A New Concept for Cooling Low-Energy Heavy Ion Beams

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Several experiments like e.g. mass measurements in Penning traps have to be provided with high-quality (radioactive) heavy ion beams. Beam coolers are used for delivering low-emittance beams with narrow energy distribution.

A conventional method for stopping and cooling low-energy (10 - 100 eV) beams is the application of buffer gas filled Radio Frequency Quadrupoles (RFQ) where the incoming ions are thermalized due to collisions with the atoms of a buffer gas under pressures between 0.01 and 0.1 mbar and transversely focused by the oscillating RFQ field [1,2].

Presently we are investigating a new concept of a buffer gas filled ion cooler built from single Radio Frequency (RF) ring electrodes with varying inner diameters.

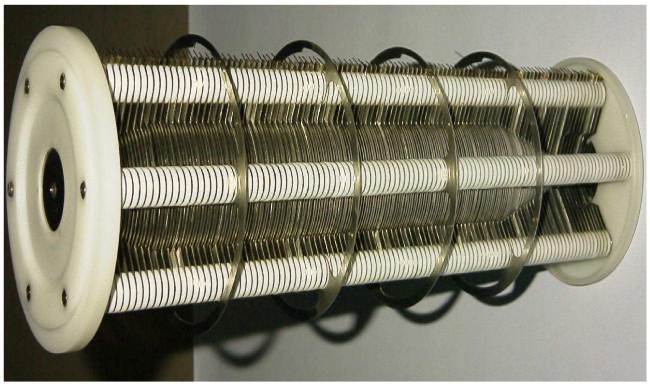

Fig. 1: RF ring electrode cooler; the beam is entering from left to right

We have built a 450 mm long cooler [3] which is composed of 223 RF rings forming the cooling channel with a maximum inner diameter of 60 mm (Fig. 1). The thickness of each RF ring is 1 mm and the gap between adjacent electrodes is 1 mm as well. The construction is enclosed by a stainless steel cylinder which is designed with beam entrance and exit apertures of 6 mm and 3 mm respectively. In its interior a Helium buffer gas pressure of about 0.1 mbar is kept for stopping and cooling the ions.

Each electrode is supplied by an RF field at a frequency around 5 MHz and an amplitude of 100 - 150 V while the phase difference between adjacent electrodes is π. The RF fields generate an average repelling short-range force perpendicular to the electrode surfaces which causes a reflection of the ions. The created RF potential is box shaped (symmetric to the cooler length axis) in contrast to the harmonic pseudo potential of RFQ devices. Additionally a DC electric field gradient of about 0.5 V/cm is applied along the electrodes to compensate friction losses and to drag the ions toward the exit.

Dedicated Monte Carlo simulations have been performed to investigate the transmission and cooling performance of the RF ring electrode structure. In Fig. 2 calculated ion trajectories in the cooler exit section are shown (the beam is coming from left). The combination of the reflecting fields and the shape of the cooler causes the focusing of the ion beam toward the exit.

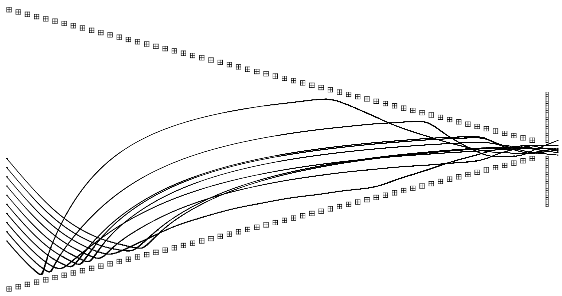

Fig. 2: Simulated ion trajectories in the cooler exit section

The simulations were based on a microscopic model taking into account single collisions between the ions and buffer gas atoms. For masses between 60 and 130 u we found maximum transmission efficiencies of 90 % which is a promising result since the maximum transmission of RFQs was measured to be 50 % [1]. In RFQ coolers the losses mainly occur at the entrance due to the restricted angular acceptance. In comparison, simulations showed that the acceptance of the ring electrode structure is 4 times higher than the one of an RFQ when choosing the hyperbolic shape of the entrance section like shown in Fig. 1. Also the cooling performance of the RF ring device could be demonstrated by the simulations. Starting with an energy distribution of 100 eV FWHM we found a spread of 5 eV FWHM at the cooler exit (for the RFQ device the measured energy spread was about 1 eV in comparison).

First experiments have been carried through with a 45 mm long prototype RF ring structure for testing its performance as RF ion guide at pressures between 0.01 and 0.1 mbar. The device was used for extraction of a cooled ion beam from the Jyväskylä RFQ cooler [1]. The measurements were done for beam currents up to 5 nA and revealed a high transmission for the RF ring structure close to 100 %.

In the next step the 450 mm long RF ring cooler will be investigated experimentally at the Jyväskylä IGISOL facility [1]. Moreover, qualitative considerations hint that due to the box shaped pseudo potential RF ring structures should be able to cool high currents (up to 100 nA) with smaller losses than RFQ coolers with their quadratic potentials and their space between the RFQ rods not used for ion transport. This is presently investigated by simulations.

References

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[2] H. Herfurth *et al.*, *A linear radiofrequency ion trap for accumulation, bunching and emittance improvement of radioactive ion beams*, Nucl. Instr. Meth. **A469** (2001) 254-275

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