THE MAGNETSYSTEM OF THE TSR

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Summary

The heavy ion test storage ring TSR [1] is an experimental facility for accelerator, atomic and nuclear physics studies at the Heidelberg MPI. The machine is designed for HI beams of up to 30 MeV/u at a charge to mass ratio of q/A = 0.5, corresponding to a magnetic rigidity of $B\rho$ =1.5 Tm.

The main magnet system is composed of 8 dipole and 20 quadrupole magnets. The yokes are fabricated from stamped laminations 1 mm in thickness. The dipole magnets have a gap of 80 mm in hight while the core length is 880 mm, the cross section being of C-type. The quadrupole magnets with bore radius of R = 100 mm and core length of 250 mm are laminated as well. The poles are of hyperbolic shape.

Field properties of all these magnets have been determined by using temperature stabilized Hall probes while multipole analysis was performed by a Morgan coil [2].

First test in May 1988 resulted in storage of a $^{12}C^{6+}$ beam of 73.3 MeV. The beam lifetime (1/e) of 60 s was limited by the vacuum of $\sim 10^{-9}$ mbar at that time.

Introduction

At the MPI construction of a heavy ion storage ring was started in 1985. Utilizing electron cooling and laser cooling for phase space compression, the ring will store HI beams with extreme low emittance and energy spread. Thus being essential for atomic physics experiments as well as searching for collective phenomena in the beam as cristallization [3]. The ring is of a four fold symmetry, Fig. 1. The lattice being of a FP = ODFBFBFDO type with two antisymmetric focussing periods FP forming one out of two superperiods. This unconventional lattice structure allows for 4 long straight sections of 5.2 m each in the compact geometry of the 55.4 m circumference of the ring. This free space is devoted to the injection components and a rf cavity as well as for the electron cooler and experimental area.

In the present paper the main magnets of the TSR are described and the results of magnetic field measurements are presented.

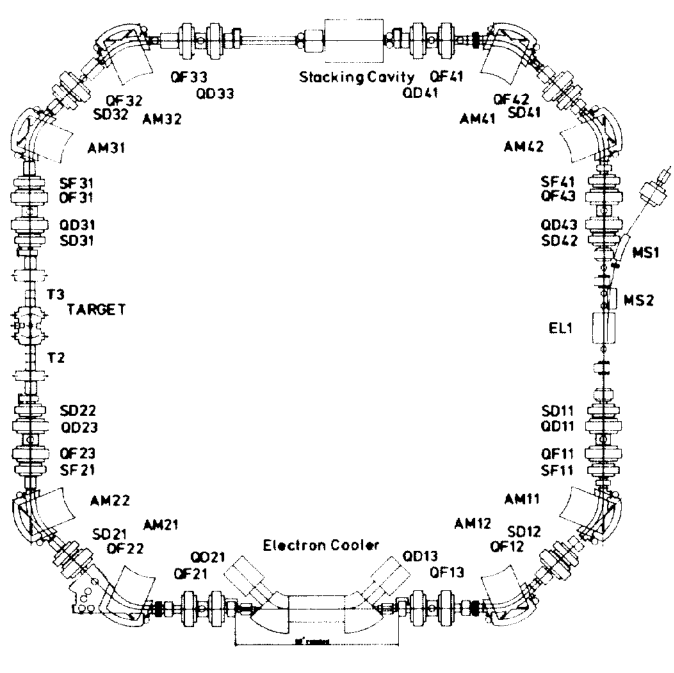

Fig. 1 Layout of the heavy ion storage ring TSR with its main components. The labels designate: AMX dipole magnets, QDX, QFX quadrupole magnets, SDX, SFX sextupole lenses, MSX magnetic septa, EL1 electrostatic septum.

Magnets for TSR

The main ring magnets of the TSR are 8 dipole and 20 quadrupole magnets. The required usefull aperture for the ring magnets is typically 200 x 55 mm^2 in the bending magnets as well as in the focussing quadrupoles. The reason for that large apertures is to realize multi charge state mode of operation, that is storing of ions in different charge states simultaniously (e.g. $^{127}J^{45+}$ to $^{127}J^{47+}$) in the ring. Aperture requirement for normal operation is much relaxed - even when low intensity beams have to be accumulated by combined stacking into transversal and longitudinal phase space (multiturn injection and rf stacking).

