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RFQ-COOLER FOR LOW-ENERGY RADIOACTIVE IONS AT ISOLDE

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Abstract

A radio frequency ion cooler and buncher project at the CERN-ISOLDE facility is presented. Monte Carlo simulations, based on the ion mobility concept will be discussed. Future options for the facility are outlined.

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PACS. 29.27.Eg, beam handling, beam transport; 29.27.Fh, beam characteristics; 41.85.-p, beam optics

Keywords: Radio frequency quadrupole, buffer gas cooling, Monte Carlo simulations, ion mobility

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INTRODUCTION

The exploration of nuclear structure in the wide landscape of the nuclide chart, with various spectroscopic methods, has set new demands for the handling of the ion beams. In the past couple of years, emittance improvement of low-energy radioactive ion beams has gained a lot of interest and several prototype devices for an emittance improver and buncher have been constructed, see for example [1,2,3,4,]. A proposal to install an ion cooler and buncher at the ISOLDE-facility at CERN [5] will be discussed in this article.

Emittance improvement requires a dissipative environment, where Liouville's theorem does not apply. Despite the wide variety of cooling schemes, only one method, namely buffer gas cooling, is easily applicable for low-energy radioactive ion beams. In this scheme, the ions lose their energy in collisions with neutral buffer gas atoms. This would normally lead to the loss of the ions in the gas by diffusion to the walls. By applying additional confinement, this can be avoided and the ions are cooled down to the temperature of the buffer gas.

A linear version of the three-dimensional RF-trap (Paul trap) can be used to confine the ions in the transverse plane when the ion beam passes through it. A linear RF-trap is made of four parallel rods connected to an RF-supply in such a way that opposite rods are coupled to same phase and voltage. This oscillating quadrupole field focuses the ions towards the center of the rod structure as the ions lose their energy through gas collisions.

RFQ COOLER AND BUNCHER AT ISOLDE (RFQC)

Presently the ISOLDE separator routinely provides low-energy radioactive ion beams of more than seventy elements with an intensity range exceeding 10^{10} ions/sec. Typical figures for emittance and longitudinal energy spread are 35 $\pi \times$mm$\times$mrad and 5 eV at 60 keV. The quality of the ISOLDE beam depends on the ion source and is generally adequate for conventional spectroscopy. However, many of the existing and planned projects at ISOLDE would benefit from an improved emittance and lower energy spread as well as bunching of the ion beam. For example, in collinear laser spectroscopy the overlap of the incoming beam and laser light can be increased. In addition, the broadening of the resonance signal due to energy spread and the divergence of the ion beam can be avoided. Injection efficiency to REX-TRAP, the first section of the REX-ISOLDE experiment [6] can be increased. Transmission efficiency of the MISTRAL spectrometer [7] should increase considerably. In solid-state experiments, the spatial size of the implanted source can be reduced without cutting the beam envelope by the slits. The sensitivity of angular correlation measurements will improve because of the better definition of the source. A bunched beam allows tagging experiments, where measurement is correlated in time with the arrival of the ions. The list of experiments benefiting from RFQC could be easily extended, but the examples emphasize the fact that ISOLDE-RFQC will finally serve many experiments. Thus, it is necessary to install such a device as early as possible in the beam line system.

The ISOLDE beams originate from two different target stations. The first, General Purpose Separator (GPS), serves all beam lines in the ISOLDE hall. The High-Resolution Separator (HRS) serves only beam lines connected to the central beam line. Thus, it would be desirable to connect the RFQC to the GPS to have the widest possible use of the RFQC as an emittance improver. Unfortunately, the present layout of the ISOLDE facility makes it practically impossible to install the RFQC in the GPS separator and thus it will be combined with the HRS, just after the final focus of the second magnet of the HRS-separator. This layout allows full functioning of the HRS-separator in high-resolution mode with an additional beam improvement by the RFQC for the mass-separated ion beam. This solution also allows operation of the GPS-separator without influence from the RFQC.

SIMULATIONS AND TECHNICAL DESIGN

The conceptual design of the ISOLDE RFQC is based on Monte Carlo simulations, with a prerequisite that ion mobility data is properly reproduced. The main advantage of such an approach is that it allows to use the SIMION ion optical simulation package [8], while providing a more realistic model for buffer gas cooling compared to the simple macroscopic ion mobility approach.

