Measurement and Tuning of Beam Parameters in the Heavy Ion Storage Ring ESR

F. Nolden, S. Baumann, K. Beckert, H. Eickhoff, B. Franczak, B. Franzke, O. Klepper, W. König, U. Schaaf, H. Schulte, P. Spädtke, M. Steck, J. Struckmeier,
GSI, Postfach 110552, D-6900 Darmstadt, Germany

Abstract

The ESR is a cooler ring with large momentum acceptance $\Delta p/p_0$ of about 2.5 %. We could bound the Q variation in both transverse planes to less than 0.02, thereby allowing for rf stacking over the large momentum range without crossing resonances up to the fifth order. Tunes are measured very accurately in cooled beams via the BTF technique. The field quality in the large dipole magnets was improved by the excitation of pole face windings, leading to an improved linearization of natural chromaticity. Linear coupling due to large solenoid fields in the electron cooler could be detected and was then corrected by auxiliary solenoids installed in the vicinity of the cooler. Momentum compaction was determined by comparison of the cooler voltage and the measured revolution frequency. Transverse beam dimensions are measured by means of position sensitive detection of ions that captured an electron in the cooler.

1 Introduction

The experimental storage ring ESR is dedicated to experiments with heavy ion beams [1]. Beams are accumulated via rf stacking of bunches from the heavy ion synchrotron SIS [2], cooled in an electron cooler [3], and are then used for several types of in-beam experiments. There will also be a slow extraction to the experimental areas at GSI and a fast reinjection back into the SIS.

Commisioning of the ESR began in early 1990. Here we report on how important beam parameters were measured and set.

2 Schottky and BTF Diagnostics Hardware

Schotkky and BTF diagnostics is employed as a tool for the measurement of longitudinal distribution functions, synchrotron frequencies, longitudinal and transverse machine impedances, and betatron tunes.

The necessity to observe low-velocity ($\beta < 0.1$) as well as moderately relativitic ($\beta = 0.75$) beams led to the choice of an electrostatic pick-up. By means of a tunable cable resonator, the signal-to-noise ratio of the Schottky signal can be enhanced in a chosen freqency band. The exciter is a quarter-wave kicker. It is used in the BTF measurements, as well as for beam excitation by rf noise with simultaneous electron cooling, in order to measure and optimize the cooling force. Typical frequencies are 30 MHz, the amplifiers work up to 100 MHz.

The instrumentation in the control room consists of an analog spectrum analyzer, a network analyzer, a digital Fast Fourier Transform analyzer (FFT), and various signal sources. All of these are connected to a computer providing automatic measurement procedures, data analysis, and graphic processing. The analog spectrum analyzer is a general, easy-to-use tool for the observation of processes like storing, stacking, energy-loss measurements with internal target, etc. The network analyzer is used for BTF measurements. For measurements with very good frequency resolution we use FFT processing. Image reject mixers (IRM) provide a unique mapping into the FFT working range of 100 kHz. FFT measurements are both faster and more sensitive than analog ones. The FFT is also used as a source of well-defined noise.

3 Tune Measurements with Cooled Beams

Tunes are measured via the technique of the tranverse BTF which has maxima at the first horizontal sidebands of the revolution frequency $\omega(p)$

$$\omega_{x,z}(m,p) = (m \pm Q_{x,z}(p))\,\omega(p) \qquad (1)$$

By means of electron cooling, the momentum width $\Delta p/p$ of the beams is easily cooled down to values of $2 \cdot 10^{-5}$. With the same precision the momentum can be set by variation of the cooler voltage. The revolution frequency $\omega(p)$ is determined by standard Schottky diagnosis. The error of the Q measurements is at most

$$\Delta Q_{x,z} = \sqrt{2} m \eta \frac{\Delta p}{p} \qquad (2)$$

if the BTF's and revolution frequencies are measured around the same harmonic m. Even for m=20, the typical error $\Delta Q_{x,z}$, measured with a beam cooled by electrons, is no larger than 10^{-4}, which is very convenient. The method still works at currents below 10μA. There is a computer-controlled semi-automatic searching procedure for a fast mapping of the working point in the interesting momentum range.

