FIELD MEASUREMENTS OF THE ESR MAGNETS.

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ABSTRACT

A short summary of the magnet systems in the Experimental Storage Ring ESR is given, including the Electron Cooling device. The methods are described which were applied for field measurements and the results are presented.

INTRODUCTION

The Experimental Storage Ring ESR of GSI (Fig. 1) is an instrument to store, cool and accumulate either highly stripped ion beams accelerated in the Heavy Ion Synchrotron SIS or beam fragmentation products analyzed in the Fragment Separator FRS halfway between SIS and ESR. Circulating beams will interact with an internal gas jet target while electron cooling sustains beam quality. Beams can be also extracted and transfered to external target stations. The maximum beam rigidity is 10 Tm and corresponds e.g. to fully stripped Uranium ions of 550 MeV/u. The ring circumference is 108 m.

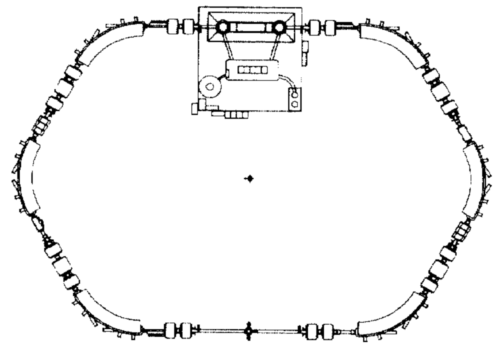

Fig.1 Layout of the storage-cooler ring

THE MAGNET SYSTEMS OF THE RING

Beam bending is established by six equal dipoles. Their maximum field strength is 1.6 T. As a consequence of their C-structure and of the large aperture, 100×300 mm², the weight of each is 90 to. For an easy handling the yokes are, therefore, subdivided along the beam direction into four segments. The good field region is 220 mm. Beam Focussing is done by four long (1.17 m) and 16 short (0.75 m) quadrupoles of equal cross-section. Their circular aperture is 256 mm, their hyperbolic good field region 350 mm. The maximum field gradient is 6.2 T/m, the weight 16 to and 11 to, respectively. The eight chromaticity sextupoles have an aperture of 320 mm, their length is 0.34 m, the weight 800 kg, and their field corresponds to $B'' = 14$ T/m². Furthermore the ring includes three septum magnets and three kicker modules for injection and extraction, and vertical correction magnets.

The magnetic components of the Electron Cooler are the cooler solenoid, 2.5 m long, gun- and collector solenoids, 1.1 m each, and two pairs of toroid sectors which bend the electron beam by 90° into and out off the ion beam direction, respectively. The aperture of all magnets is 500 mm. The design field strength is 0.25 T. Fields in the regions of transition between solenoids and toroids are optimized by short solenoidal trim coils. Dipole coils in the toroids supress electron beam drift perpendicular to the bending plane, dipole coils in the solenoids are used to steer the electron beam direction. A carefully designed additional correction coil minimizes field errors in the cooler solenoid. The total weight of the magnets is 14 to. Finally, two compensating solenoids in front of and behind the system cancel out phase space rotation of the ion beam which is caused by the Cooler.

THE MEASUREMENT SYSTEMS

We used five equipments to verify the field quality: a three-dimensional measuring machine (the Mapper) to get field maps of the dipole magnets and of the cooler magnets, and to check overlapping fringe fields of a quadrupole/ sextupole/steerer group of the ring; secondly, a long gradient-coil system to test quadrupoles and to optimize their pole end piece structure; a rotating coil equipment for the harmonic analysis of quadrupole and sextupole fields; a Hall probe moved on a small circle around the axis of quadrupoles and sextupoles to determine subharmonics which, if present, would cause a mismatch between the magnetic and mechanical axes of the magnets; finally a system to detect the local field harmonics along the axis of the cooler solenoid during winding the correction coil.

The Mapper consists of a large granite table on a support subframe, two longitudinal slideways for the x-direction and one for the y- (vertical) and z-direction, respectively. The movable parts are on air bearing shoes. The linear scan range is $2.7 \times 1 \times 1$ m³, the resolution is 1μm (if room temperature is kept constant). The probe head with three Hall probes (Siemens SBV 613, orthogonal to each other) is mounted on a long probe arm made from carbon fiber epoxy.