An incoming beam from the ISOLDE separator has to be decelerated from 60 keV down to a few hundred eV before an efficient capture in a buffer gas. Deceleration optics should focus the ion beam into the inlet of the RFQ, which size should be as small as possible to avoid outflow of buffer gas towards the beam line. Our present design uses a cylindrical tube of 6 mm in diameter and 10 mm in length. According to injection simulations, it is possible to transfer the ISOLDE beam to the RFQ without losses.

The RFQ structure itself is designed to be slightly larger in the radial direction compared to existing comparable devices [1,2] to be able to capture higher intensities and larger emittance of the incoming beam. The distance from the rods to the optical axis is 20 mm. The cooling section of the RFQC is 60 cm in length, which is enough to thermalize transverse motion in a buffer gas pressure of the order of 0.1 mbar. In fact, 60 cm leaves sufficient freedom to permit an optimization of the different parameters affecting the cooling process. Cooling down to buffer gas temperature occurs in less than a millisecond, see figure 1, and the required length of rod structure depends on gas pressure as shown in figure 2. One should notice that when ions are actually cooled, an axial motion is only diffusion-driven. As a result, the transmission time through the cooler structure is orders of magnitude longer than the cooling time. The transmission time of the ion beam through the ion cooler can be reduced to milliseconds by applying a modest axial field. This is generated by segmenting the rod structure and applying small DC-voltage component on top of the RF-voltage. As an option, we are also studying the possibility to add separate DC-electrodes placed between the RF-rods. This would electronically separate DC and RF-supplies. The axial field provides an additional feature, namely the possibility to collect and store ions and release them in bunches for physics experiments.

A special emphasis will be put on the extraction of the cooled and possibly bunched ion beam. First, heating of the ion beam should be avoided through ion and atom collisions during acceleration. This can be achieved by mounting a so-called miniature quadrupole in the end of RFQ-structure that transports the ions to better vacuum before re-acceleration. Although it has proved good for low energy spread, such a solution results in a poorly time-resolved ion bunch. Thus, we intend to collect the ion cloud in a lower pressure regime, which allows immediate transport of the ion cloud to the beam line system and thus preserves its time structure.

OUTLOOK

The injection of the ISOLDE beam into the RFQC is one of the most critical parts for the efficiency of the RFQ. Our present design takes advantage of many deceleration electrodes and the possibility to gently decelerate ions into an entrance of the RFQ. Although simulated capture efficiency reaches 100 %, it is obtained with a very small margin. Thus, we will further develop the injection geometry, aiming for larger acceptance to ensure the highest possible efficiency in realistic operation conditions. One of the options under investigation is to enlarge the radius of the RFQC at the beginning of the structure.

The present design of the ISOLDE-RFQC is based on room temperature operation. It is well known that a lower temperature would improve the operation of the RFQC. Intuitively, the final temperature of the ion cloud will be lower if the buffer gas temperature is lowered. Thus, it is of interest to explore possible low temperature operation of RFQC. Although not available in the first phase of the RFQC, the option of cryogenic cooling will be taken into account in the design and material selection of the RFQC.

The REX-ISOLDE experiment [6] at CERN provides post-accelerated radioactive ion beams of practically all elements available at ISOLDE. The present configuration of REX-ISOLDE applies Penning trap technique to cool and bunch the ion beam before injecting it to a REX-EBIS-source [9] for charge state breeding. The installation of the RFQC in principle, would allow direct injection of the ISOLDE beam to an REX-EBIS source. Such an operation mode will be studied carefully and compared with the present configuration.

Finally, we have started to explore theoretically the ion funnel structure [10], which may provide a competitive alternative for RFQC. Such a device may be implemented at a later phase at ISOLDE, since our design aims for flexibility in respect to possible reconfiguration of the device. However, more theoretical and experimental investigation is needed for a reliable comparison between the RFQ and the funnel.