4 Quadrupoles, Sextupoles, and Pole Face Windings

The large ESR momentum acceptance ($\approx 3\%$) facilitates rf stacking, and it allows for the simultaneous storage of beams with different charge states, for example fully stripped and hydrogen-like beams of ions with $Z > 33$. To avoid beam loss, the machine must be operated over the full momentum range in a region free from disturbing betatron resonances.

The 20 quadrupole magnets of the ESR are fed in pairs by 10 different families of power supplies. Tunes and values of the dispersion function at important locations (i.e. at the internal target and the electron cooler) can be set independently, provided a correct ion optical model of the machine. One important mode of operation has a vanishing dispersion function at both the cooler section and the internal target. In that case we use the the neighbouring quadrupole dublets to change the working point without affecting the dispersion function elsewhere.

Chromaticity is corrected by means of 8 sextupoles, each with its own power supply.

The design width of the good field region in the dipole magnets is 220 mm. As we intend to operate the magnets at low excitation as well as close to saturation, the form of the remaining field error depends on the field level. In order to minimize higher order multipoles, the dipoles are equipped with 24 pole face windings which can be set independently.

5 Control of Betatron Tune Variation

In our first storage experiments, we excited neither the sextupoles nor the pole face windings. Due to

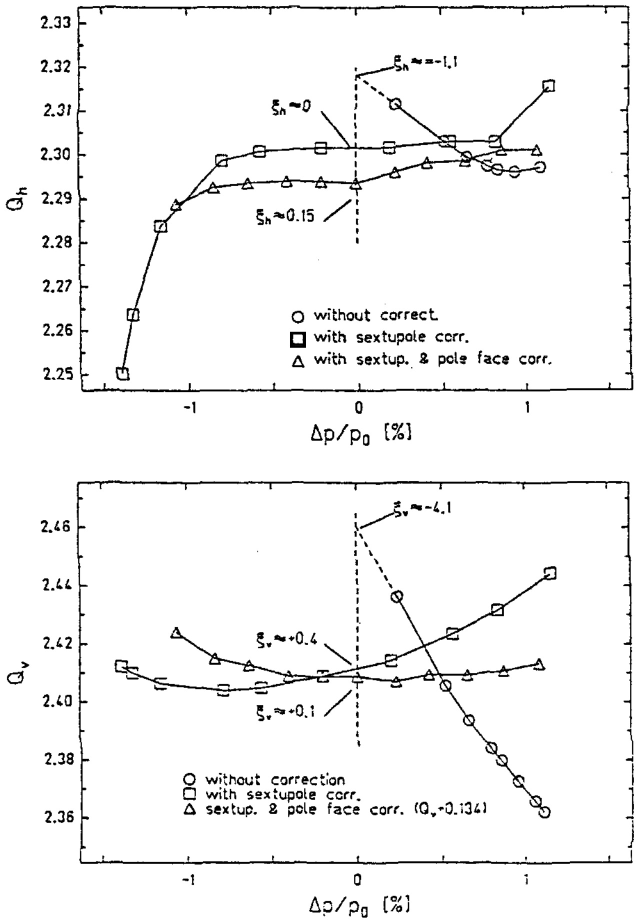

Figure 1: Q_x and Q_z vs. $\delta p/p_0$ measured with different settings

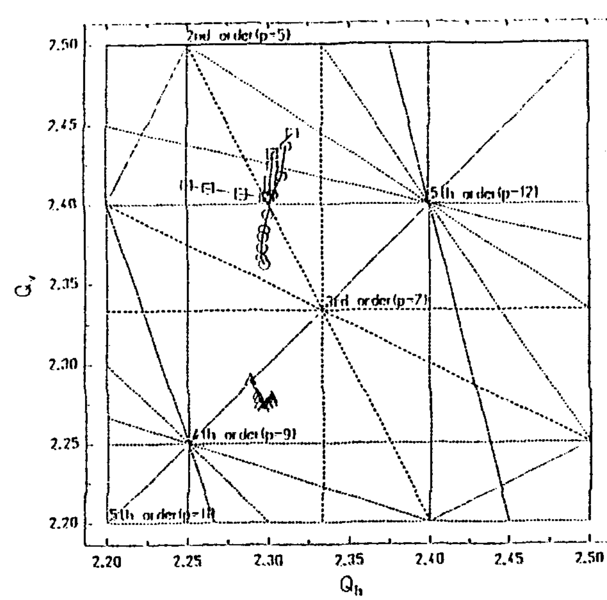

Figure 2: Resonance diagrams at the different settings

natural chromaticity, it turned out to be impossible to cover more than 1 % of momentum range without hitting fatal resonance lines (see fig. 1). With the notation (m, n, p) for the resonances

