MEASUREMENTS AT THE MAFF IH-RFQ TEST STAND AT THE IAP FRANKFURT

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Abstract

The IH-type RFQ for the MAFF project at the LMU in Munich was operated at a beam test stand at the IAP in Frankfurt. It is the second IH-RFQ after the HIS at GSI [1] and it has been designed to accelerate rare isotope beams (RIBs) with mass to charge ratios A/q up to 6.3 from 3 keV/u to 300 keV/u at an operating frequency of 101.28 MHz with an electrode voltage of 60 kV. Experimental results such as shunt impedance, energy spectrum and transmission will be presented and compared to simulations.

INTRODUCTION

After manufacture at NTG the MAFF IH-RFQ was been set up to a test stand at the IAP Frankfurt [2] consisting of a volume ion source volume for He+, an electrostatic quadrupole triplet and electrostatic steerer, the IH-RFQ and a fast Faraday cup. With this setup only transported beam was measured behind the RFQ [3]. The steps which proofed the machine can accelerate and meets its design values are presented in the following.

SHUNT IMPEDANCE

The shunt impedance of the structure was measured with two different methods: perturbation capacitor and gamma spectroscopy. Using the gamma spectroscopy the intervane voltage is measured at a given RF power level. The first measurement of the bremsstrahlung spectrum of the RFQ was done with an RF power of 32 kW (Figure 1). The maximum energy of the photons is between 28 keV and 30 keV. The corresponding R_p-values are 24.5 and 28 kΩ. This value was so much lower than expected. Up to that point, the IH-RFQ was equipped with four tuning plates to capacitively adjust the flatness and resonance frequency (Figure 3). It was observed that the stamps of these tuning plates became quite warm during operation. After the removal of the tuning plates the R_p-value of the structure had increased. Figure 2 shows the spectrum without the tuning plates. A maximal photon energy between 32.5 keV and 38 keV was determined, corresponding R_p-values are 35 kΩ and 48 kΩ. The values vary much, because the RF amplifier was at this point not able to produce and transmit a stable RF power amplitude to the resonator and because of discharges and a thermal drift of the resonator. The error of the R_p-value measurements are typically between 5 and 10% due to the precision of the RF power measurement and to the field measurement in the resonator. In our measurements the unstable RF power amplitude increased to error additionally, but the R_p-values are clearly below the expected. The measurements with three different perturbation capacitors give similar results (Table 1).

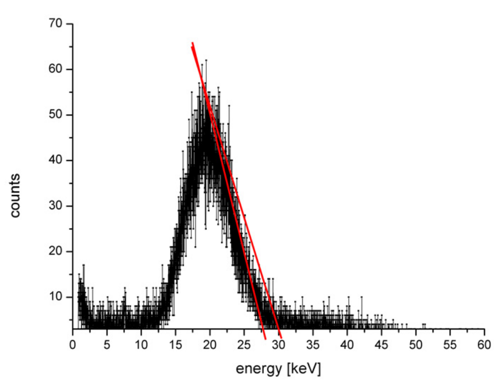

Figure 1: Gamma spectrum of the RFQ with tuner at a RF power level of 32 kW

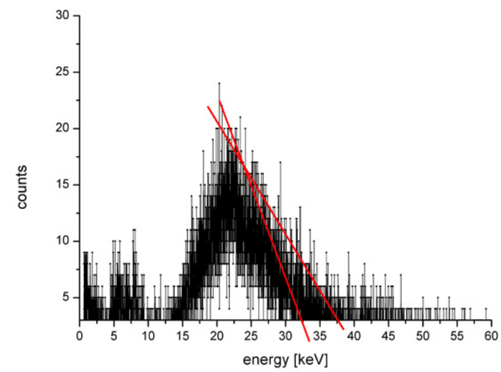

Figure 2: Gamma spectrum of the RFQ without tuner at a RF power level of 30 kW (unstable RF amplifier)

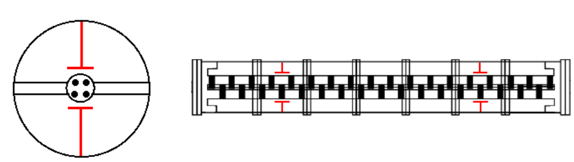

Figure 3: Scheme of the IH-RFQ with tuning plates (red).