The quadrupole measurement facility uses two 2.6 m long gradient coils. One of these is fixed along the axis of the reference magnet, the other one can be positioned radially and vertically by synchronous motors in the quadrupole aperture to check the gradient homogeneity. Both coils can be turned by $\pm 180°$ around their axes. The system allows an immediate comparison of the magnets with the reference element by integration of the difference of the induced voltages.

Multipole analysis was done with a single rotating pick-up coil which is radially oriented. Its length is 2.5 m, the radius 120 mm. 41 voltage scans were taken per revolution and digitized in a 12bit storage ADC. The mean values of ten turns then were submitted to a Fourier analysis. Rotation frequency was adjusted to make full use of the ADC range. The resolution is 2×10^{-4} relative to the main amplitude.

To save time during the series measurements we did not attempt an alignment of the pick-up coil in the magnets better than

±1 mm. Therefore, the subharmonics (dipole amplitude for quadrupoles, dipole- and quadrupole amplitudes for sextupoles) have large systematic errors and can not be used for a determination of the magnetic axes. To get in a quick way the subharmonics a Hall probe was fixed near the axis of a non-magnetic cylinder which fits tightly between the poles of the magnets. The probe is radially oriented and measurement of the flux densities opposite the four (or six) poles is sufficient to get the subharmonics. Distances between magnetic and mechanical axes could be determined in that way with an accuracy of 50 μm.

A similar system was used to determine the local field distortions along the cooler solenoid. The radially oriented probe could be moved on a slide way along a rigid aluminium tube through the solenoid. The tube, in turn, could be rotated around its axis. We took 11 field scans per revolution. Fourier analysis has given us the harmonics as a function of the position in the coil. Knowing amplitudes and phases it is possible to eliminate each multipole with the help of a single set of correcting windings by a proper choice of the local number of windings and their orientation. The absolut term of the Fourier analysis may have three reasons: either the solenoidal field varies along the axis ($B_{rad} \sim dB/dz$), or the probe is not perfectly adjusted perpendicular to the main field direction, or the electronic has an offset value. Dipole-, quadrupole-, sextupole amplitudes are not seriously affected by these error sources.

RESULTS

The measurements of the dipoles were done with the help of the mapper. Work had to be done in three different positions along each magnet because of the limited length of the mapper. Fig.2 displays the field distribution at a low and a high field level showing the dips caused by the 20 mm gaps between the four magnet sectors. Fig.3 shows the flatness of the effective field boundary at the magnet ends. Equalizing its absolute position for all dipoles was done by a proper choice of the number of thin laminations behind the demountable pole end pieces. The effective bending radius was so adjusted to 6.324 m at 1.0 T. For 1.6 T it shrinks to 6.298 m. Fig.4 shows the radial field homogeneity at low and high field levels. Measurements with the pole face windings in action could not yet be done, they will be supplemented during the shut down in autumn. The field quality will then be 0.02% in 220 mm for all field levels.

