ESR Operation and Development

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After very good vacuum conditions in previous years, the operation of the ESR in 2007 was hampered by various problems with the ultrahigh vacuum system. This was particularly distracting, as many experiments with low charge state or low energy beams were scheduled, which are most dependent on good vacuum conditions.

The commissioning of the HITRAP facility was continued with beams of bare ions decelerated to 4 MeV/u and fast extraction of the beam which was re-cooled at the low energy by the electron cooling system. The ESR was also used as a test bed for developments for the FAIR project. Two accumulation schemes which are proposed for the New Experimental Storage Ring (NESR) of the FAIR project were successfully demonstrated. Benchmarking experiments to verify computer simulation tools were continued.

A beam time request for fixed target experiments with low energy bare ions has triggered an ion optical study of the feasibility of slow resonance extraction of decelerated ions from the ESR. Although considered from the beginning of the ESR design, this mode has never been implemented. The design study confirmed that by proper choice of the beam orbit and adjustment of the tune and the chromaticity the existing beam extraction components should allow a slow extraction of bare ions by resonance extraction. The modification of the operating software has been initiated and machine experiments for a demonstration of this type of slow extraction are foreseen in the first quarter of 2008.

1 Operation for Physics Experiments

In a three weeks period the ESR was operated with rare isotope beams of ^{142}Pr and of ^{142}Pm in various charge states for detailed studies of the decay behavior of these ions. At the injection energy of 400 MeV/u a combination of stochastic precooling and final electron cooling was applied. After a total cooling time of about 5 s the ions were cooled to lowest momentum spread with an uncertainty of their revolution frequency below 10^{-6} which allowed detection and observation of the decay of single ions. The observation of single decays allows the determination of the instant of decay with an accuracy of about one second, which is determined by the time for re-cooling the decay product to smallest frequency uncertainty.

The reaction microscope, which was recently installed in the interaction chamber of the internal target, was used in experiments with bare nickel ions at 400 and 30 MeV/u. The ions and electrons emerging from the gas jet after collisions between a fast projectile ion and a target atom are detected in the reaction microscope in coincidence. A pair of Helmholtz coils installed around the target chamber provides a homogeneous magnetic field to guide the low energy electrons. Other experiments at the internal target used decelerated uranium ions in various charge states (92+, 91+, 90+). The injection energy was chosen for maximum production of the required charge state in the stripper foil between SIS and ESR, whereas the energy in the ESR after deceleration was determined by the experiment. Electron cooling after deceleration was mandatory to provide good beam quality for precision experiments and to compensate the heating by the internal target.

Two experiments with low charge states (Li^{1+} and U^{28+}) suffered from the poor vacuum conditions. Due to the beam lifetime of a few seconds these experiments had to be cancelled. After some provisional repair work the conditions for the time dilation experiment with Li^{1*} could be improved, and a beam half life of 15 s was achieved, still a factor of 5 shorter than in the previous year. Although the operation of the ion source and the preparation of lithium ions in the metastable state for the precision spectroscopy is demanding, the feasibility of improving the precision in this experiment by excitation of the metastable ions with two counter propagating laser beams could be finally demonstrated [1].

Decelerated beams of bare ions, neon and nickel, at an energy of 4 MeV/u were provided in two beamtimes scheduled for the commissioning of the HITRAP facility. In order to reduce the total cycle time a deceleration mode with stochastic cooling at the injection energy of 400 MeV/u has been established. The stochastic cooling reduces the cooling time to a few seconds compared to cooling times in excess of 10 s with electron cooling at the injection energy. No degradation of the deceleration efficiency was observed. The accelerating voltage of the electron cooling system needs less variation during the deceleration cycle which simplifies the cycle and reduces its duration by a few seconds. The quality of the decelerated beam is determined by the power of electron cooling at the extraction energy of 4 MeV/u. Results on the beam parameters of the extracted beam, which also provide information on the quality of the cooled beam at low energy, are reported in the HITRAP commissioning report [2]. So far only coasting beams were extracted, but the maximum length of the kicker pulse of 3 μs does not allow to extract more than 75 % of the circulating particles. In order to extract the decelerated beam completely and to provide a short bunch of less than 1μs length for efficient capture in the trap, a system for bunching the beam at harmonic number $h = 1$ after deceleration is in preparation using the modified second ESR cavity.

In preparation of mass measurements in the isochronous mode the ion optical setting of the beam line between SIS, FRS and ESR has been optimized. By improved matching, particularly between FRS and ESR an increase of the number of injected ions by a factor of 10 was demonstrated. This improvement will allow the use of the isochronous mode for rare isotopes with correspondingly lower production rate [3].

At the internal gas target preparations are under way to install a micro-jet target which can produce a hydrogen liquid jet with micrometer diameter. This new set-up should allow an increase of the target thickness for light gases by several orders of magnitude.

