THE ANKA INJECTOR

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Abstract

ANKA [1] is a 2.5 GeV synchrotron radiation storage ring under construction at the Forschungszentrum Karlsruhe in Germany. The beam is accelerated up to 0.5 GeV in a booster synchrotron and afterwards injected into ANKA. In ANKA the beam is accumulated to 200 mA (second stage: 400 mA) and afterwards accelerated to 2.5 GeV. The injector system will consist of a pre-injector with an end energy of 20 or 50 MeV, a booster synchrotron and transport channels. The booster synchrotron should be as simple and inexpensive as possible. In the following three different concepts for designing the booster synchrotron are compared.

1 THE SELECTION OF THE OPTICAL CODE

For a compact and low energy accelerator the length of a bending magnet is comparable with the bending radius. In this region the basic beam optical parameters such as emittance and damping times are significantly influenced by edge effects. The beam parameters are calculated via the 5 synchrotron integrals I_1 to I_5 [2]. I_4, which describes the emittance and the damping times, consists of two parts: the contribution from the bending magnets and the contribution from the edge effects [2]

$$\Delta I_4 = -\sum_{polefaces} \frac{\eta_{poleface.} \tan\Phi}{\rho^2}$$

wherein η is the dispersion, Φ is the pole face angle in the usual definition and ρ is the bending radius. The sum has to be taken over all pole faces of the machine. For high energy synchrotrons and storage rings the contribution from the edges is negligible; hence, many programs like MAD [3] and BETA [4] do not take these effects into account. The codes DIMAD [5] and RACETRACK [6] take the edge effects fully into account. Both the horizontal emittance ε

$$\varepsilon = C_q \gamma^2 \frac{I_5}{I_2 - I_4}$$

and the horizontal damping partition numbers

$$J_x = 1 - \frac{I_4}{I_2}, \quad J_\varepsilon = 2 + \frac{I_4}{I_2}$$

depend on I_4. In the following parameters depending on I_4 were calculated with the program DIMAD. Beta-functions and the momentum compaction factors were calculated either with the program MAD or DIMAD.

In the following three layouts of boosters are compared. Only booster synchrotrons which are radiation damped in all 3 directions are considered: they can be operated with power supplies of any repetition rate, for instance 1 Hz, 3 Hz or 10 Hz.

2 OPTICAL COMPARISON OF THREE DIFFERENT DESIGNS

a. The booster synchrotron introduced in the ANKA proposal

The optics of the booster synchrotron introduced in the ANKA proposal [7] is shown in fig. 1. The lattice consists of 8 45° bending magnets and 2 quadrupole families.

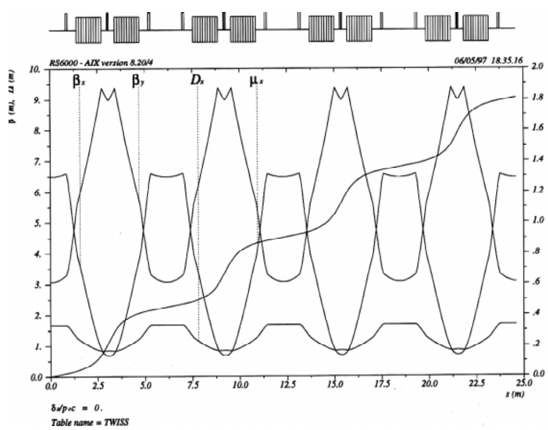

Fig. 1 β_x, β_y, η and horizontal phase advance of the booster synchrotron from the ANKA proposal (MAD calculations). The optical parameters are listed in Table 1.

b. Weak focusing booster synchrotron

An example of a simple weak focusing booster synchrotron is shown in fig. 2. It consists only of four 90 degree sector bending magnets with a gradient. The parameters for a zero pole face angle are listed in table 1. Using a pole face angle ≠0 can improve emiitance and α significantly.

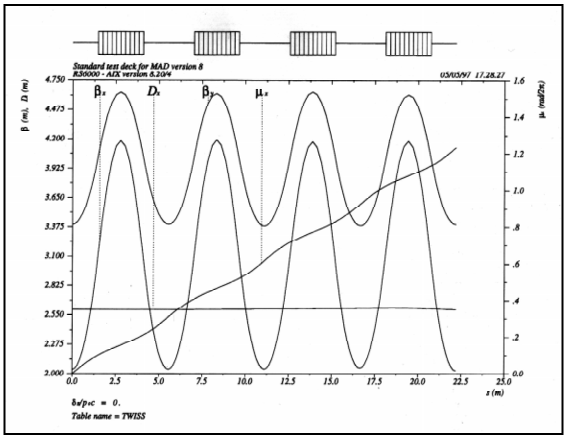

Fig.2 A simple weak focusing synchrotron consisting of only 4 bending magnets with a gradient (MAD calculations)

c. Strong focusing booster synchrotron with a gradient in the bending magnets

An example of a strong focusing booster synchrotron with 90^0 bends with gradients and 1 quadrupole family is shown in fig. 3.

