COSY - A COMPACT ELECTRON STORAGE RING FOR SYNCHROTRON RADIATION

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Abstract: The general layout of COSY, a compact superconducting synchrotron radiation source dedicated to x-ray lithography is presented together with a discussion of the most important design considerations. Prior to the installation of the SC-dipole magnets the injection process has been studied. First experimental results are reported.

Introduction

The increasing importance of synchrotron radiation for industrial applications calls for the development of small and inexpensive sources. There are many approaches for the design of compact synchrotron radiation storage rings, which is also reflected by the increasing number of projects dedicated for x-ray lithography scattered all over the world [1].

In a feasibility study we have investigated four alternative solutions [2]: a conventional ring with normal conducting (nc) magnets, a hybrid version with superconducting wigglers in a nc-ring, a weak focussing super conducting (sc) machine with circular symmetry and a race track version with two sc 180° dipoles, the final COSY design.

Beside the advantage of a more compact set-up compared to the nc-machines, the decision to use superconducting magnets was mainly motivated by the higher development potential, to obtain even shorter critical wavelengths with future improvements in sc-magnet technology. This will open the door for possible applications in the field of micromechanics and medicine.

General Layout

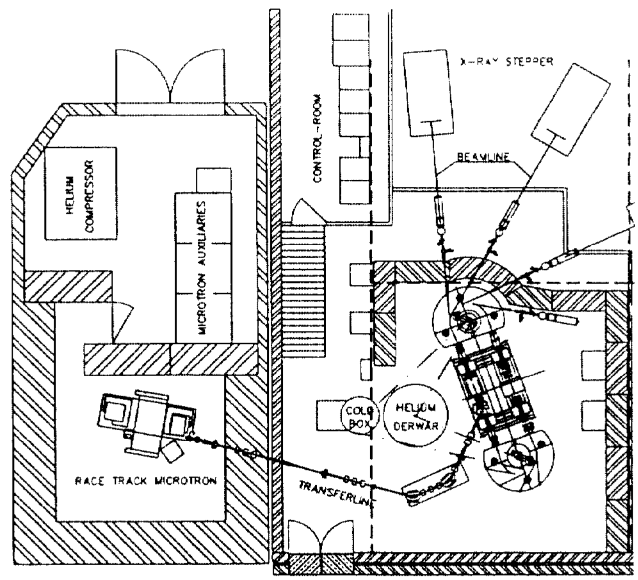
The general design of COSY is shown in fig. 1. Electrons from a 50 MeV race track microtron (Scanditronix) are injected via a transport line of about 10 m length into the vertical phase space of the storage ring, which consists of two 180° sc-dipoles with a field index of 0.525, four nc-quadrupoles and a 500 MHz rf-cavity. About 115 m² of floor space are needed for the injector, rf-transmitter, power supplies and LHe-system, whereas for the storage ring itself an area of 2 m x 5 m is sufficient. The sc-magnets have been built by Siemens/Interatom, details of their technical layout can be found in [3].

Electron Optics

The sc-dipoles are pure air-coil magnets, so the field distribution along the orbit deviates significantly from a hard-edge magnet (fig. 2). Therefore the linear optics functions, the nonlinear particle dynamics and the reference orbit have been calculated with non-isomagnetic fields [4].

As a result there are no important deviations of the linear lattice parameters from the hard edge approximation, with the only exception of the momentum compaction α, depending sensitively on the local behavior of the dispersion function in the dipoles. So for most practical purposes the hard-edge model is a good approximation. This is also true for nonlinear

Fig. 1: General layout of the Cosy-system



tracking calculations. Only in the calculations of the reference orbit the non-isomagnetic treatment of the dipoles is unrenouncable (fig. 3). The deviations of the non-isomagnetic reference orbit from the isomagnetic approximation are important for the geometrical layout of the vacuum chamber, and the local curvature variations of the orbit in the region of the coil back-bends give rise to a fan of synchrotron radiation in the direction of the opposite magnet. For cold bore magnets this may cause problems with respect to increasing LHe consumption. The most important parameters are summarized in tab. 1 and the lattice functions are shown in fig. 4.