2 Machine Development

For the NESR storage ring of the FAIR project two new longitudinal stacking schemes are proposed which use a combination of rf manipulations and electron cooling. By means of these longitudinal stacking techniques it is foreseen to accumulate intense beams of rare isotopes. One scheme uses barrier buckets to confine the circulating ions to a fraction of the circumference and make the empty part of the circumference available for the injection of additional particles. The second scheme uses an rf system operated at harmonic number $h = 1$, which compresses the circulating beam to a fraction of the circumference. By injection of new beam onto the unstable fixed point, the stored beam is not affected by the new injection. A precise timing and short rise and fall times of the injection kicker are crucial for the longitudinal accumulation.

For the experimental verification of the proposed stacking schemes the second ESR rf cavity, which is not needed for standard operation, was modified for broadband operation. A parallel resistance was installed in order to reduce the cavity impedance to 50 Ω. This increased the bandwidth sufficiently to generate barrier pulses with a period of 200 ns, corresponding to a maximum repetition rate of 5 MHz, at the expense of reduced gap voltage. Due to the small momentum spread of the cooled beam the maximum amplitude of the gap voltage of 170 V was sufficient for a first demonstration of both accumulation methods with the same cavity and comparable rf voltages. These accumulation methods also require very accurate synchronization of the pulse of the injection kicker in order not to destroy the stacked beam. Details of the experimental study are described in a separate report [4].

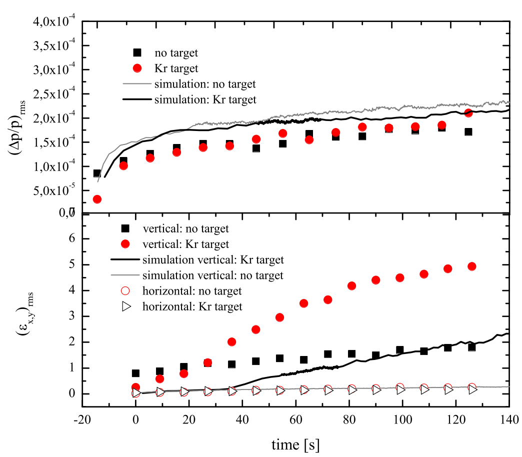

Figure 1: Comparison of measurement and BETACOOL simulation of the longitudinal and transverse heating of a bare nickel beam at 400 MeV/u interacting with a Kr target of 6×10^{12} atoms/cm^2. The initial heating is due to intrabeam scattering, the target is switched on after 30 s.

The experiments aiming at a benchmarking of simulation tools for the prediction of beam parameters in experiments with cooled beams interacting with an internal target were continued. As the results of previous experiments were impaired by the finite dispersion of about 1 m at the target, a new ion optical setting was tested which reduced the dispersion at the target location to less than 10 cm. This could be confirmed by measurements with a horizontal scraper in the target section. An experimental result with a Ni^{28+} beam at 400 MeV/u and the new setting for the dispersion in the target section is shown in Fig. 1. Krypton gas with a thickness of 6×10^{12} atoms/cm^2 was used as target. The measured values are compared to a simulation with the BETACOOL program [5] which is frequently used to predict the parameters of cooled beams. The temporal evolution is well reproduced, but the simulation predicts too small initial emittance of the cold beam.

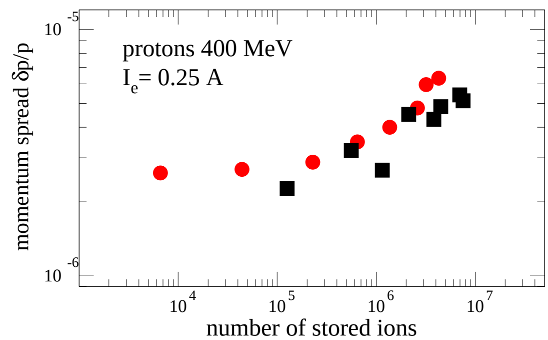

Figure 2: Measurement of the momentum spread (2σ) of a proton beam at 400 MeV cooled with an electron current of 250 mA. By connecting a resonant circuit to the Schottky pick-up (red circles) the sensitivity could be increased by more than one order of magnitude.

In another machine experiment the cooling and detection of protons has been studied. For protons, because of the low charge, the Schottky noise is reduced and therefore protons are useful to find the sensitivity limit of the Schottky noise detection system. The low charge results in much weaker intrabeam scattering, but also in a reduced cooling rate of the electron cooling system. The dependence of the Schottky noise signal on the ion beam intensity was measured in the low intensity regime (Fig. 2), where for highly charged ions an ordering effect was evidenced as a sudden reduction of the momentum spread for less than a few thousand ions. For protons a minimum momentum spread of 2×10^{-6} was found, which saturated below 1×10^5 ion. With the standard set-up for Schottky noise detection the beam signal could not be resolved from the thermal noise for less than 10^5 stored ions. After connecting a resonant circuit to the Schottky pick-up the detection limit could be lowered by one order of magnitude to about 1×10^4 ions. The minimum momentum spread was due to the ripple of the power supply for the main dipole magnets, which were operated at lower current compared to highly charged heavy ions. In order to increase the sensitivity of the Schottky pick-up or alternatively to reduce the required averaging time of the frequency analysis system a new Schottky pick-up operating at higher frequency (a few hundred MHz) is in preparation.

References

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[5] A.O. Sidorin et al., NIM A 558 (2006) 325.