Table 1: Shunt Impedance Measurements with Three Different Capacitors

Capacitor	1	2	3
$\Delta f[MHz]$	0.143	0.136	0.13
$R_p[k\Omega]$	48	46	45
Shunt impedance $[k\Omega m]$	150	142	136

ENERGY SPECTRUM

The energy spectrum of the MAFF IH-RFQ was measured with a proton beam and the ion source mounted directly in front of the RFQ. Simulations of this scenario predicted a proton transmission of only 10%. For measuring an energy spectrum a low transmission is no problem. The energy measurement was done using a dipole magnet and a Faraday cup. In Figure 4 the energy spectrum for two different RF levels is showing. The accelerated protons

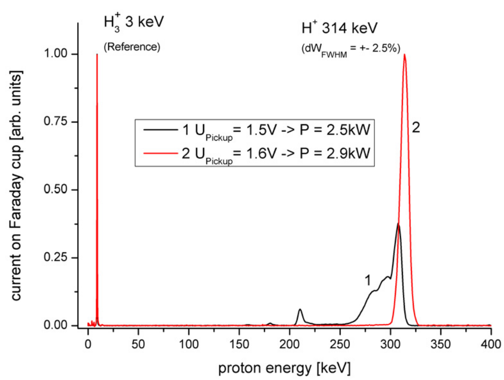

Figure 4: Energy spectrum of a proton beam with different RF power levels.

are clearly noticeable at an energy of about 314 keV (red curve) by an RF power level of 2.9 kW. When the RF levels is not high enough (black curve, 2.5 kW), the acceleration process could not be completely finished and many particles leave the RFQ bunched, shaped, and accelerated to a certain fraction of the output energy. With the intervane voltage from the dynamic simulations taking the flattness of the field distribution along the beam axis into account the R_p-value is determined to 38 kΩ.

TRANSMISSION

For measuring the transmission of the MAFF IH-RFQ the following setup for the beamline has been chosen: volume ion source which has been used before, Faraday cup with electrode to propel secondary electrons to measure the dc beam behind the ion source, a single solenoid lens to match the beam to the RFQ, RFQ, and a fast Faraday cup behind the RFQ to measure the bunched, accelerated beam. The beam current behind the ion source was measured to be 0.8 mA. The signal of the Faraday cup after the RFQ is shown on Figure 5. The black curve shows the signal when

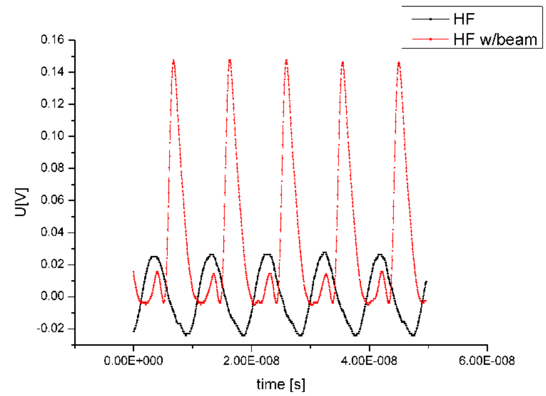

Figure 5: Signal on the fast Faraday cup after the RFQ with and without beam.

the ion source is turned off and only the HF is inducing a signal on the cup (a periodic signal with an average of zero). The red curve is the signal with beam and HF. One can clearly see the bunched beam with a peak current of 3 mA. The average current is 0.6 mA. This leads to a transmission of 75% ± 15%. The error of the transmission is due to the uncertainty of the beam current before the RFQ and the proper match to the RFQ and partly to the averaging of the signal behind the RFQ which should also get rid of the perturbation of the RF signal. Since the unflatness of the IH-RFQ, a higher value for the intervane voltage than the design voltage is necessary to accelerate particles. Simulations show that a 10% higher voltage should be assumed which leads to an increase of the R_p-value to 38 kΩ.

OVERVIEW OF SHUNT IMPEDANCE MEASUREMENTS

The shunt impedance of the MAFF IH-RFQ has been measured using different techniques. Table 2 gives an overview of the different results. Although the error of each

Table 2: Overview of the Different Measurements of the R_p Value

Perturbation Capacitor (average)	46 kΩ
Gamma Spectroscopy	42 kΩ
Acceleration of protons	38 kΩ
Acceleration of He	44 kΩ
Average	42.6 kΩ ± 3.6 kΩ

measurement was estimated to be quite high, the four different methods have an average of 42.6 kΩ ± 3.6 kΩ. The standard deviation is less than 10%. The length normalized shunt impedance of the MAFF IH-RFQ is 128 kΩm and is therefore in the range of REX-ISOLDE RFQ.

