COMMISSIONING OF THE HEAVY ION STORAGE RING ESR

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Abstract

The assembly of the ESR [1] was completed at the end of February 1990. A low energy beam of Ne^{+3}–ions could be transported over a full turn in the following days. One month later Ar^{+18} beam bunches from the SIS [2] at 200 MeV/u were stored on the injection orbit. The longitudinal Schottky–signal of the coasting beam was still observed five hours after injection. At the end of May electron cooling was successfully applied to a coasting beam of Ar^{+18}–ions at 92 MeV/u. The relative momentum spread in the beam could be reduced from initially 1×10^{-3} to 3×10^{-5}.

1. Status of the ESR

At the beginning of the ESR–commissioning on March 5, 1990, the ring installation included the 320 keV electron cooler, the internal gas jet target and special devices for in–ring experiments (particle detectors, 50 μm–stainless steal windows for X-rays and some glass windows for laser light).

The 20 main quadrupole magnets supplied by 10 independently controlled power supplies, and the 6 bending magnets fed in series by a single supply had been operated during several month of power supply commissioning and magnetic measurements [3]. In addition, independent supplies are provided for twelve horizontal orbit correction coils, eight vertical orbit correction magnets, and eight sextupoles for chromaticity correction in both phase planes.

All components for beam injection and extraction are ready for use: Three septum magnets for the injection and two extraction channels, the 150 kV–electrostatic wire septum for slow beam extraction to the target hall, and the 3–module ferrite kicker used for both injection and fast ejection back to SIS.

One of two rf-cavities (h = 2) was ready for operation at the end of March. It provides a gap voltage amplitude of 5 kV in the frequency range 0.85 MHz to 5.5 MHz.

For the first turn diagnosis two beam profile grids and two beam current blocks are installed. Measurements of the coasting beam current and calibration of other beam signal sources can be made by using the beam current transformer which – in its present state – resolves beam currents as low as 10 μA within a bandwidth of a few kHz. Longitudinal and transverse beam bunch signals are available from 14 capacitive pick-up stations, each equipped with two pairs of probes for horizontal and vertical beam position measurements. In addition, the useful apertures can be defined by movable copper bars (beam scrapers). Two scraper pairs are provided for the horizontal, one single scraper for the vertical aperture.

For picking up longitudinal and transverse Schottky signals the probes of one pick–up station are equipped with tunable receiver circuits by means of which the maximum sensitivity can be shifted close to a harmonic of the circulating frequency of beam particles. The determination of betatron tunes and chromaticities can be made by means of a longitudinal and transverse rf-exciter, which enables to measure corresponding beam transfer functions via a network analyzer.

After two weeks of ion–pumping an average vacuum pressure of 2×10^{-9} mbar was attained before baking out. After baking at 150°C and activating all titanium pumps it was reduced to slightly below 1×10^{-10} mbar.

The electron cooler [5] had been completely assembled somewhere outside the ESR–cave and moved to its position in February. Thus, at the beginning of ESR–commissioning, it served only as part of the UHV–system. During March the remaining cabling and installation work for the electron cooler was done. Within the eight weeks from first switching on the electron current could be raised step by step to 1 A at an accelerating voltage of 50 kV. So far, the attainable voltage is limited by Penning discharges in the gun and collector parts of the cooler. Improvements are expected after another baking procedure, but then at the design temperature of 300°C.

The internal jet apparatus is completely installed, but the commissioning of the device was delayed so far by repeated failures of turbomolecular pumps. Since two weeks, all 10 pumps are working without interruption and tests with the jet will be started as soon as possible.

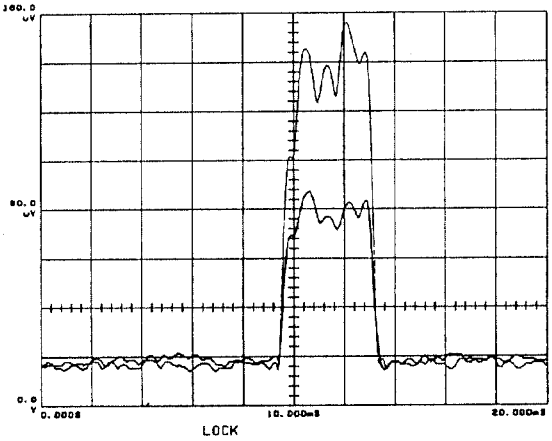

Fig. 1: 27 MHz beam signal from capacitive probes in ESR.

