THE HEIDELBERG TEST STORAGE RING FOR HEAVY IONS TSR[*]

E.Jaeschke, D.Krämer, W.Arnold,[+] G.Bisoffi, M.Blum, A.Friedrich, C. Geyer, M. Grieser,
D.Habs, H.W.Heyng, B.Holzer, R.Ihde, M.Jung, K.Matl, R.Neumann,[++] A.Noda,[§] W.Ott,
B.Povh, R.Repnow, F.Schmitt, M. Steck, E.Steffens
Max-Planck-Institut für Kernphysik
Postfach 103980, D-6900 Heidelberg, West Germany

Summary

TSR, the Heidelberg Heavy Ion Test Storage Ring has been set up at the MP-Tandem-Postaccelerator Combination of the Max-Planck-Institut für Kernphysik. After a very short construction time of only two and a half years it has just started operation with the successful storage of a $^{12}C^{6+}$ beam of 73.3 MeV energy. The $1 \cdot 10^{8}$ ions were stored with a lifetime of 1 min at a vacuum pressure of $1 \cdot 10^{-9}$mbar in the not yet baked ring chamber. Tune measurements using the knock out method yielding values of Q_x=2.84 and Q_y=2.77 as well as Schottky scans of unbunched beams showing a momentum spread of $\Delta p/p=1.7 \cdot 10^{-4}$ could already be performed. The ring is able to store ions up to a magnetic rigidity of 1.5 Tm corresponding to about 30 MeV/u for a charge to mass ratio of 0.5. The TSR is specially designed to investigate the electron cooling of heavy ions. The availability of a combination of partially and fully stripped ions together with a cold intense electron bath (I = 1.0 A typically) of adjustable relative energy does provide unique possibilities for plasma- and atomic physics as well as for high resolution experiments in nuclear physics. The general design criteria of the TSR as well as a description of its main components is given. Results of first storage experiments are reported.

Introduction

The Heidelberg Heavy Ion Test Storage Ring TSR [1] is an experimental facility for accelerator-, atomic,- plasma- and nuclear physics , that has started operation at the MP- Tandem Postaccelerator combination [2]. TSR has been built in close cooperation with the GSI Darmstadt and working groups of the physics institutes of the universities of Heidelberg, Gießen and Marburg. It is a unique research facility designed to study many still open questions related to electron cooling [3]of heavy ions. Furtheron it allows completely new experiments investigating the interaction of electrons and laser-photons with heavy ions in all possible charge states. Laser as well as electron cooling are planned to compress the phase space to extreme values giving rise to new collective phenomena and possibly even leading to the crystallization of ion beams [4].

General Description of the TSR

The Storage Ring is located in a newly built addition to the experimental hall of the Heidelberg accelerator complex. Fig.1 is a photo of the TSR as of April 1988. The injection line from the extended linac booster can be seen in the lower right guiding the beam to the electrostatic septum in the center of the first straight section. The details of the ring can best be identified by looking at the layout of TSR depicted in Fig.2; Table I lists the basic parameters of the machine.

The TSR has a fourfold symmetry, its circumference is 55.4m. Deflection is accomplished by eight 45 degree C-shape magnets. Always two dipoles with inbetween horizontally focussing quadrupoles (QFX2) form the center of one focussing period FP, which is completed on both sides by quadrupole dublets and half the long straight sections. In the main operation mode of TSR two antisymmetric focussing periods (FP,-FP) form one of the two superperiods. The details of the magnet system are described in [5].