For horizontal and vertical steering of the beam the quadrupole magnets can be shifted in the respective plane. This saves space and has the additional advantage that the steering fields follow synchronously during energy ramping. There are no sextupole

Fig. 2: Field distribution on the design orbit for one half of the sc-dipole

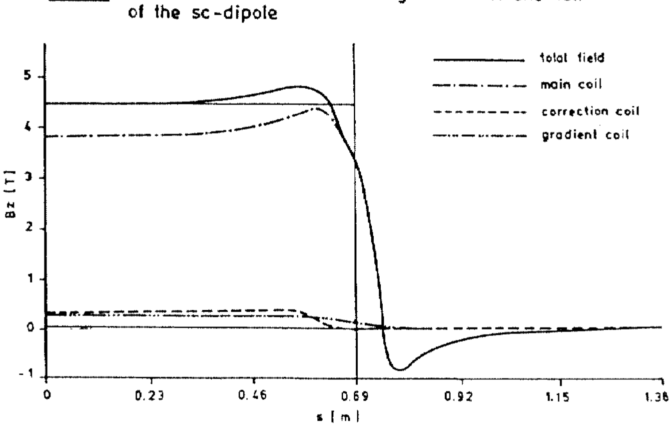
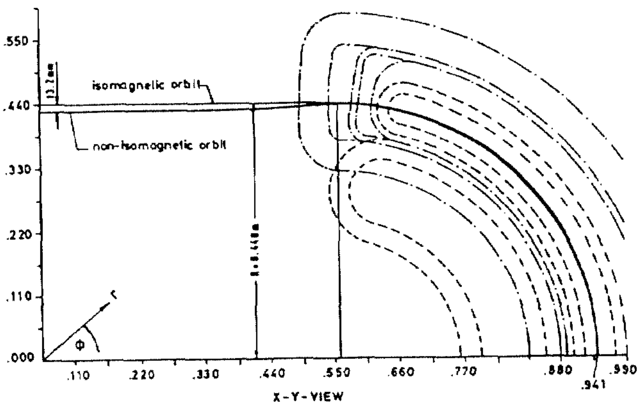


Fig. 3: Design orbit and isomagnetic orbit in the sc-dipole magnet



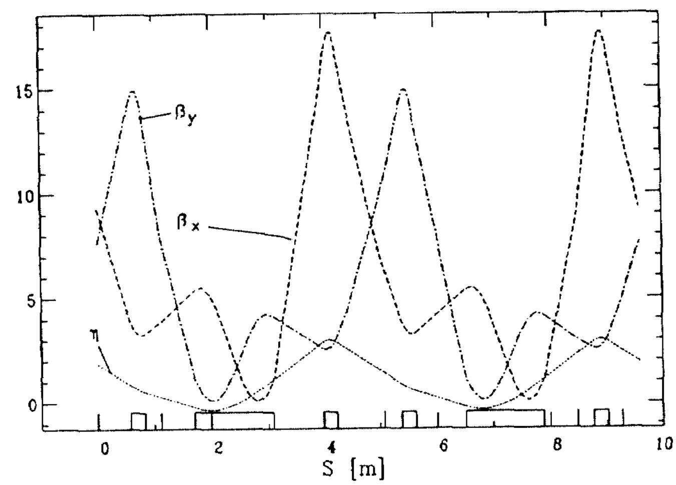


Fig. 4: Linear lattice functions β_x, β_y and η(m)

Table 1: Principal COSY Parameters

injection enery	E_{inj}	= 50 MeV
final energy	E_f	= 592 MeV
magnet radius	ρ	= 0.44 m
circumference	L	= 9.6 m
critical wavelength	λ_c	= 12 Å
number of lattice cells	N	= 2
nominal field in sc magnet	B_0	= 4.47 T
rf-frequency	f_{rf}	= 500 MHz
harmonic number	h	= 16
tunes	ν_x	= 1.139
	ν_y	= 1.189
chromaticities	ξ_x	= -2.5
	ξ_y	= -6.3
emittance (592 MeV)	ε_0	= 2.6 10^{-6} πmrad

magnets in the ring for chromaticity correction. Part of the chromaticity is compensated by the sextupole component of the SC-dipoles. However, there is an alternative possibility to suppress the head-tail instability in case it proofs to be current limiting. By minor changes of the optics the zero-crossing of the dispersion function in the dipoles can be shifted slightly with the result of a negative momentum compaction factor. This is an interesting feature of such type of optics.