Fig. 2 TSR dipole magnet after installation into the ring.

These conditions determine the gap in the dipoles to be 80 mm taking into account additional space for vacuum chamber and thermal insulation for 300° C bake out of the machine essential to obtain UHV ($P < 10^{-11}$ mbar) in the TSR. This vacuum being necessary to achieve adequate storage times even for partially stripped HI beams.

As the ring is designed to change beam energy at an rate of dB/dt = 0.16 T/s for the dipoles the yokes are made of stamped laminated steel of 1 mm thickness to reduce eddy current effects. The steel used is of V1400-100A quality insulated with an epoxy resin Stabolit 70 [4]. The laminations are of C-shape to have access to the beam even in the gap.

The large sagitta of 87.5 mm is resulting from the small bending radius of $\rho = 1.15$ m. Although this value is reduced by about 9 mm due to the integral effect of the long ranging fringe fields the pole width gets very large for a box magnet. Therefore the yokes were manufactured with a radius of curvature equal to ρ. Figure 2 shows a photograph of a TSR dipole magnet after installation in the ring.

The plane parallel poles of the magnet are without any shims. The pole width is 520 mm to ensure homogeneity $\Delta B/B < +/- 2{*}10^{-4}$ perpendicular to the beam's orbit in order to achieve small betatron amplitudes ($\Delta x_{rms} < 2$ mm) due to field errors of the magnet. The pole ends are shaped according to Rogowski's profile [5] by approximating the exponential by six straight cuts. The shape of this shim was determined by the use of the computer code POISSON [6].

A TSR quadrupole magnet is shown in figure 3. The lenses are "figure of eight" type. The yoke is made from 250 1 mm thick laminations completely glued, giving a mechanical stable solution to the four quarters, which are clamped together.

The pole shoes are shaped according to a pure hyperbola, the pole width is 122 mm, the aperture radius R = 100 mm.

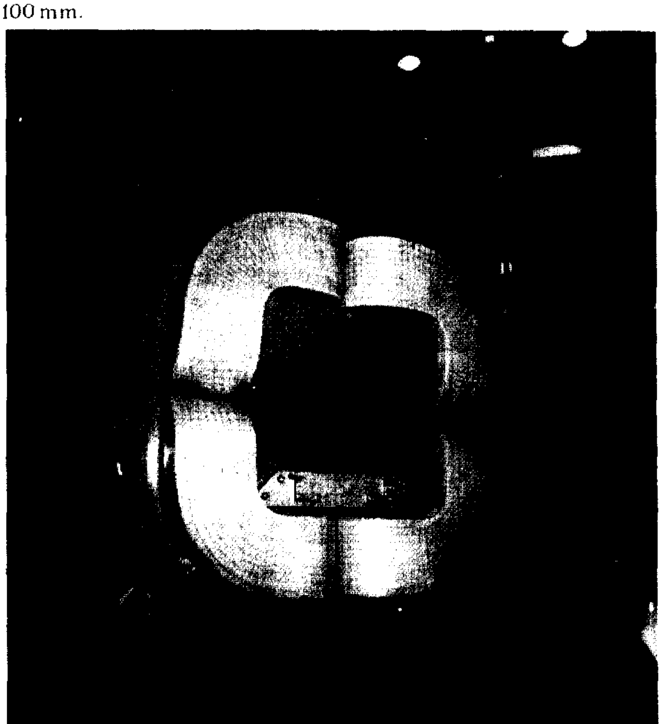

Fig. 3 Quadrupole magnet in the heavy ion test storage ring

To ensure a +/- 100 mm flat region of effective length of the quadrupole magnet a roll off profile is applied to the pole ends consisting of a 15 mm cut of 45° with respect of the beam axis.

Though there are five individual families in the TSR all quads are made identical in shape in order to reduce the costs having a common maximum gradient of 7 T/m.