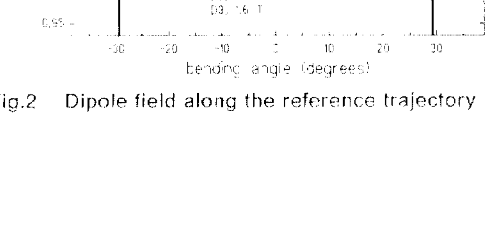

Fig.2 Dipole field along the reference trajectory

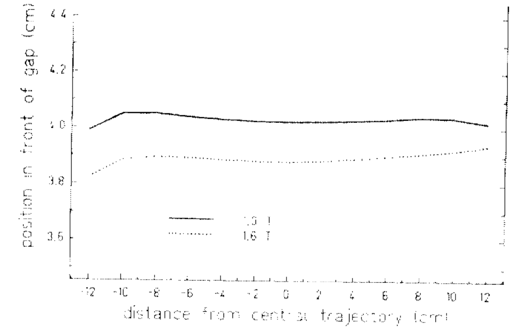

Fig.3 Effective field boundary of the dipoles

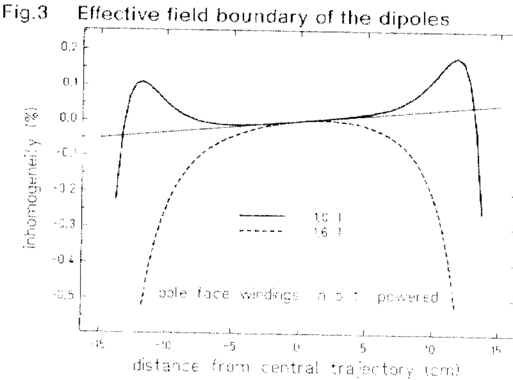

Fig.4 Radial field homogeneity of the dipoles

Figures 5 to 8 show results obtained from the quadrupoles. Field quality is the same for the short and long magnets. The effective lengthes are 0.835 m and 1.255 m, and shrink for the highest field level by 1.0% and 0.5%, respectively. A mapping of a quadrupole with a neighboured sextupole (Fig.8) showed that by screening the length is reduced by 1.3 cm. The difference between magnetic and mechanical axis was only in a few cases larger than 0.1 mm. This was taken into account during alignment in the ring.

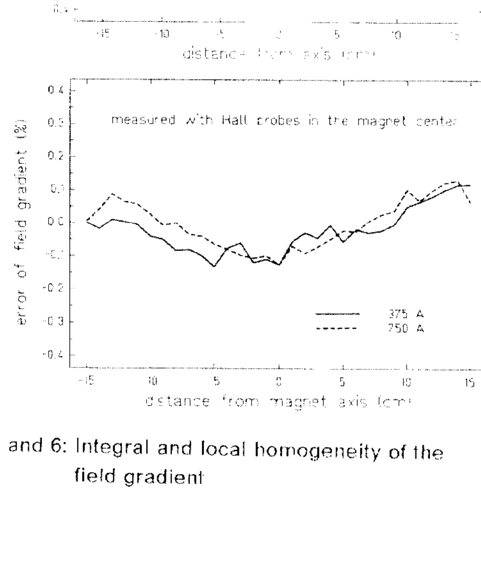

Fig.5 and 6: Integral and local homogeneity of the field gradient

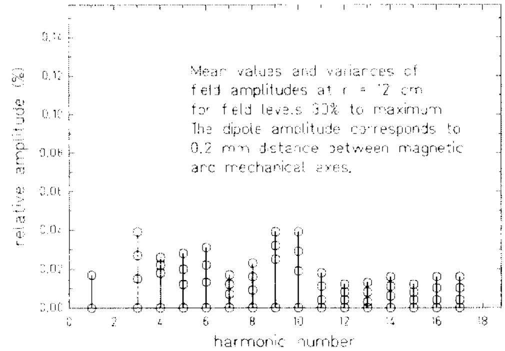

Fig.7 Spectrum of harmonics in the quadrupole

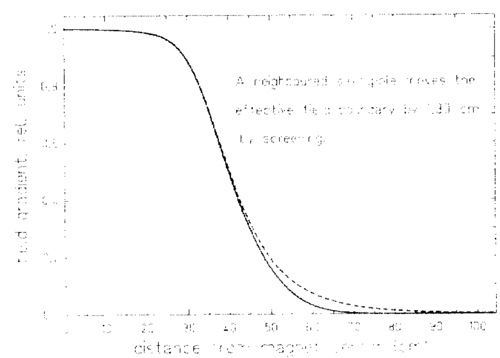

Fig.8 Fringing field of the quadrupole

The spectrum of the sextupoles is shown in Fig.9. No chamfer of the pole ends was done. The amplitude of the first systematic harmonic (0.6%) will not to harm ion optical behavior of the ring. The effective length is 347 mm.

