 in 'The Physics and Technology of Ion Sources', ed. by I.G. Brown, Wiley, New York, 1989, p.245
[5] Handbook of Ion Sources, ed. by B. Wolf, CRC Press, Boca Raton, 1995
[6] R. Geller Ann. Rev. Nucl. Part. Sci. **40** (1990) 15
[7] B. Visentin *et al.*, Nucl. Instr. and Meth. **B101** (1995) 275
[8] E. Beebe *et al.*, Nucl. Instr. and Meth. **B93** (1994) 378
[9] C. Tamburella *et al.*, Rev. Sci. Instr. **68** (1997) 2319
[10] R. Geller and H. Nifenecker, proc. of the HIAT98, October 5-9, 1998, Chicago, USA
[11] T. Sieber *et al.*, this report, p. 72
[12] W. D. Kilpatrick Rev. Sci. Instr. **28** (1957) 824