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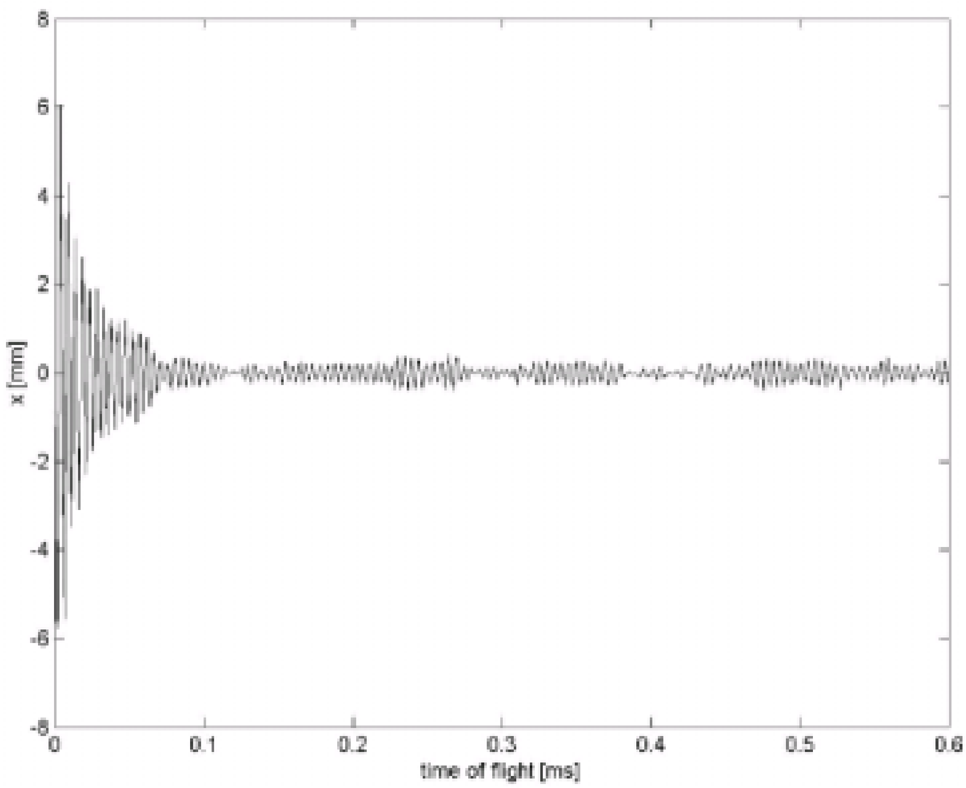
Figure Captions

Figure 1. Simulated displacement from an optical axis as a function of time-of-flight.

Figure 2. Cooling length as a function of pressure of buffer gas (He) for the ions with mass A=100 in room temperature.



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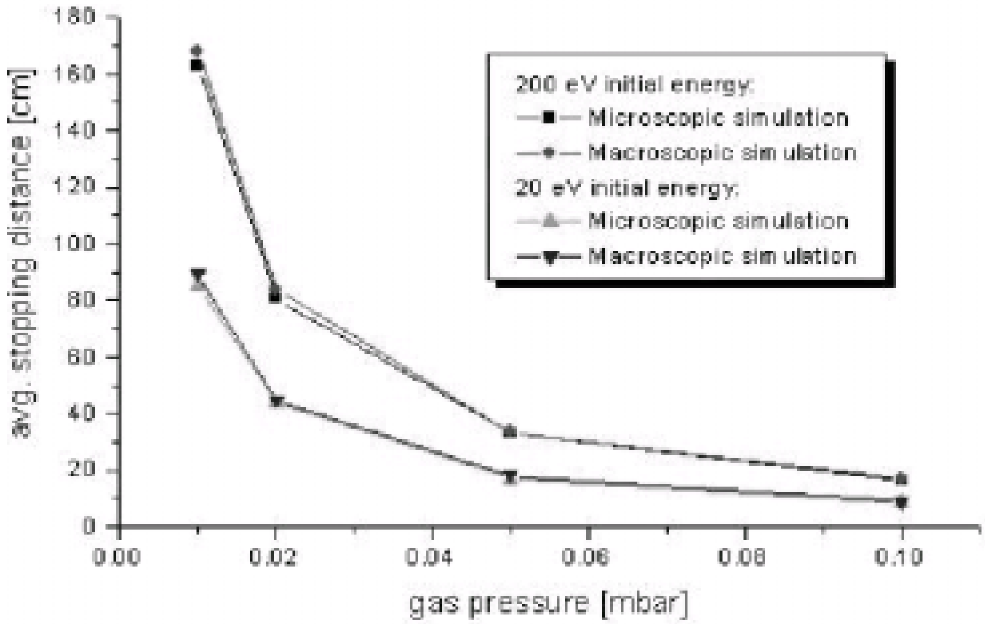

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