Injection Scheme

A transfer line performing phase space matching guides the beam from the exit of the racetrack microtron (20 mA) to a bending magnet deflecting the beam both in horizontal and vertical direction to hit the channel of a pulsed septum magnet. Its thin septum sheet is optimized with respect to strayfields. A vertical injection scheme was chosen due to a dispersion function of $D_x \cong 1.8$ m in horizontal direction. For injection, a local beam bump, consisting of three fast pulsed kicker magnets, moves the vertical acceptance in the direction of the septum magnet (see fig.5), thereby avoiding excitation of the stored beam. At the maximum of beam elongation, the injected beam, leaving the septum magnet channel, enters the machine acceptance (broken line). A short kicker pulse duration prevents the injected beam from hitting the septum sheet after a few revolutions. Due to the short distances between the kicker magnets and the small revolution time in COSY, stable kicker amplitudes and a small time jitter of the kicker pulses is mandatory to avoid an excitation of the stored beam.

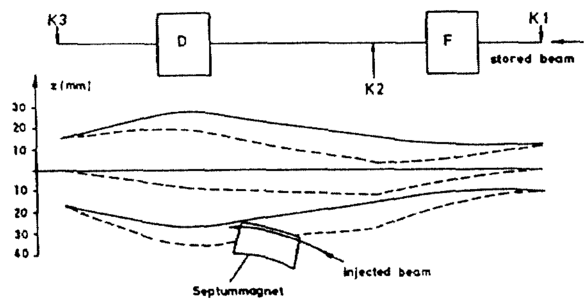


Fig. 5: Straight injection region, indicating the kicker positions (K1 - K3) and two quadrupoles (F, D) (upper part). The fully drawn lines mark the envelope and the center of the linear vertical acceptance (lower part), the broken lines illustrate its displacement in the direction of the septum magnet (not to scale) in order to catch the injected beam.

First Results of Injection Studies

To study the injection process in parallel with the development and construction of the superconducting dipoles, a normal conducting version of the COSY ring has been built and operated at the injection energy of 50 MeV. All experimental results described in the following were obtained with this setup. The optics has been verified measuring tunes, β-functions and chromaticities; maximum currents of more than 90 mA have been stored. There is no evidence of head-tail instabilities nor transverse multibunch-oscillations could be observed, whereas longitudinal multibunch oscillations are excited already at threshold currents of a few mA's. However, there is no indication that these oscillations are current limiting.

In fig. 6 the lifetime is shown as a function of beam current for different operation modes of the storage ring. A lifetime of about 100 min is obtained in the limit I → 0 independent of the mode of operation. This is in good agreement with the Coulomb scattering lifetime [5] for $P_0 \cong 5 \cdot 10^{-10}$ mbar which is the dominant single particle lifetime limiting process at low energies.

The strong current dependence of the lifetime, however, is caused by multi-particle effects, where ion trapping is the most important process. The ions have two detrimental influences on the beam. First they increase the effective pressure as seen by the circulating beam, $P_{eff} = P_0 + P_{ion}$, where an estimate of the ion component of the effective pressure gives $P_{ion} \approx 3 \cdot 10^{-9}$ mbar for COSY with 100 mA stored current [5]. Secondly, the ions introduce transverse focusing forces on the electron beam and thus change the betatron tunes of the ring. A rough estimate gives transverse tune shifts of $2 \cdot 10^{-3}$ and $6 \cdot 10^{-2}$ at 1 mA and 100 mA stored current respectively. To get rid of at least part of the ions we use electrostatic electrodes for ion clearing.