The main lattice functions of TSR in the normal mode can be seen in the diagramms of Figs. 3a, showing the beta functions β_x and β_y , and 3b displaying the dispersion D_x for half the ring circumference in each case. The dispersion is set to zero in the the two long straight

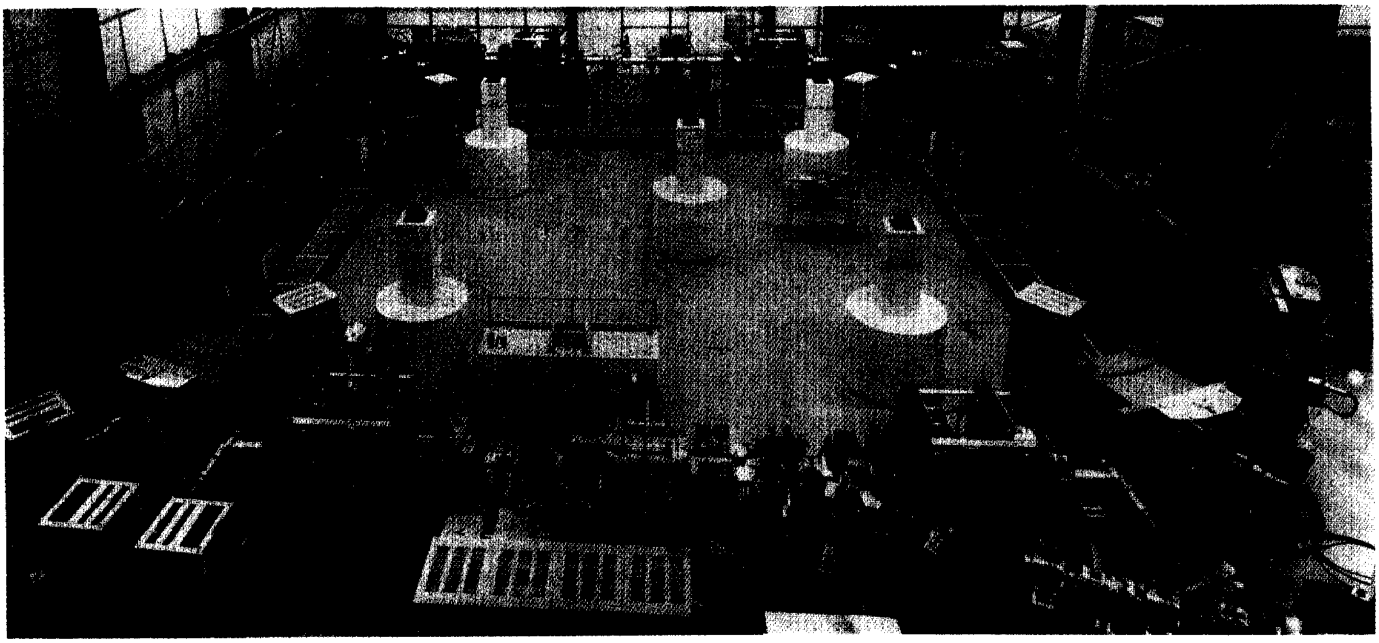

Fig. 1 The completed Heidelberg Test Storage Ring for Heavy Ions TSR in the new experimental hall

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[+] Strahlenzentrum der Universität Gießen, [++] Physikalisches Institut der Universität Heidelberg, [§] INS Tokyo sections reserved for the rf -system and the electron cooler, while it is adjusted to a value of about 2 m in the sections housing the injection and the experiment.

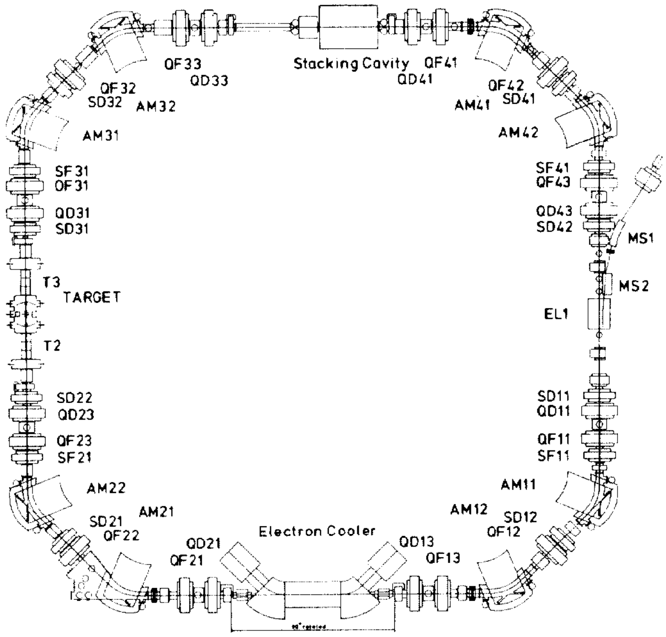
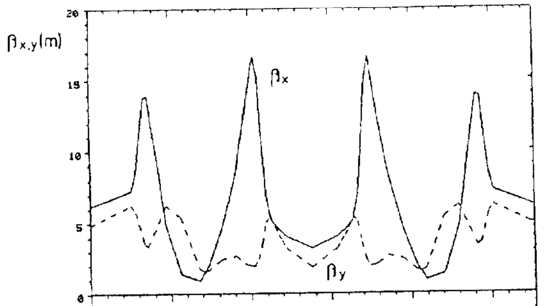


