THE BESSY II* BOOSTER SYNCHROTRON

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1 ABSTRACT

For injection into the BESSY II 1.9 GeV storage ring a full energy fast cycling booster synchrotron is under construction. The optical structure is a FODO-lattice with 16 cells and a circumference of 96 m. To ensure a fast filling rate, an emittance in the 10^{-7} m · rad range and a 10 Hz cycling frequency were chosen. A 50 MeV racetrack microtron is used as preinjector. The main features of the design are presented together with the results of the series measurements for the guide field magnets.

2 INTRODUCTION

Injection at full energy offers several advantages for a state of the art high brilliance synchrotron radiation (SR) facility. It ensures a short filling time, avoids intensity problems at low energy related with lifetime limitations (gas scattering, Touscheck effect, ion trapping), and allows for effective vacuum conditioning through SR induced desorption during commissioning and after vacuum incidents in user operation. On the other side the injector is only needed during a few percent of the facility operation time. Efficiency arguments therefore ask for minimum investment cost for the injector to make full energy injection competitive.

3 LATTICE

We have adopted an injection system using a fast cycling (10 Hz) separated function synchrotron with a 50 MeV racetrack microtron as preinjector. Several lattices were studied in a comparative cost evaluation: two FODO lattices with superperiodicity N = 2 and 3 based on a missing magnet scheme to generate straight section space for injection, extraction, and rf-acceleration, and a FODO lattice with N =16, where every second cell is empty and shortened to minimize the circumference. Although the higher magnet packing density of the missing magnet schemes allows for a smaller circumference (~ 10 %) we have chosen a lattice with 16 cells (see Fig. 1) which needs a lower number of magnets for the same emittance, overcompensating the saving in circumference [1]. Other design goals have been a low sensitivity to magnet alignment errors and the provision of sufficient space for steerers and for diagnostic elements. All guide field magnets of one cell are mounted on a common girder. Table 1 gives the essential machine parameters.

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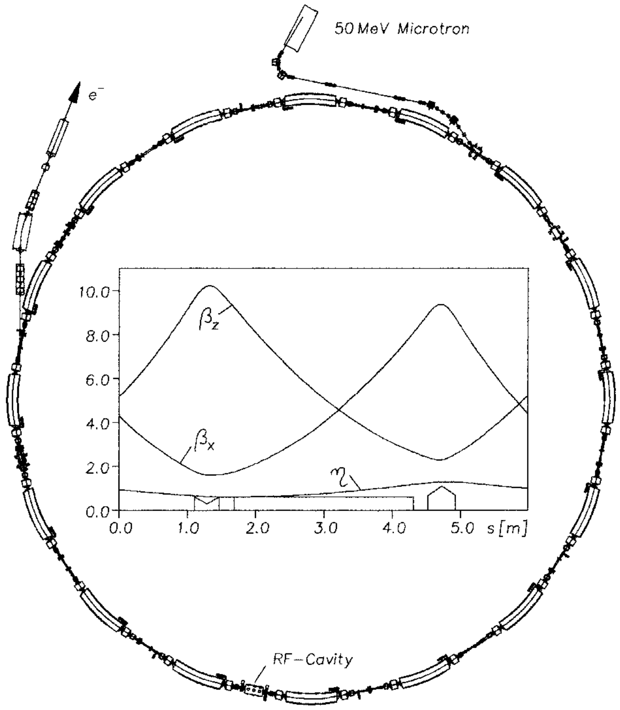

Fig. 1: Footprint and lattice of the BESSY II synchrotron

Table 1: Main Parameters for the BESSY II Synchrotron

Max. energy	[Gev]	2.
Circumference	[m]	96.
Repetition rate	[Hz]	10.
Number of cells		16
Bending radius	[m]	6.67
Inj. energy	[MeV]	50.
Field @ E_{inj}	[T]	0.0250
Field @ E_{max}	[T]	1.
Emittance	[m·rad]	2.0 10^{-7}
Tunes Q_x/Q_z		4.42/3.38
Mom. compaction		0.054
Nat. chromaticities ξ_x/ξ_z		-4.7/-3.9
Current (multibunch)	[mA]	3
Rf-frequency	[MHz]	499.66
Harmonic number		160
Energy spread [@ E_{max}]		6.6 10^{-4}
Damping times $\tau_x/\tau_z/\tau_s$	[msec]	6./6./3.

Magnet	Number	Strength	Length	Gap/Radius
Dipoles	16	1. T	2621 mm	h = 36 mm
Quads	32	14. T/m	300 mm	r = 35 mm
Sext.	16	70 T/m²	150 mm	r = 35 mm
Steerer	16	0.05 T	150 mm	h = 120 mm

For orbit correction at injection energy horizontal and vertical steerers are foreseen. As the natural chromaticities are small there is no need for sextupoles in multibunch operation to avoid intensity limitations due to the head-tail instability. Only for operation with a single bunch sextupoles will be used in every second cell. These sextupoles also include windings for dipole corrector fields.