$$mQ_x + nQ_z = p \tag{3}$$

strong beam loss occurred around the third order sum resonances (3,0,7), (2,1,7), and (1,2,7). This is not surprising as the toroidal fields in the electron cooler section are considerably non-linear with respect to the ion beam closed orbit. With appropriate sextupole current settings, we reduced the chromaticities

$$\xi_{x,z} = \frac{\delta Q_{x,z}(p)/Q_{x,z}(p_0)}{\delta p/p_0} \tag{4}$$

to values $|\xi_{x,z}| < 0.1$ for orbits near the center of the horizontal aperture. However, there remained a considerable Q variation at the aperture limits. Using tables from magnetic measurements, by excitation of the pole face windings we limited the excursion of the working point over the momentum range of 2.2 % inside limits $|\Delta Q_{x,z}| < 0.02$ in a region which is free from resonances up to the fifth order. As soon as the working point approached the coupling resonance $Q_x = Q_z$, vertical betatron sidebands appeared in the horizontal BTF. We got rid of these lines by tuning the current in the solenoids installed closely in front of and behind the electron cooler. These solenoids correct for the coupling due to the main solenoid that guides the electron beam in the cooler.

6 Frequency Dispersion And Momentum Compaction

With beams cooled in an electron cooler, it is possible to determine experimentally the frequency dispersion η and the momentum compaction factor α_p to an absolute accuracy of better than 10^{-2}. The basic relationship involved relates the off-momentum $\delta p/p_0$ to both the variation of effective cooler voltage δU and the corresponding change $\delta\omega$ in revolution frequency

$$\frac{\delta p}{p_0} = \frac{1}{\beta^2}\frac{e\delta U}{\gamma m_e c^2} = \frac{1}{\eta}\frac{\delta\omega}{\omega} \tag{5}$$

where m_e is the electron rest mass. The momentum compaction factor is

$$\alpha_p = \eta - \gamma^{-2} \tag{6}$$

Typical α_p values in the ESR are around 0.16. The electron energy inside the beam depends on the degree of space charge depression, which can be deduced from measurements of the revolution frequency as a function of electron current.

7 Transverse Width of Cooled Beams

In beams cooled by electrons it is hardly possible to detect any tranverse Schottky signals. For the measurement of transverse beam dimensions we detect ions that captured electrons in the cooler by means of a position sensitive gas detector installed inside the chamber of the dipole after the cooler.

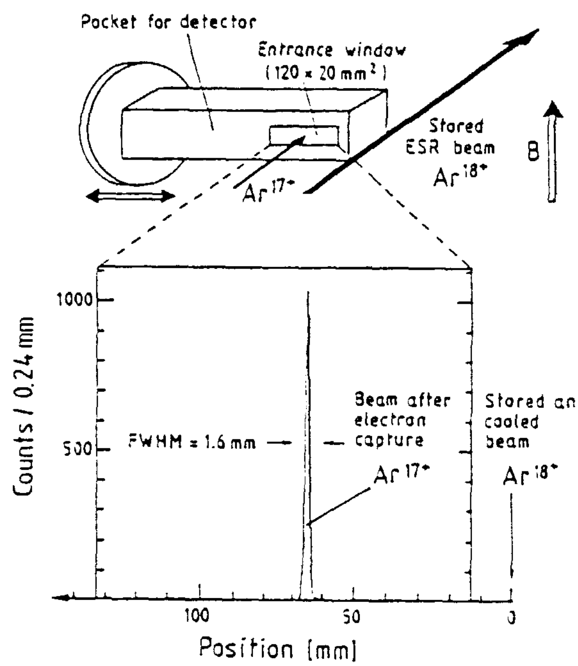

Figure 3: Measuring the Transverse Width of Cooled Beams

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