Accumulation Cooling and Bunching of Radioactive Ions in REXTRAP

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Effizient post acceleration of radioactive ions produced by present target ion source on-line facilities normally requires beam preparation, as the occupied transversal pase space most often is too large. Furthermore pulsed beams and ions at high charge states are desirable for a compact set-up. For example at ISOLDE, the radioactive beam facility at CERN, the ions are delivered as a continous beam of singly carged ions at an energy of 60 keV whereas the post accelerator REX-ISOLDE [1] requires a pulsed beam at a repetition frequency of about 50 Hz and a mass to charge ratio of about 1/4.5. Therefore a unique system consisting of a large Penning trap (REXTRAP) for accumulation, cooling and bunching followed by an electron beam ion source (EBIS) for charge state breeding is used. In REXTRAP the ions are decelerated electrostatically in a first step and finally captured and cooled by the dissipative force provided at collisions with buffer gas atoms. At the end of the cycle they are released from the trap as a bunch and accelerated again to 60 keV for transport to the EBIS. Transversal cooling is necessary to match the relatively small EBIS acceptance and to ensure high capture efficiency there. Normally reducing the energy by collisions in a Penning trap causes a loss of the ions due to an increase of their magnetron radius. Additionally, if the number of stored ions becomes high Coulomb repulsion will occur. To overcome this and to limit the transversal emittance of the ejected bunches a radial compression of the ion cloud is necessary. In principal two methods are available. The first uses sideband excitation of the ions at their cyclotron frequency [2,3,4]. Thus, coupling the magnetron motion to the reduced cyclotron motion, which can be cooled by collisions with the buffer gas. Secondly, the ion cloud can be spinned up by applying a rotating electrical multipole field in the azimuthal plane [5,6,7]. This causes a Lorentz force in inward direction acting on the ions, which then compensates their Coulomb repulsion and centrifugal forces. The density of the ion cloud changes with the applied frequency and can theoretically reach the Brilloin limit if the cloud rotates at half of the ions cyclotron frequency.

The experimental set-up of REXTRAP is described in detail in [8,9]. The cylindrical trap is located in the field of a 3 T superconducting solenoide on a high voltage platform near to 60 kV. Up to 10^{-3} mbar Ne or Ar have been used as buffer gas in the trap center. As the ions have to pass a small diaphragm at the trap exit, cooling, i.e. centering of the ions, can be detected by an increase in the extracted number of ions.

Using the sideband cooling technique, experiments have been performed on stable and radioactive ions covering the mass range between ^{7}Li and ^{238}U. With an accumulation and cooling time of together 20 ms an efficiency of about 40% has been reached. Most losses occur at the injection of the ions into the magnetic field of the trap. In a collaboration with the INRS at Orsay, France, an emittance meter developed there has been adapted to the pulsed structure of the ion beam released by REXTRAP and the transversal emittance of the ejected ion beam could be determined. With sideband cooling it is about 7 π mm mrad at 30keV compared to nearly 20 π mm mrad without cooling. The method works well if the number of stored ions per cycle is not too high, i.e. below 10^6. Above this a significant decrease in the efficiency and also an upward shift in the frequency necessary for the cooling have been observed [10]. This indicates, that the diameter of the ion cloud becomes larger than the extraction diaphragm, and the sideband cooling is not longer sufficient for compressing the ion cloud. The shift of the frequency can be interpreted as a rotation of the ion cloud due to the higher space charge density. Thus, the frequency the ions see in their rest frame changes. To overcome this problem, rotating wall compression has been tested for ion numbers of more than 10^7. For the first test the central trap electrode for applying the rotating field was four times segmented. Thus only a rotating dipole field could be used. Experiments have been performed with stable sodium and potassium ions. Cooling occurred if the frequency of the azimuthally rotating field coincides with the axial frequency of the ions. A similar coupling of azimuthal and longitudinal modes, which increases the compression rate in an electron plasma, has been observed in [11]. Even with these first experiments no decrease in efficiency up to $5 \cdot 10^7$ simultaneously stored ions has been observed. Further experiments using an eight fold segmented electrode to couple in a rotating quadrupole field and higher frequencies for an even higher compression of the ion cloud have just started.

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