A short IH-cavity for the Energy Variation of Radioactive Ion Beams

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Abstract

In order to perform experiments with radioactive ions at the Coulomb barrier, energy variation of the ion beams over a wide range is required. Short LINAC structures, like the 7-gap resonators for REX-ISOLDE [1] are suitable for that purpose. For the Munich Accelerator for Fission Fragments (MAFF) a set of two identical IH-7-Gap resonator was designed to vary the final beam energy between 3.7 MeV/u and 5.9 MeV/u. These resonators operate at 202.56 MHz and 10% duty cycle [2]. A prototype of one of these cavities was built and will be tested with beam in the Munich tandem laboratory. Therefore a test beam line including an emittance rig, an analyzing magnet and a fast Faraday cup has been assembled. Furthermore a modification of the drift tube structure is planned in order to use the cavity as an additional booster for the REX-ISOLDE LINAC. This new design and the test measurements will be presented.

1 INTRODUCTION

Short, independently phased cavities in ion LINACS are used to vary the final energy by means of different phase settings and adjustment of the power amplitude of the resonators. One concept is to use 7-gap resonators to gain effective acceleration voltage, but to stay flexible in the transit time factor. For experiments with radioactive ions at the Coulomb barrier, 7-gap resonators are used at REX-ISOLDE and will be used for the MAFF project. For MAFF IH-resonators are planned to establish the energy variation, because of the high shunt impedance and the flexibility of the drift tube structure, which can be easily changed to adjust a different velocity profile. For instance at TRIUMF short IH-cavities are used in the ISAC separated function DTL [3], which can deliver beam energy in the range between 0.153-1.53 MeV/u. There five independent IH-structures provide the acceleration, while quadrupole triplets and triple-gap split ring resonators between the IH-tanks provide periodic transverse and longitudinal focussing respectively. Thus, for energy variation, which is especially required for nuclear physics experiments, a bunch of short structures are used depending on the energy range to be addressed.

2 LINACS FOR RADIOACTIVE BEAMS

2.1 *The MAFF LINAC*

The LINAC of the new Munich Accelerator for Fission Fragments (MAFF) is planned to accelerate heavy neutron rich fission fragments produced in an inpile source within a through going reactor tube of the Munich high flux reactor FRM-II. The available neutron flux of $1.5 \cdot 10^{14}$ n/cm^{2}s of the reactor at the target results in a fission rate of 10^{14}/s. Intensities of several 10^{11} ions/s for ^{91}Kr, ^{132}Sn or ^{144}Cs e.g. are expected after mass separation. After separation, the ions are charge bred in an ECRIS and then injected into the LINAC [4]. The structure of the LINAC is shown in fig.1.

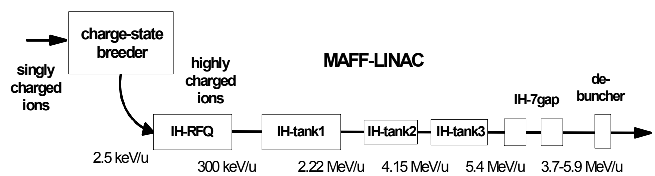

Fig. 1: Overview of the MAFF-LINAC

To increase the efficiency of the 7-Gap structures compared to the split ring resonators used e.g. for REX-ISOLDE, the resonators are designed as IH-structures. 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 compared to split ring resonators. The booster LINAC of MAFF injects the ions either at 4.15 MeV/u or 5.40 MeV/u into the IH-7-gap resonators by switching tank 3 off or on. This beam is then accelerated or decelerated to the final energy. Since the resonators are used both for acceleration and deceleration respectively, they are designed identically with constant cell and gap lengths. The cell length of 74 mm at 202.56 MHz was chosen, which corresponds to a design speed of ß=0.1. This results in a total length of 518 mm for the seven cells per resonator. The inner tank length is 520 mm and the overall outside length is 646 mm for each resonator. A drift tube length of 50 mm and an aperture of 20 mm were used. This still provides transit time factors in the range of 0.88 to 0.92 and even in the case of deceleration from 4.15 MeV/u to 3.7 MeV/u (biggest mismatch between design speed and actual bunch speed) a sufficient energy transfer can be provided at the resonator ends.

2.2 *The REX-ISOLDE-LINAC*

The radioactive beam experiment REX-ISOLDE at ISOLDE/CERN is designed to deliver post accelerated radioactive ion beams with a variable energy between 0.8