4 ERRORS OF SERIES MAGNETS MAGNET SORTING

All guidefield magnets have been manufactured at the BINP in Novosibirsk/Russia. Technical details and field measurements of the prototypes can be found in [2]. To characterize the quality of the series magnets, the integral bending strength errors of the dipoles have been determined by an AC-method exciting the magnets with a current $I = I_{DC} + I_{AC} \cdot \cos \omega t$ ($I_{DC} = I_{AC} = 500$ A, $\omega = 2\pi \cdot 0.75$ Hz). Long induction coils were used to compare the induced voltage from the dipoles with a reference magnet [3]. The integral focusing strength errors of the quadrupoles were deduced from rotating coil measurements at I = 100.4 A with a systematic error of 1.10^{-3}. Figure 2 shows the relative errors for the dipoles and quadrupoles with respect to their ensemble mean value.

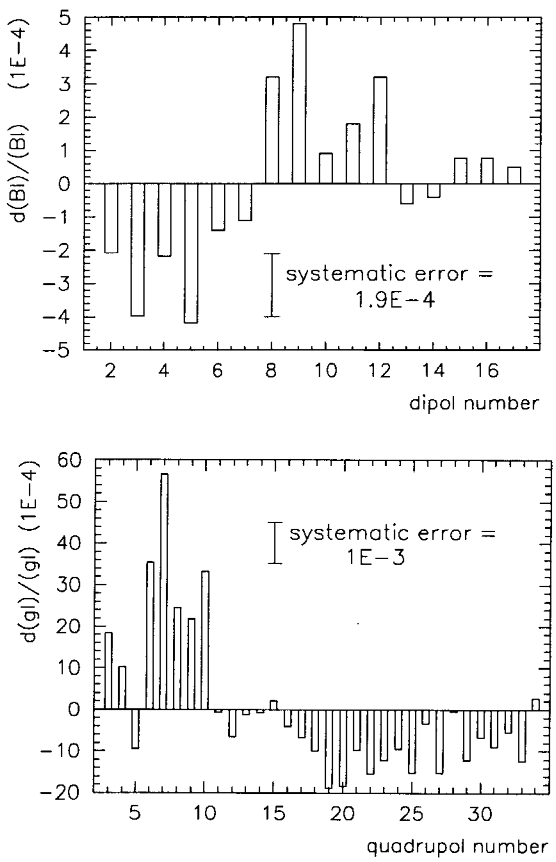

Fig. 2: Dipole strength errors and integral gradient errors of the series magnets

The differences in bending strength give rise to horizontal orbit deviations. For a given set of errors the deviations can be minimized by an adequate arrangement of the dipoles. Figure 3 shows the best and worst case determined by a sorting algorithm [4] with the result of a max. orbit excursion of ± 3 mm even for the worst case. Gradient errors of the quadrupoles perturb the symmetry of the lattice and increase the stopband widths. With the focusing errors of Fig. 2, however, the β-beat $\Delta\beta/\beta$ does not exceed 5%, and the corresponding stopband width $\Delta Q = 2\, \Delta\beta/\beta \cdot (Q\text{-}p/2)$ near the nominal tunes Q is only of the order of 0.01 which is tolerable (p integer, Q -p/2 distance to the nearest stopband).

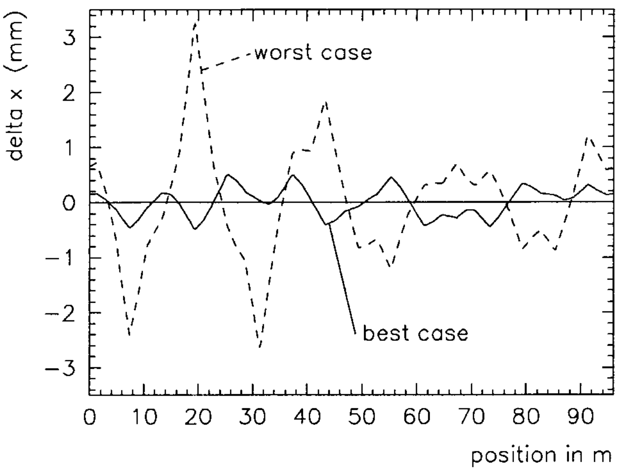

Fig. 3: Horizontal orbit errors after magnet sorting

For an estimate of the total closed orbit deviation also misalignments of the magnets have been included. Assuming realistic rms alignment errors for the quadrupoles ($\Delta x = \Delta z = 0.1$ mm, $\Delta s = 1$ mm, $\Delta\Theta = 0.1$ mrad) and for the dipoles ($\Delta\Theta = 1$ mrad rotation around the s, x, z-directions, $\Delta s =$ 1mm) we obtain maximum orbit errors of 9 mm and 7 mm in the horizontal and vertical plane respectively, which is well within the acceptance of the synchrotron.