Fig.2 Layout of TSR showing its major components. The labels designate: AMX dipoles, QDX and QFX quadrupoles, SFX and SDX sextupole lenses, MSX and ELX magnetic and electrostatic injection septa.

Table I

Basic Parameters of the TSR

Magnetic rigidity	$B\cdot\rho$	1.5 Tm
Circumference	C	55.4 m
Mean radius	R	8.8 m
Straight sections (4)	SS	5.2 m
Focussing period	FP	ODFOBOFOBOFDO
Superperiodicity	S	2 ; 2 x (FP,-FP)
Betatron tune	Q_x, Q_y	2.75 , 2.825
Chromaticity (nat.)	ξ_x, ξ_y	-5.9 , -3.7
Transition energy	γ_{tr}	2.96



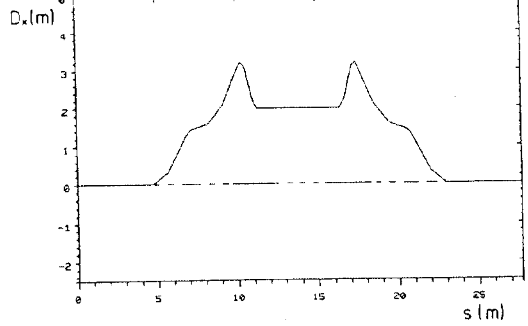


Fig. 3a (Top) Beta functions β_x and β_y calculated by the code MAD [6] for one superperiod of TSR.

Fig. 3b Dispersion function D_x for one superperiod.

The small dispersion and the large apertures of all ring components will allow a multi charge state operation, the principle of which is illustrated by the result of tracking calculations (See Fig. 4) with the code MAD [6] for ^{127}J ions of equal energy varying however in their charge states from +46 to + 48. Differences of one charge state correspond in the case of Iodine to a momentum mismatch of $\Delta p/p$ = 0.021. It is obvious, that extreme care in applying chromatic corrections using multipole elements must be taken . This is why the TSR is using three already installed sextupole families (12 lenses) , that can be independently operated by individual power supplies. The installation of three octupole families is planned.

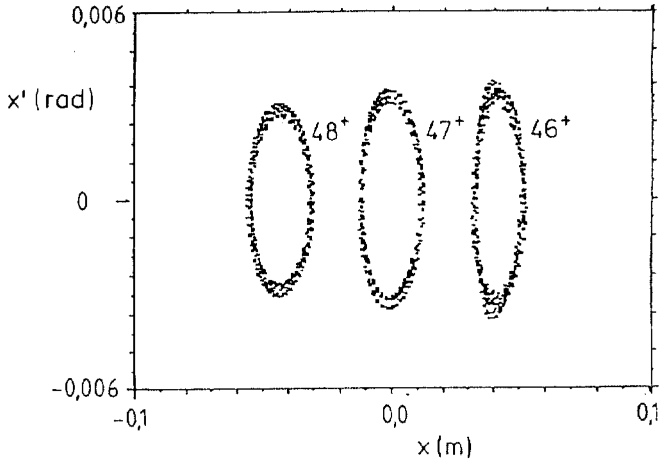


Fig. 4 Tracking in horizontal phase space (dispersive straight) for 500 iodine ions differing in charge states. [6]

Another feature, still to be implemented, is the low beta optic necessary for operation with spatially well defined internal targets as for example atomic beams. Fig.5 shows the betafunctions of TSR in this mode.

