ESR operation and development

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The ESR storage ring operation extended in 2014 over a rather long total period of 21 weeks due to the fact that many experiments as well as machine and detector development were scheduled before the complete shutdown foreseen for the years 2015 and 2016. A variety of physics experiments were performed using the different operational modes of the ESR.

An experiment to perform precision laser spectroscopy of the hyperfine transition in the hydrogen-like bismuth ion aimed at an improved accuracy in the measurement of the beam energy by monitoring the accelerating voltage of the electrons applied for electron cooling of the stored beam. A high precision high voltage divider provided by Physikalisch-Technische Bundesanstalt (PTB) was installed. It was found that the output voltage of the power supply showed significant variations with time. By continuous measurement of the voltage with the divider the variations of the high voltage could be tracked and corrected in the offline analysis. Despite the problem of the power supply, an improved determination of the beam energy was achieved and a correspondingly improved value of the energy of the hyperfine transition could be measured by laser spectroscopy. After the experiment the supplier of the high voltage generator found a problem with resistors recently installed in the power supply. After replacement of the resistors the usual stable operation was reestablished.

Experiments at the internal target benefitted from recent improvements of the target performance. A target density of 1×10^{13} cm^{-2} is now routinely available with hydrogen gas. In another experiment xenon gas was used with good reliability, however, with a reduced density of some 10^{11} cm^{-2} due to the high beam loss rate of the stored highly charged Xe-ions at the energy of 50 MeV/u.

For various experiments the beam was decelerated in the ESR. For a scheduled experiment with the internal target with hydrogen gas a $^{124}Xe^{54+}$ beam was decelerated from 230 to 7 MeV/u. So far, this is the lowest energy of an experiment using a stored beam in the ESR and the lifetime of the cooled beam of highly charged ions at the low energy in the residual gas was about 20 s. Due to the target operation and the presence of special detectors in the vacuum, the lifetime decreased to 5 s. Systematic measurements with the stored bare xenon beam at various energies in the range 30 to 7 MeV/u showed a decrease of the lifetime in the residual gas very close to the expected E_{kin}^2–dependence on the kinetic energy E_{kin}. The feasibility of such an experiment using a particle detector installed inside the vacuum chamber of the dipole magnet after the internal target could be demonstrated with the presently achievable vacuum conditions. Unfortunately the experiment had to be cancelled after serious damage to several components caused by a thunderstorm.

In two one week periods with decelerated beam, a beam of bare nitrogen was decelerated to 4 MeV/u for HITRAP commissioning and extracted with the fast kicker extraction. In order to have a short cycle time the nitrogen beam was injected at the low energy of 30 MeV/u which reduced the time for cooling and deceleration of the ion beam to 4 MeV/u to about 30 s.

In the future the ESR has to deliver decelerated ions to the CRYRING which is presently being installed in the target hall south of the ESR. There is no dedicated kicker for fast extraction of a beam from the ESR towards the target hall. However, it was found that with a special closed orbit distortion of the stored beam the existing injection kicker can be used to extract the beam to CRYRING [1]. The implementation of the special orbit distortion and the kick extraction towards CRYRING was investigated first with a stored beam at a rigidity of Bρ=3.2 Tm. Subsequently, the rigidity of the stored beam was reduced iteratively to Bρ=0.58 Tm, with a $^{14}N^{7+}$ beam decelerated to 4 MeV/u. This corresponds to the design values for the transfer of beam from ESR to CRYRING. The extraction was successful and the beam could even be transported about 20 m along the transport line. Further beam transport tests suffered from a lack of available test time. It was also found that with the special orbit distortion the beam can be extracted from the same orbit either to HITRAP (northern extraction channel) or CRYRING (southern extraction channel) simply by tuning the angle of the extraction kick. That would even allow a fast change of the destination of the stored decelerated beam by changing the kick strength pulse to pulse. The major disadvantage of this extraction mode with closed orbit distortion is the fact that the large angle of the closed orbit, which has to be applied in the cooling section does not allow electron cooling in the last phase of beam manipulation before extraction.

In October 2014 beam for a channeling experiment in HTA was provided with charge change extracted Li-like U^{89+} ions at 190 MeV/u. This beam was used to recommission the extraction beamline towards the target hall with the help of the new CUPID diagnostics system [2]. An additional vertical steerer and upgraded scintillating screens in the beamline and the experimental cave now allow for a much more precise adjustment of the beam parameters of the extracted ions.

The requirements of minimal transverse divergence of the cooled extracted beam could be fulfilled by widening it to a parallel beam in the target area, that has further been trimmed with slits to a 5×5 mm quadratic beam spot as shown in fig 1.