5 WHITE CIRCUITS AND POWER SUPPLIES

For the excitation of the dipoles and the two quadrupole families three conventional white circuits will be used as sketched in Fig. 4 . Tracking errors between the dipole and quadrupole fields are not allowed to exceed $\pm 2.6 \cdot 10^{-4}$ in order to keep the tunes in both planes within $\Delta Q \leq \pm\, 0.05$ during the acceleration cycle. This puts constraints on the linearity of the magnets and the chokes, on the stability of the power supplies (± 10 ppm for DC-PS, ± 50 ppm for AC-PS), and on the maximum tolerable phase difference between the dipole and quadrupole excitation currents, $\Delta t \leq 23$ µs.

To avoid odd harmonics from the AC-power supplies, the concept of a current source controlled by Isolated Gate Bipolar Transistors (IGBT) has been adopted, which is driven by a high quality low power sinewave generator. Higher harmonics of 10 Hz in the fields are therefore mainly due to the nonlinearities in the magnets and chokes. Long term stability of the field amplitudes is controlled by slow analogue feedback loops (τ ~10 sec), whereas the phase difference between the magnet circuits, caused mainly by thermal effects, is minimized by a digital feedback. All chokes have been designed and manufactured at the BINP. The big choke for the dipole circuit is a surplus component from the low energy booster of SSC

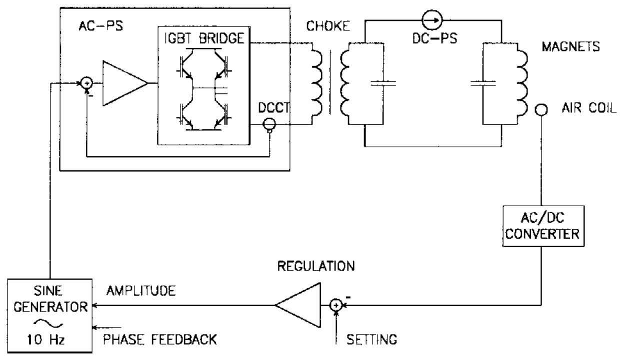

Fig. 4: Schematic diagram of the White circuit and power system

6 VACUUM SYSTEM

To minimize eddy current induced perturbing fields from the chamber walls, the vacuum vessels in the magnets are made of 0.3 mm thin stainless steel (AISI 316L, $\mu \leq 1.02$) tubes. The chambers are reinforced by 1 mm thick stainless steel ribs brazed to the tubes following a procedure developed at DESY [5]. With a total of 22 ion pumps (60 l/sec) distributed around the ring, a mean pressure of $1 \cdot 10^{-7}$ mbar is expected without any bakeout.

7 RF-SYSTEM

For acceleration a surplus 3-cell 500 MHz cavity from the old DESY synchrotron will be used, offering a shunt impedance of 10 MΩ and an unloaded Q of about 30000. To keep the resonance frequency within the tuning range of 150 kHz, the cooling water temperature is stabilized to ±1° C. A maximum power of 35 kW from a klystron transmitter is coupled magnetically to the cavity ($\beta = 1.06$) via a waveguide section with a ceramic disc window.

8 MICROTRON INJECTOR

A 50 MeV racetrack microtron (initially built by Scanditronix) with an emittance of $5 \cdot 10^{-7}$ m · rad and a relative energy spread of $2 \cdot 10^{-3}$ has been upgraded for the use as a preinjector. Installation of a fluorescent screen, which can be moved through all 10 orbits, and computer control of all magnetic elements helped to reduce the start-up time after power failures. Improvement of the gun vacuum system led to a significant reduction of the conditioning time after cathode replacement. Beam currents of 15 mA in a 1 µs pulse have been obtained so far. A 500 MHz prebuncher will be implemented behind the gun to reduce beam loading of the microtron rf-cavity in an attempt to further increase the beam current. For single bunch operation a pulsed triode replacement gun is under development.

9 INJECTION AND EXTRACTION

The electrons, after passing a matched transfer line, are injected in one turn with a 22.5° pulsed septum and a 7 mrad ferrite kicker magnet (80 nsec fall time). For extraction the beam is displaced with a slow local bump generated by 3 pulsed dipole magnets towards the extraction septum sheet and then kicked into the septum channel by a 1.8 mrad/80 nsec rise time kicker magnet.

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