Narrow band analysis of the bunch structure in the Unilac beam can be utilized for measurements of mean beam positions along the first turn orbit in the ESR. In fact, our measurements were disturbed by strong changes of the beam current within the time between consecutive signal records from related probes.

2. Beam injection and storage

First beam injection to the ESR and transport over a full turn took place on March 8, 1990. A Ne^{+3}–beam at the prestripper energy of 1.4 MeV/u from the Unilac was transported without major difficulties over half a turn of the SIS and bent by several orbit correction coils into the extraction channel of the synchrotron. A major fraction of the scheduled beam time was spent for the very first test of the beam transport line from SIS to ESR, which at this time was equipped with very preliminary beam diagnostics. Hence, it was difficult to optimize transmission to the ESR and to adjust beam position and direction at the injection septum magnet.

Primary results of the beam transport test were that first there was obviously no obstacle in the useful aperture of the ring, but secondly all main quadrupole magnets had systematically the wrong polarity. The attempt to determine mean beam positions by measuring amplitudes of the 27 MHz time structure in the beam with narrow bandwidth (see Fig. 1) was not successful. The systematic errors caused by strong variation of the beam current within consecutive measurements were too large. On the other side, simultaneous recording of signals from correlated probes within a pair were not possible.

On April 4th, long term storage of SIS–bunches of Ar^{+18}–ions at 200 MeV/u with a half intensity beam life time of about 30 min could be attained. A longitudinal Schottky–signal from stored ions was detected even 5 hours after injection (see Fig. 2). During this long time a shift of the mean frequency of the Schottky band was observed which is consistent with the estimate of the loss of mean energy in ionization and excitation collisions with residual gas molecules at an average pressure of about 1×10^{-10} mbar. The best value for the bunch transmission between SIS (circulating) and ESR (stored) was 30% (see Fig. 3), according to a circulating current of approximately 100μA. Assumed that the nominal particle energy of 200 MeV/u is correct, we deduce from the mean frequency of the Schottky signal that the closed injection orbit is about 200 mm longer than the central orbit of the ESR (108 360 mm±5 mm). The FWHM of the momentum distribution after free debunching is found to be close to 1×10^{-3}. A first horizontal BTF-measurement yielded $Q_h \approx 2.36$ which is near the expected value for the central orbit.

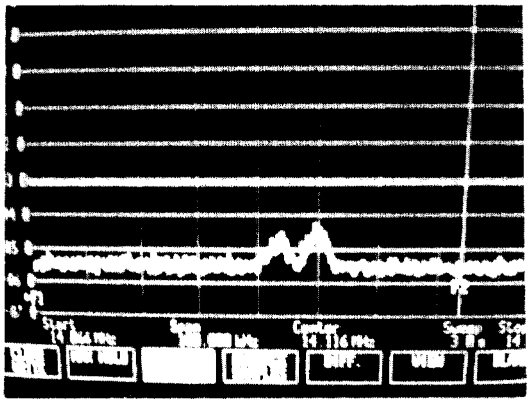

Fig. 2: Longitudinal Schottky–spectra from coasting Ar–beam. The band on the right comes from the coasting beam immediately after injection and free debunching, that on the left side from the beam after 1.5 hours storage. The frequency shift of about 6 kHz is due to the loss of mean momentum $\Delta p/p \approx 1 \times 10^{-3}$ by the interaction of beam particles with residual gas molecules.

The following scheduled commissioning times with Xe^{+48} and Ar^{+18} beams at 92 MeV/u aimed at beam storage and consecutive electron cooling. A major task was to learn first how to inject and store the beam in the presence of the solenoid and toroid fields of the cooler and to provide suitable orbit corrections simultaneously for both the injected beam and the stored beam. Because of numerous failures in the beam transport systems only a few hours of useful beam time was left for this purpose, not enough to be successful.