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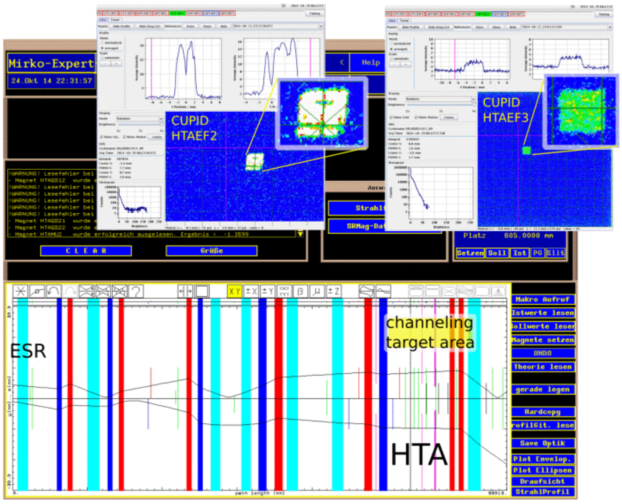

Figure 1: MIRKO envelope of the extracted beam as well as CUPID images of the quadratic beam shape measured with two different scintillating screens in a distance of 2 m installed in the experimental area.

Both transverse emittances could be determined to be smaller than 0.5 π mm mrad (FWHM) with a corresponding divergence of around ±100 μrad in the target area.

The longest experimental period was devoted to a repetition of the measurement of bound-state beta decay of $^{142}Pm^{60+}$ with better statistics. In previous measurements the reliable operation of the injection kicker was doubted. Missing injection kicks were suspected to compromise the determination of the time of decay of the nucleus. During the new measurement all three modules of the injection kicker were monitored individually. Only 1 failure of the injection kicker was found within 10000 injections during the experiment, proving an excellent reliability of the system. The whole experiment including stochastic precooling and final electron cooling of very few secondary ions stored in one injection showed very reliable operation of the ESR and its technical systems.

Over the year various machine experiments were performed. Studies of the isochronous mode were continued aiming at an increased acceptance for isochronous mass measurements and the improvement of the ion optical model. A measurement of the ring dispersion in the isochronous mode and the comparison with lattice calculations is reported in a separate contribution [3].

In another machine development experiment a proton beam was used to test the ability of the ESR cooling systems to prepare a cooled beam of particles with low charge. This was a study in preparation of the potential future use of the ESR in a chain of decelerators for antiprotons at FAIR. It could be demonstrated that both cooling systems, electron cooling and stochastic cooling, can be used. Stochastic cooling with notch filter and time-of-flight (ToF) cooling was performed. The damping time for some 10^8 protons with an initial rms momentum spread of 4×10^{-4} was about 15 s with ToF –cooling and about 8 s with notch filter cooling. With notch filter cooling even for 1×10^9 protons the damping time was as low as 15 s. For electron cooling the damping time for protons at the edge of the initial momentum distribution was 600 s, which is expectedly much longer than for stochastic cooling. The damping time decreased in the course of the cooling process (Fig.2). On the other hand, the final momentum spread with electron cooling was $2\text{-}3\times10^{-5}$ compared to $1\text{-}2\times10^{-4}$ with stochastic cooling.

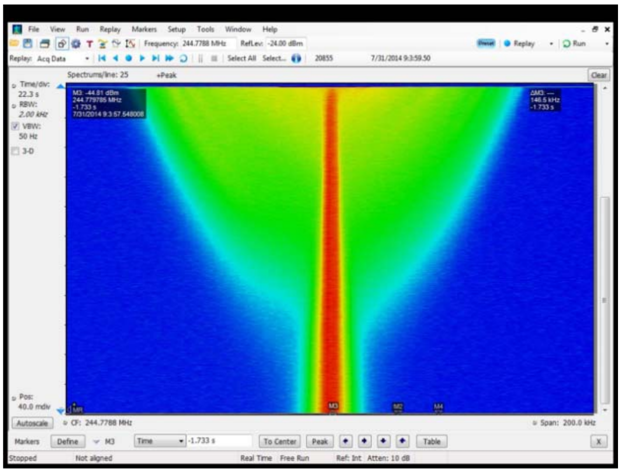

Figure 2: Longitudinal cooling of a proton beam at 400 MeV/u with an electron current of 0.25 A. The total time for the reduction of the momentum spread from 4×10^{-4} to 3×10^{-5} was 7 minutes.

A new controls program for the stochastic cooling system has been developed and is now available for operation of the system. It is a graphical interface which allows control of all components which are needed for operation and tuning of the stochastic cooling system. The new control software is compatible with FAIR standards and will be integrated into the future ESR controls concept.

For an improved understanding of the resonant structure which is used in the ESR for Schottky diagnostics a series of measurements with beam were performed. The main goal was the determination of the sensitivity of the cavity and the dependence of the sensitivity on the beam velocity, which is reflected in the transit time factor of the cavity. Measurements with proton beam at energies between 100 and 400 MeV and more systematic measurements with a $^{58}Ni^{26+}$ beam in the energy range 14 to 376 MeV/u (velocity range β = 0.17 - 0.71) were performed. For a beam velocity below β= 0.17 the Schottky signal vanished due to transit time factor effects.

References

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