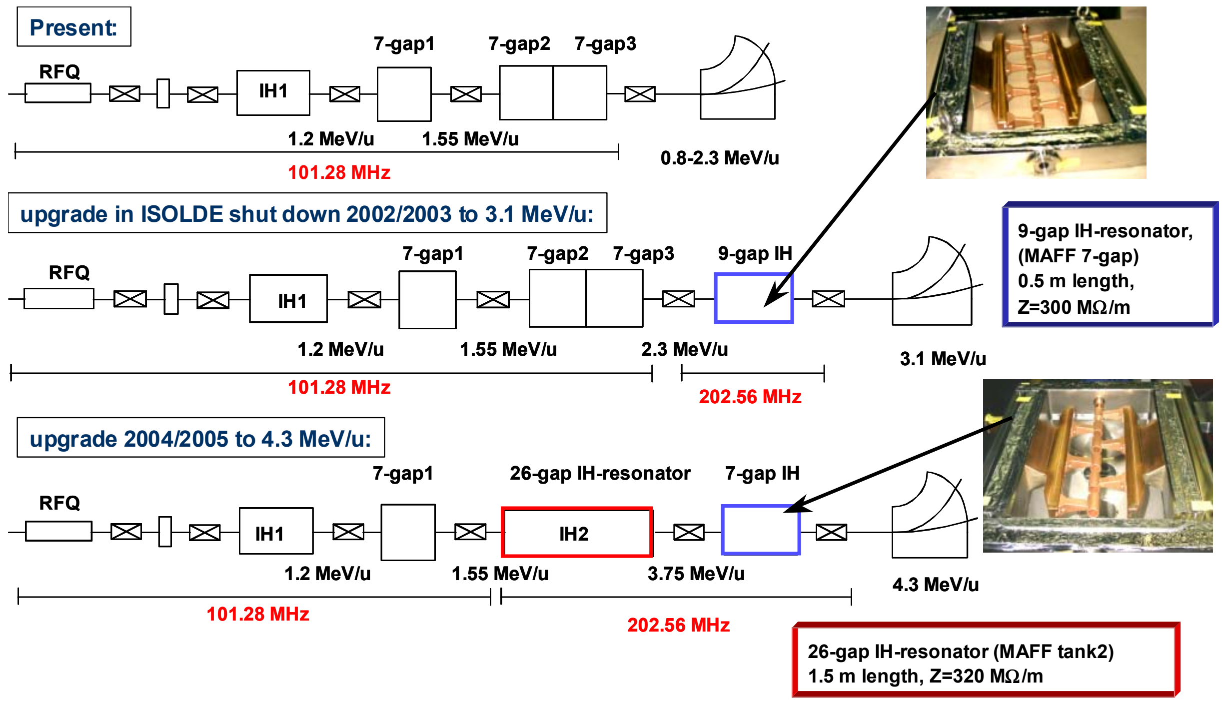

Figure 2: Schematic overview of the proposed upgrades for REX-ISOLDE. In the shut down period 2002/2003, the IH-9-gap structure will be added as post accelerator. 2004/2005 the last two 7-gap resonators will be replaced by MAFF Tank 2 and the IH-7-gap resonator.

and 2.2 MeV/u. In order to address many nuclear physics aspects, the full variety of ions available at ISOLDE should become accessible in form of accelerated beams for experiments. Thus, a new technology of charge multiplication and post acceleration was introduced for the first time. Despite the moderate size of the accelerator the charge multiplication of the radioactive ions allows accessing the heavier mass region of the nuclear chart, which is not possible in case of acceleration of single charged ions. The charge state breeder allows the acceleration of ions with A < 40 to energies at the Coulomb barrier with a LINAC of only 9 m length. For future upgrades a two-step plan has been worked out to increase the beam energy to approximately 4.2 MeV/u. Thus, the nuclear structure of heavier isotopes up to A = 150 can be investigated in the near future.

3 PROPOSED ENERGY UPGRADE FOR REX-ISOLDE

In order to use the full range of isotopes from ISOLDE for nuclear physics experiments, higher beam energies are required. An increased energy of about 3 MeV/u would allow to study nuclear reactions up to mass A=85 on deuterium targets. A beam energy of 4.2 MeV/u would be suitable up to mass A=145. Therefore we want to boost the energy of REX-ISOLDE in the near future in a two-step upgrade to about 4.2 MeV/u. Since the final authorization to operate the Forschungsreaktor München II (FRM II), is delayed, a proposal was made to modify the prototype of the MAFF IH-7-Gap resonator in such a way, that it could be used as post accelerator for twofold energy upgrade [5], shown in figure 2. Simulations using the Codes MAFIA for the resonator design and LORASR for the beam dynamics confirmed that the desired energy increase can be reached at the given resonator frequency of 202.56 MHz using the prototype resonator tank designed for MAFF.

3.1 First Step to 3.1 MeV/u

The first upgrade from 2.3 MeV/u to 3.1 MeV/u, planned to be done at the ISOLDE shut down period 2002/2003, the prototype resonator will be added to boost the final energy. The drift tube structure has to be exchanged by 8 smaller drift tubes of the same basic design. Thus the 7-Gap structure would be turned into a 9-Gap structure. Like the original drift tube structure all units are built identical. To adjust for the new cell length of 56 mm, the length of the drift tubes is shortened and the radii and the holding rods are thinner to match the required frequency by reducing the capacity. For a detailed comparison between the properties of the original design and the IH-9-Gap structure see table 1. In order to focus the beam onto the target an additional magnetic quadrupole triplet lens is required. The beam dynamics of the injection into the 9-gap resonator, of the resonator itself and of the transport towards the target has been calculated with COSY infinity and LORASR. A beam of 2.25 MeV/u from the 7-gap resonators with $\varepsilon_{xx'} = 6.5\ \pi$ mm mrad and $\varepsilon_{yy'} = 4.1\ \pi$ mm mrad has been matched to the 9-gap resonator. The LORASR calculation delivers a final energy of 3.0 MeV/u at –10° synchronous phase. For A/q=4 an effective voltage of 2.85 MV is required. Until now it is not decided to adjust the drift tubes according to the velocity profile or to establish a constant gap length for all 9 gaps. The beam transport in the modified HEBT allows a beam spot at the target of 4 mm diameter in case of the emittances given above.