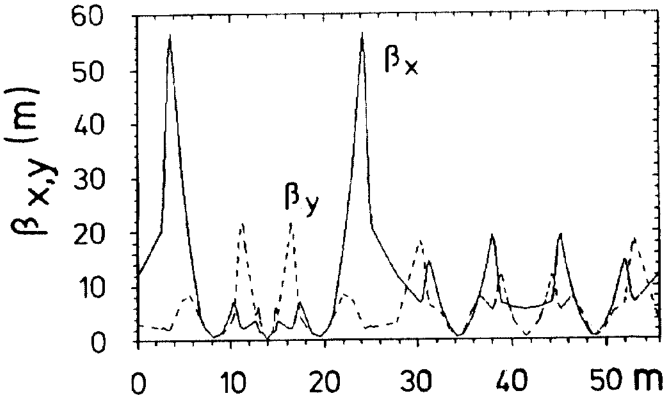


Fig.5 Beta functions β_x and β_y in the low beta mode for the whole circumference of TSR. Values at the target are $\beta_x = \beta_y = 0.2$m; the tune is changed to $Q_x = 2.75$, $Q_y = 3.9$.

Filling a storage ring up to the planned limit of 10^{10} ions at an accelerator system having an electrostatic Tandem accelerator as its main injector, requires a reliable pulsed negative ion source [7] and an elaborate stacking procedure combining in the case of TSR multiturn injection and rf- stacking. As shown in [8] this combination technique is well suited to store as many as 40 (multiturn) x 25 (rf-stacking) = 1000 equivalent turns in the TSR. All necessary components,- magnetic- and electrostatic septa, four fast bumper magnets (B'= 2000T/s) and the rf- cavity are installed and tested in the machine.

First Storage Tests at the TSR

After the successful tests of the injection components end of 1987, the ring was completely assembled by April 1988, showing in static beam transport tests around the whole circumference, that all major components were operating reliably as designed. Mid May 1988 the fast bumper magnets as well as ultra thin bumper chambers (0.3 mm stainless steel) were installed. In the following test run almost immediately a stored beam of 73.3 MeV $^{12}C^{6+}$ ions could be detected with a lifetime of 4.5 s. The beam was adiabatically captured in rf-bukkets at the 11th harmonic of the revolution frequency of 617 kHz. Subsequent adjustments and mainly improvements of the vacuum in the not yet baked ring chamber to a value of $1 \cdot 10^{-9}$ mbar resulted in a lifetime of τ_e= 1 min. The further results of this test are listed in table II. Fig.6 shows the time dependent stored intensity as derived from the rf-signal of one of the electrostatic position pick ups . The signal of the DC-current transformer gave a stored intensity of $> 10^8$ particles.

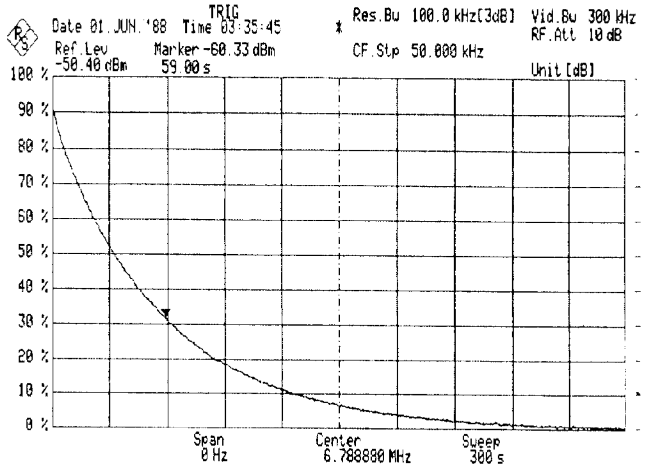


Fig. 6 Time dependence of stored intensity in the TSR Lifetime of $^{12}C^{6+}$ ions is τ_e= 1 min.