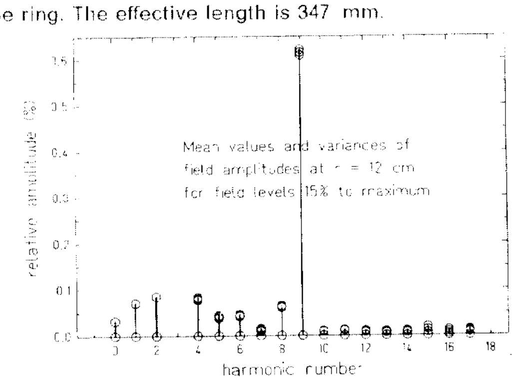

Fig.9 Spectrum of harmonics of the sextupole

The transition from the cooler solenoid field to the toroid field was optimized with the help of the trim coils according to $B_z = B_0/[1+(z-z_T)^2]$. z_T is the coordinate where toroid starts [1]. The result is shown in Fig.10. Radial flux densities caused by z-dependence of the axial field in the cooler solenoid are small and well inside the spezified upper limit (Fig.11). The dipole field error in the cooler could be flattend by the correction coil to $\pm 2.5 \times 10^{-4}$. An offset of 2 G of the vertical component is probably due to unavoidable alignment imperfections (Fig.12). During cooling operation such errors can be balanced by steerer coils. Fig. 13 shows the quadrupole field error which is negligible in the region useful for cooling (2 m); the same is true for higher harmonics.

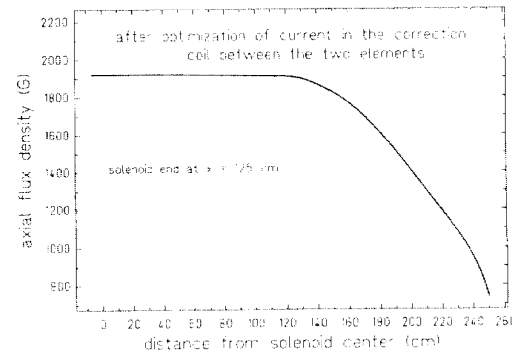

Fig.10 Axial flux density in cooler solenoid and toroid

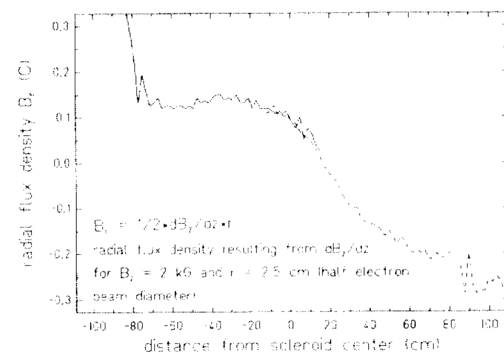

Fig.11 Radial flux density in the cooler solenoid

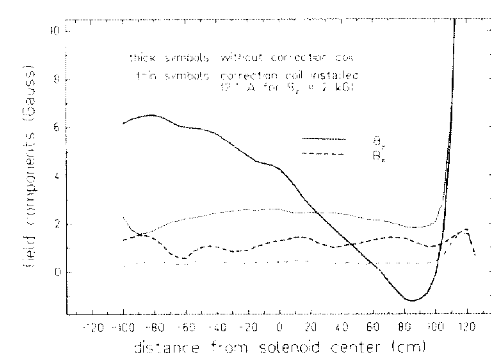

Fig.12 Dipole field error of the cooler solenoid

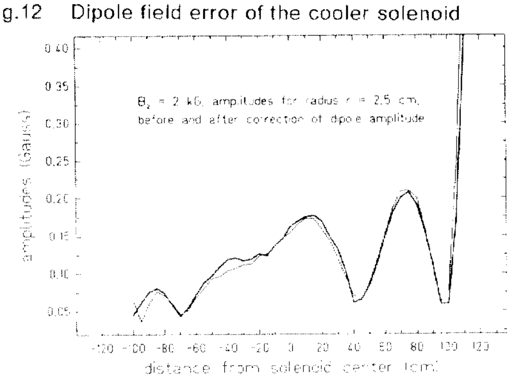

Fig.13 Quadrupole field error of the cooler solenoid

[1] A. Wolf et al., Field Measurements in the Electron Cooling Device for LEAR, CERN EP Internal Report 84-1.