Table 1: Comparison between the characteristics of the IH-7-Gap resonator and the proposed IH-9-Gap resonator.

	Energy variable IH-7-Gap Structures for MAFF (MLL)	IH-9-Gap Post Accelerator for REX-ISOLDE (CERN)
Number of Resonators	2	1
Number of Gaps	14	9
Total Length [mm]	1350	646
Gap Length [mm]	24	22 - 26
Cell Length [mm]	74	54 - 58
Drift Tube Length [mm]	50	32
Drift Tube Diameter [mm]	20/26	16/22
A/q	6.3	4.5
Design Speed [ß]	0.1	0.073 – 0.078
Injection Energy [MeV/u]	4.15/5.40	2.3
Exit Energy [MeV/u]	3.7-5.9	3.1
Design Frequency [MHz]	202.56	202.56
Frequency Range [MHz]	200.9 - 202.9	201.6 – 203.4
Shunt Impedancy [MΩ/m]	160	300
Q	18000	15000
HF-Power / Duty cycle	100 kW / 10 %	100 kW / 10 %

3.2 Second Step to 4.3 MeV/u

For the second upgrade, planned for 2004-2006, it is proposed, that the last 2 split ring 7-gap structures of REX-ISOLDE will be replaced by a cavity similar to tank2 of the MAFF-LINAC, which is an IH-cavity with 26-gaps. This accelerator will boost the energy from 1.55 MEV/u to 3.75 MeV/u. The final step to 4.2-4.3 MeV/u will be done by the original MAFF IH-7-Gap resonator. Though the original design of the 7-Gap resonator will work fine, further tuning to optimise the structure in respect to beam quality instead of a wide range of energy variation is advisable in that case.

4 MEASUREMENTS AND TESTS

Intensive simulations of the different versions of the IH resonator have been done to determine all significant design parameters. An IH-7-Gap prototype and the drift tube structure for the 9-Gap resonator are already built and successfully tested in respect to their resonance properties. These measurements had been carried out at the manufacturer when the final dimensions of the resonators flanges were determined. Low-level tests have been performed both for the 7-gap und the 9-Gap resonator. These test have been in very good agreement (+/- 0.05 %) with the simulations as shown in figure 3.

Currently the resonator is being prepared for high-level tests at the Maier-Leibnitz-Labor MLL (formerly Munich Tandem Lab). It is possible to test the new structure with the equipment currently available. A test beam line has been assembled at the –25° beam line of the MLL including a bending magnet for energy analysis, a fast Faraday cup for bunch length measurements and our low intensity emittance rig. Preliminary test measurements of the available ion beams from the tandem have been performed to confirm that the transverse and longitudinal emittance can be matched according to the requirements for the MAFF LINAC. Thus, the transverse emittance of a O^{6+}-beam at 4.15 MeV/u has been measured with the emittance meter. The beam emittance had been 0.05-0.2 π mm mrad (normalized) for a cw-beam and 0.1-0.4 π mm mrad for a pulsed beam. For realistic beam tests we have to stay below 0.4 π mm mrad for the injection into the 7-gap resonator. A chopper-buncher combination in the tandem beam line has been modified for that purpose.

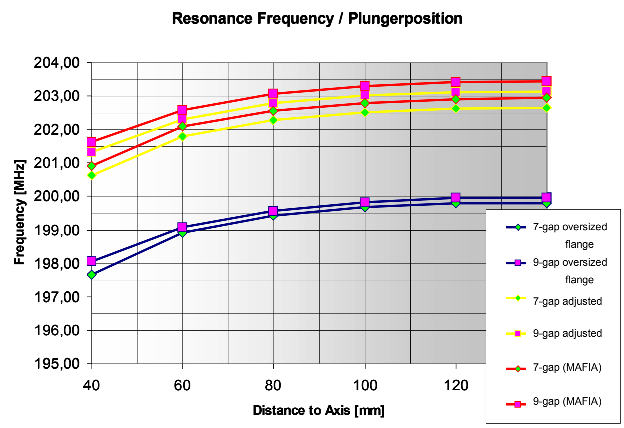

Fig. 3: Measurement of the frequency characteristics of the IH-7-Gap and the IH-9-Gap resonators. the proposed values are based on MAFIA simulations taking the final flange dimensions and cooper plating into account.

5 CONCLUSIONS

The modular design of the IH-7-Gap resonator and the consistent use of identical and easily interchangeable parts proofed to be very successful. A big advantage of the IH-structure is that no cooling of the drift tubes and stems is required, if the design with MAFIA is done properly. The same small and compact structure can be put to use for a lot of different applications that otherwise would require to built dedicated devises.

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