Table II

Results of first Storage Tests at the TSR

Ion beam		$^{12}C^{6+}$
Ion energy	E	73.3 MeV
Number of stored ions	N	$> 10^8$
Lifetime	τ_e	1 min
Pressure (aver., unbaked)	p	$< 10^{-9}$ mbar
Number of stored turns	n	> 10
Tunes measured (K.O.)	Q_x,Q_y	2.84 , 2.77
Schottky scan of coasting beam	$\Delta p/p$	$1.7 \cdot 10^{-4}$
Lifetime is pressure limited		

To determine the influence of the pressure on lifetime, the vacuum in the ring chamber was deliberatly deteriorated. Fig. 7 gives in a logarithmic plot the time dependence of stored intensity for $p = 5 \cdot 10^{-8}$ mbar (τ_e= 4.1 s) and for $p = 2 \cdot 10^{-9}$ mbar (τ_e = 29 s). These results are encouragingly showing, that lifetimes in the order of 1000 s can be obtained for carbon ions when the chamber is baked, and pressures below $1 \cdot 10^{-11}$ mbar are reached as planned.

The surprisingly long storage times allowed to perform already in this first test run a number of diagnostic measurements as tune determination by the knock out method and Schottky scans of the coasting beam. Fig. 8 gives a Schottky scan of an unbunched beam at the 10th harmonic, showing a momentum resolution of $\Delta p/p= 1.7 \cdot 10^{-4}$.

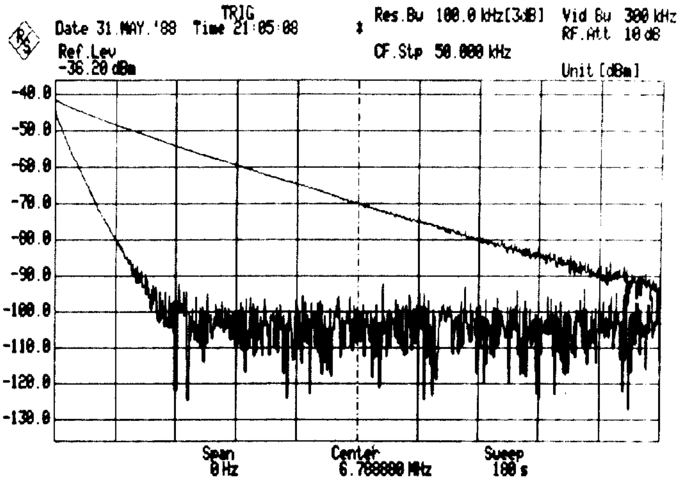


Fig.7 Pressure dependence of the lifetime of stored ion beam. Upper trace taken at $2 \cdot 10^{-9}$ mbar yielding τ_e= 29 s , lower trace taken at $5 \cdot 10^{-8}$ mbar with τ_e= 4.1 s.

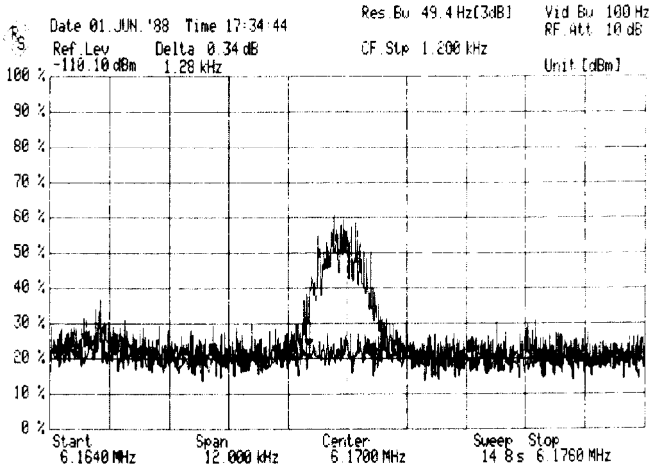


Fig.8 Schottky scan of an unbunched beam taken at the 10th harmonic. (Upper trace)

Acknowledgement

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