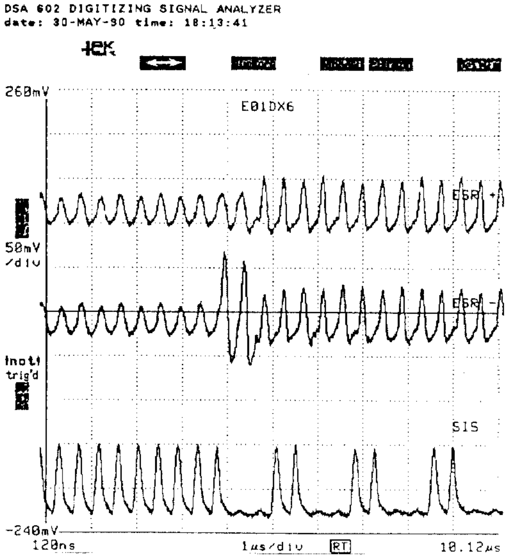

Fig. 3: Transfer of two beam buches from SIS to ESR. The lower SIS-curve show that two out of four buches are transfered to the ESR, the remaining two bunches continue circulating in SIS. The upper curves come from capacitive probes of the first horizontal pick–up station E01DX6 after the injection septum. They start with bunch signals from the preceeding shot because, in the shown case, bunch–to–bucket transfer was tested. Bunch signals from the first turn are characterized by a significant difference of signal amplitudes for ESR- and ESR+, i. e. by a beam position strongly outside the central closed orbit, whereas the orbit of the stored bunches (following bunch signals) is found to be nearly central. This is expected because of vanishing dipersion function at E01DX6.

3. Electron Cooling of Stored Beam

An important step in ESR commissioning was done two weeks ago with an Ar^{+18}–beam at 92 MeV/u. On May 30, 1990, the beam was stored and cooled by 1A electrons at 50 keV. Fig. 4 shows that the initial width of the momentum distribution in the beam of 1×10^{-3} was reduced in the first attempt to 1×10^{-4}. However, the cooling time with respect to the initial momentum distribution and to the given density of the electron current was initially found to be 15 s, i. e. a factor 20 longer than expected for ideally aligned beams. Thus, in the following two days, we tried to improve the horizontal orbit corrections for the ion beam in order to get better collinearity with the cooler electron beam. The cooling time could be reduced by a factor two by this way. The equilibrium relative momentum spread in the stored beam after cooling was as low as 3×10^{-5} (see Fig. 6).

Now, it was possible to use the electron cooler for acceleration and deceleration of the stored beam within small intervals. In parallel, measurements of betatron tunes Q_h and Q_v as a function of the mean momentum were performed using the BTF–method as mentioned above. A corresponding plot is given in Fig. 5. After evaluation of a first series of experimental Q_h-values within a $\Delta p/p$-interval of 0.6% we found a strong non–linearity in the correlated chromaticity function ξ_h. A possible explanation might be the fact, that the injection orbit used so far for long term storage passes through inhomogeneous parts of the 60^0-bending magnets. The elimination of this effect by means of pole face windings will be one of the next steps in ESR-commissioning.

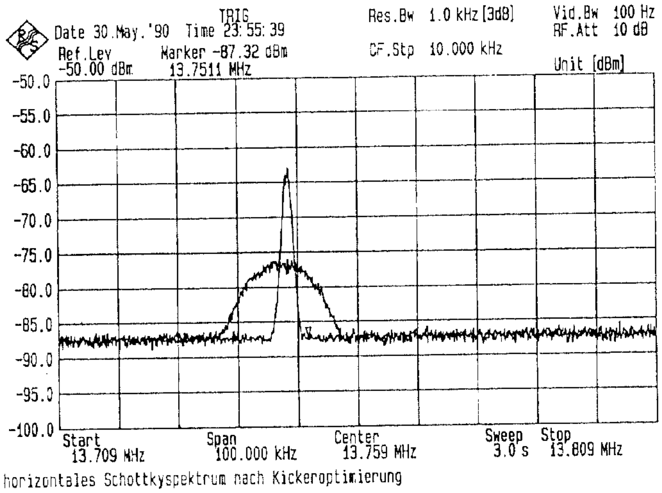

Fig. 4: First electron cooling of Ar^{+18}-beam at 91.8 MeV/u.