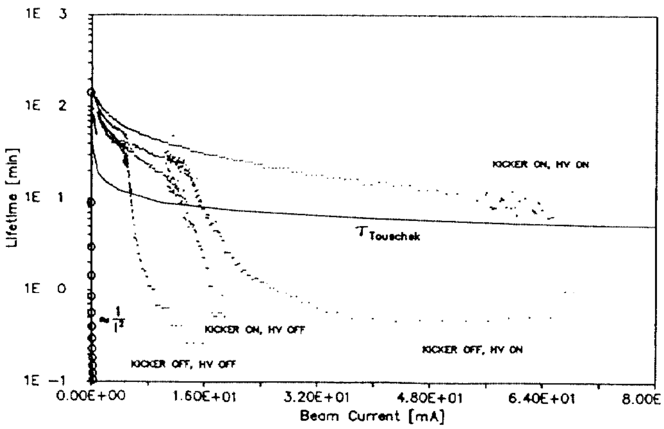


Fig. 6: Beam lifetime for different operation modes at injection energy and calculated Touschek lifetime for COSY.

The influence of the trapped ions can be seen in the lifetime characteristics of fig. 6. A common feature of the first three dotted curves is an initial smooth decrease in lifetime, followed by a strong decrease. The current threshold for the onset of this strong decrease in lifetime, however, can be influenced by exciting the beam with the kicker magnets (kicker on), and/or by using the electrodes of the orbit measuring system for ion clearing (HV on). When exciting the beam, part of the ions can leave the trapping potential after every kick, and so the accumulation has to start again. By far the best lifetimes are obtained when both methods are applied simultaneously.

We have calculated the Touschek-lifetime with the ZAP-code [6] taking turbulent bunch lengthening and emittance broadening due to multiple-Coulomb scattering into account. As can be seen, these model calculations are in qualitative agreement with the experimental data measured with the ion-clearing voltage switched on and the beam excited by the kicker magnets.

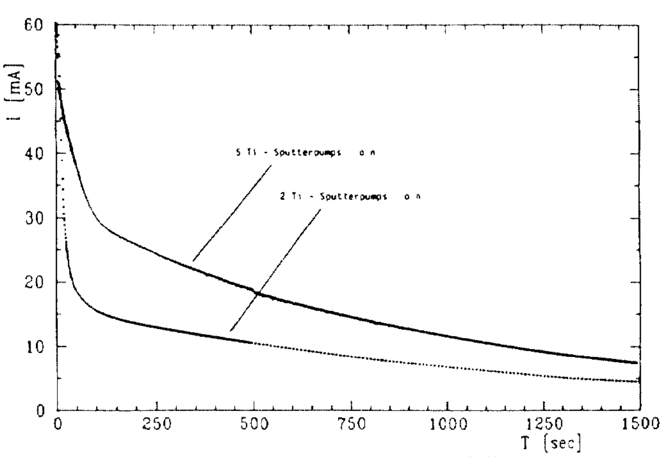


Fig. 7: Decay pattern of beam current (Kicker off, HV on).

In fig. 7 the decay pattern of the beam current is shown for different vacuum conditions in the ring which have been produced by switching off some of the Ti-sputter pumps. As expected the lifetime is generally longer for better vacuum conditions. In addition the current threshold where the lifetime improves strongly is also significantly increased under good vacuum conditions reflecting the importance of low ion densities.

Conclusion and Outlook

The feasibility to inject and accumulate electron beams of more than 90 mA at the rather low injection energy of 50 MeV has been demonstrated experimentally, confirming the accelerator physical layout of the COSY-machine. This allows to consider inexpensive injection schemes for compact electron storage rings. In order to obtain adequate currents and lifetimes at injection, good vacuum conditions and some counter measures with respect to accumulated ions are essential.

After several tests, the superconducting magnets have been installed in COSY recently and first injection experiments are under way.

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