Field Measurements of Magnets

For measuring the radial field of a TSR dipole a computer controlled x-y table was used allowing to cover an area of $2 * 1$ m^2 thus giving the possibility to map a complete magnet including the fringe fields. For field mapping an InAs Hall probe (Siemens SBV 601-S1) was used which was temperature stabilized within $\Delta T < +/- 0.3°$ C . The absolute calibration of the system was done comparing the Hall probe to a NMR yielding an overall accuracy of $\Delta B < 0.5$ G.

In Fig. 4 a field map is displayed as was taken with this device. Integrating of the field along the particle trajectory allowed to determine the deflecting strength of the dipoles. *For different trajectories parallel to the central orbit* in the magnet's midplane the integrated field is plotted in Fig. 5. Due to the fringe field structure the deflecting

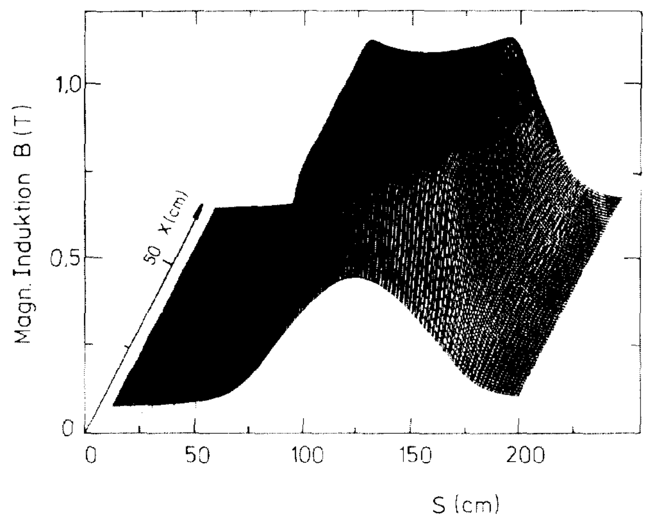

Fig. 4 Field map of a complete TSR dipole magnet.

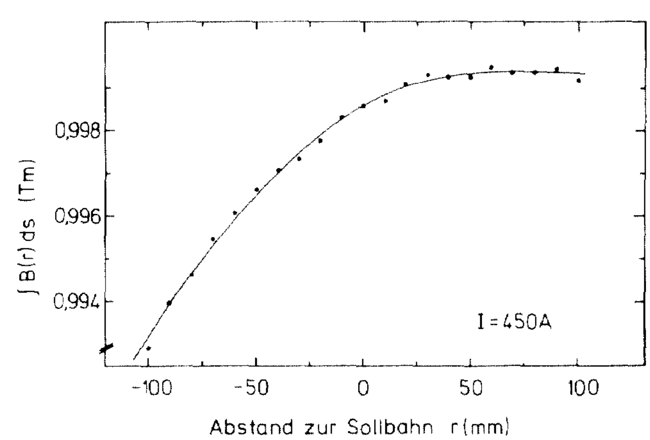

Fig. 5 Deflection strength of a dipole magnet at midplane. r denotes the distance to the central orbit.

strenght shows a quadrupole and a sextupole contribution. These multipoles can be compensated by retuning the equivalent ring magnets. The resulting field errors are due to the multipoles N > 3 amounting to a variation of the effective length at full horizontal aperture of $\Delta l/l = +/- 2.5 * 10^{-4}$.

The field gradient of the quadrupole magnets was measured by using a differential Hall probe. In figure 6 a map of the gradient distribution along the horizontal symmetry plane is shown. Integration of the gradient resulted in a flat radial distribution of the field gradient, figure 7. The quadrupole strength is uniform within 0,1 % for a usefull aperture of +/- 100 mm.