The longitudinal Schottky-spectra of uncooled (wide band) and cooled (narrow band) at 12th harmonic of the revolution frequency are shown. Assuming the theoretical value for $\gamma_t = 2.6$ the relative momentum spread (in the logarithmic scale the full width at 3 dB below the maximum) is reduced from initially 1×10^{-3} to 1×10^{-4}. The time necessary to reduce the spread to half of the initial value was approximately 15 s.

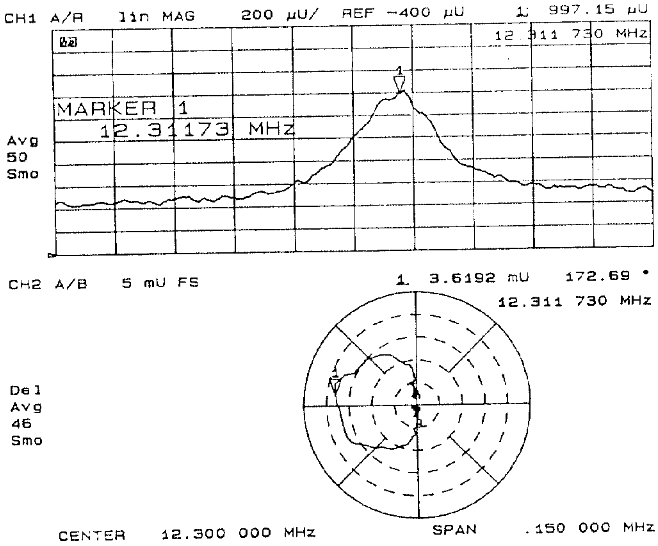

Fig. 5: Horizontal beam transfer function.

The network-analyzer plot shows in the upper part the power amplitude as a function of the exciter frequency in the vicinity of the upper horizontal sideband of the 11th harmonic. The lower diagram shows the corresponding BTF in a polar plot. The betatron tune is determined by the frequency difference between upper and lower sidebands.

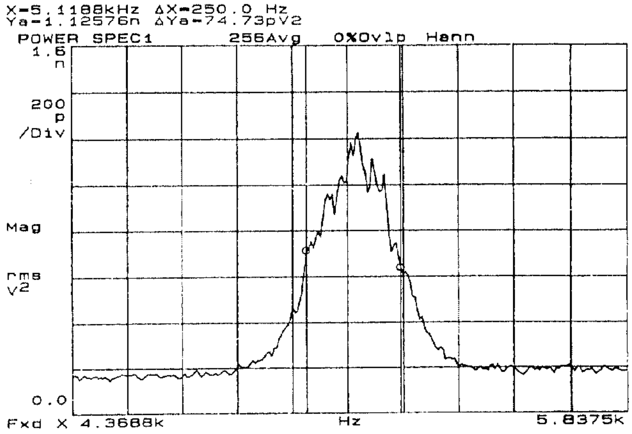

Fig. 6: Longitudinal Schottky-spectrum after improved cooling.

The FFT-spectrum of the coasting beam at 12th harmonic was obtained after symmetrization of horizontal orbit corrections on both sides of the cooler. The momentum spread at the 3 dB-level is 3×10^{-5}.

4. Conclusion

This contribution gives a report on the very first steps in the commissioning of the ESR. We are far from knowing well enough the real values of the most necessary parameters of the ring as, for instance, closed orbits, betatron tunes, chromaticities etc.. But we feel happy that, in spite of our poor knowledge, we could do some important steps in a short time. In this sense, design and technical realization of the ESR seem to have their result in a well-behaved, forgiving instrument. Thus, we are hopeful that the design goal, namely to do excellent, novel in-ring experiments, might be approached within the coming months.

Acknowledgement

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