COMPARISON TO SIMULATIONS

For simulating particle dynamic of the MAFF IH-RFQ the RFQ-structure parameters (a, m, L, V) were used to get the information of the actual shape of the vanes. Other parameters like input energy, beam current, frequency etc. are also known. The only data which is roughly known is the input emittance of the beam. The characteristics of the volume ion source was determined as a diploma work by J. Fischbach [4], but was modified to match the IH-RFQ. For an accurate simulation of the RFQ the emittance in front of the vanes (RFQ) behind the solenoid needs to be known. For the following simulation the input emittance was estimated to be 0.015 cm rad (Table 3).

Table 3: Overview of the Input Beam

beam current	0.8 mA
ϵ	0.015 cm rad
α	1.17
β	8.09 cm rad

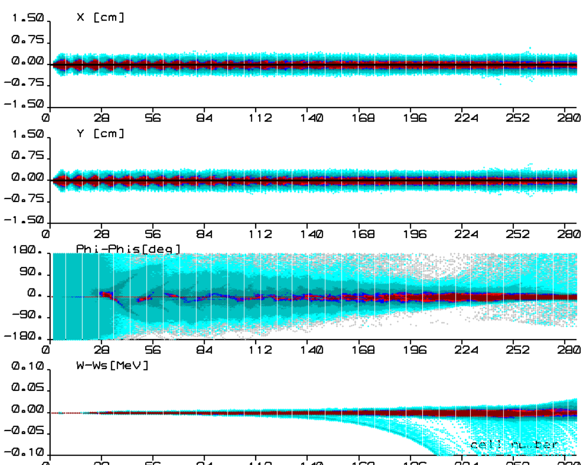

Figure 6: Evolution of the simulation of the MAFF IH-RFQ.

The evolution of the simulation in terms of x,y position, phase and energy is shown in Figure 6. The oscillation in the transverse planes indicate that the beam is slightly missmatched in the beginning of the RFQ. The bunching process takes place quite well (phase plot), but some particles leave the bucket at the end of the RFQ and fall behind. At the beginning of the RFQ the energy of all particles is the same. After some distance, when the bunching process has started, the energy distribution of the particles is expanded. Some gain and some loose energy. At the end of the structure, the energy spread of the beam is reduced to less than 25 keV/u. A small fraction of particles get transported with the wrong energy. The transmission in this case is about 77% and the percentage of accelerated particles is about 75%. The shape of the beam in the last cell of the IH-RFQ is shown in Figure 7. It is focused in the x-plane

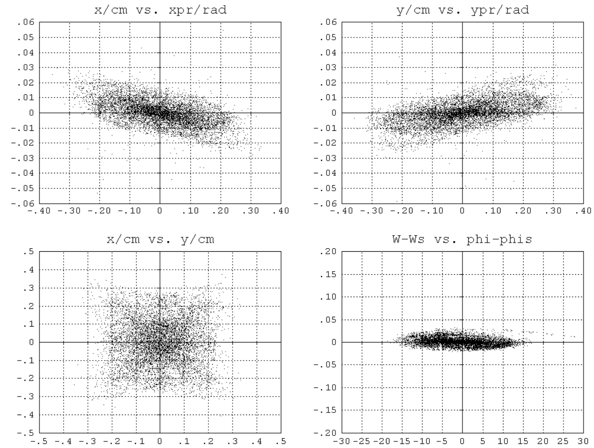

Figure 7: Beam in the last cell of the MAFF IH-RFQ.

and it is defocused in the y-plane. The phase width of the bunch is about 30° by an energy spread of less than 25 keV. The small fraction of unaccelerated beam is not shown in these graphs.

CONCLUSION

The measurements discussed above show that the MAFF IH-RFQ was assembled correctly and is capable of accelerating particles with a mass to charge ratio of 4. The problems solved include the bad R_p-value due to the tuning plates, replacement of the injection system, intensive conditioning of the RFQ, and using precise measuring methods for the beam current especially with the fast Faraday cup. Problems still to overcome are mainly to eliminate the limitation of the structure to operate at higher RF-levels. There are some regions in the RFQ which are sources for sparking, which should be upgraded. A more precise measurement of the transmission including measurements of the emittance at the entrance of the RFQ and behind the RFQ are needed which leads to a larger experimental setup to compare them to simulations more precisely. The measured values for the impedance, beam transmission and beam energy of the MAFF IH-RFQ were close to the design parameters.

REFERENCES

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