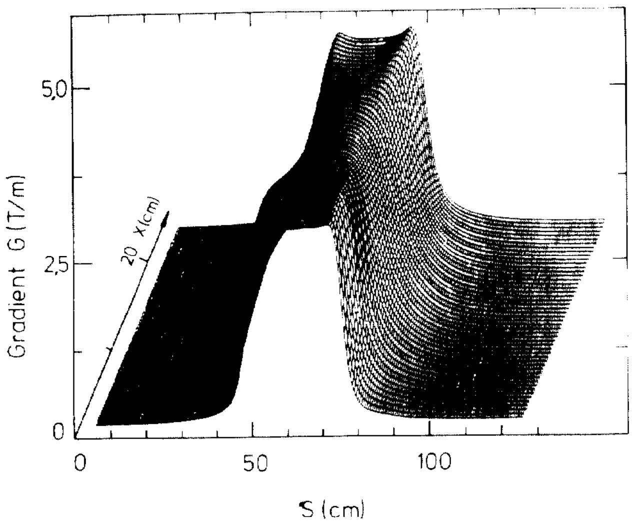

Fig. 6 Map of gradient distribution of a TSR quadrupole magnet.

Investigation of the multipole content N > 2 was performed using a Morgan coil which allowed to measure up to dodecapole. Table 1 gives typical values for the multipole coefficients a_N, 2 < N < 7. Especially the sextupole components which may be attributed to mechanical tolerances are less than 0.003 m^{-1} compared to the quadrupole coefficient a_2. The multipole coefficients are fairly constant for all levels of exitation.

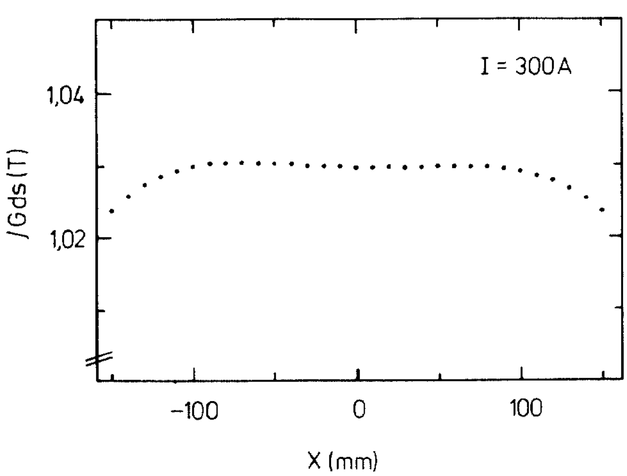

Fig. 7 Integrated gradient at horizontal position x.

Table I

Harmonic coefficients a_N normalized to the quadrupole coefficient a_2 measured at an excitation of 500 A,corresponding to a gradient of 5 T/m.

a_3/a_2 (m^{-1})	a_4/a_2 (m^{-2})	a_5/a_2 (m^{-3})	a_6/a_2 (m^{-4})
$1.02 * 10^{-3}$	$2.54 * 10^{-2}$	$1.18 * 10^{-2}$	1.14

For determination of the relative deviation of the focussing strenght kL among the 20 magnets the rms value of the quadrupole signal was measured. The corresponding variation in effective magnetic length is plotted in Figure 8. The magnets are identical within +/- 0.12 %. By proper selection to the 5 quadrupole families the variation is further reduced to a value of $+/- 2 * 10^{-4}$.

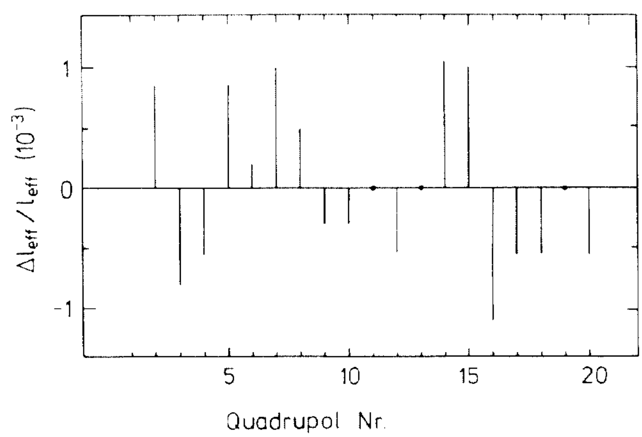

Fig.8 Relative variation of magnetic length for the individual 20 TSR quadrupole lenses.

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