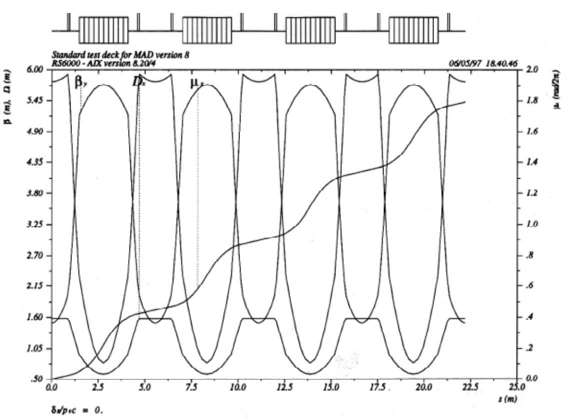

Fig. 3 A strong focusing booster synchrotron with a gradient (MAD calculation)

d. Table of the optical parameters

The optical parameters of the three machines are compared in Table 1. The most significant differences between the three machines are in the emittances and the momentum compaction factors.

e. The evolution of the emittance

With the parameters listed in table 1 the evolution of the emittances during acceleration is shown in fig. 4. In the given example the acceleration time is 0.1 sec. The emittance of 7. 10^{-7} at the beginning is given by the injection process.

Parameter	proposal	weak focusing	strong focusing
bending radius [m]	1.66	1.66	1.66
number of bending magnets	8	4	4
field index	0	0.36	0.25
circumference [m]	24.6	22.2	22.2
pole face angle [degree]	22.5	0	45
momentum compaction	0.26	0.73	0.2
Q_x/Q_y	1.81/0.8	1.23/0.89	1.79/1.2
emittance [mm.mrad]	0.14	0.87	0.058
τ_x [sec]	0.023	0.04	0.015
τ_ε [sec]	0.025	0.009	0.015
σ_ε	3.3 10^{-4}	3. 10^{-4}	4.10^{-4}

Table 1 Comparison of the optical parameters of the three boosters

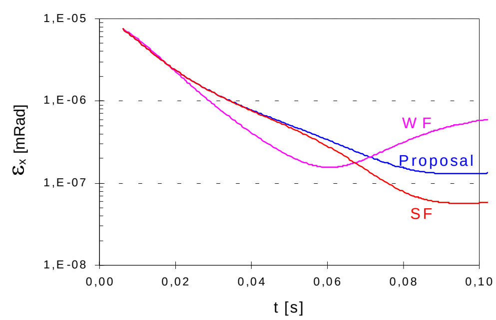

Figure 4: Evolution of the transverse emittance during acceleration. It is assumed that the acceleration time is 0.1 sec. WF: weak focusing. SF strong focusing booster with gradient from fig. 3.

3 LONGITUDINAL ACCEPTANCE

The longitudinal acceptance of the booster at injection and during ramping is mainly determined by the energy of the beam, the RF voltage and α.

a. RF system

The synchrotron radiation loss at maximum energy will be around 4 keV/turn, 40 W for a 10 mA beam. Assuming a pillbox type cavity with a shunt impedance of 3 MΩ and an overvoltage factor of around 7 the power dissipated on the wall of the cavity will not exceed 120 W.

The simplest solution for the ANKA-booster RF system is a 200 W solid state amplifier (as in SRS booster [8]). With this amplifier the peak RF voltage is 25 kV. The voltage is constant during acceleration. Only a low level control loop for the phase for synchronizing the booster with the pre-injector and the storage ring exists.

b. Longitudinal acceptance

Figure 5 shows the separatrix for the three boosters at 20 MeV. The maximum gives the longitudinal energy acceptance: 0.85% for the proposal, 0.5 % for the weak focusing (WF) and 1.0 % for the strong focusing (SF). The differences come mainly from the different momentum compactions of the boosters.

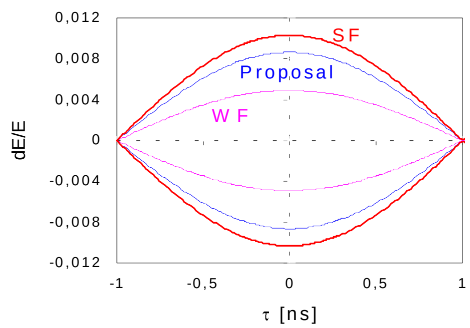

Figure 5: Separatrix for the three boosters at 20 MeV with an RF peak voltage of 25 kV.

The capture efficiency also depends on the time structure of the beam. With a bunch distance of 0.33 ns only about 4 out of 6 bunches will be accepted by the RF bucket in the booster. With a 500 Mhz pre-buncher at the exit of the gun each bunch finds a corresponding bucket.

Figure 6 shows the typical evolution of the beam envelope during ramping. Once the electrons are captured there will be no losses during the acceleration due to longitudinal oscillations since the emittance is faster reduced than the acceptance.

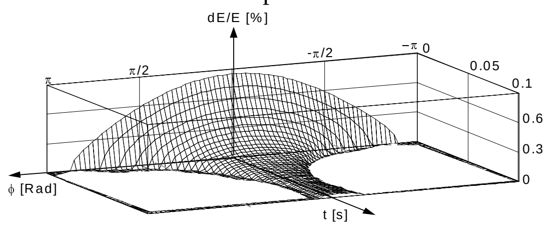

Figure 6: Evolution of the longitudinal beam envelope during ramping for the proposal booster.

The quantum lifetime depends on the momentum compaction factor: the larger α, the shorter the quantum lifetime. Assuming again a 200 W amplifier the quantum lifetime for the proposal booster and the SF is around 5 min, for the WF it is only 300 ms. With an acceleration time of 0.1 sec the WF booster will have an additional beam loss of 35% due to the quantum excitations.

4 PRE-ACCELERATOR

The pre-injector can be either a linac or a microtron. Both can be equipped with a 500 MHz prebuncher. Table 2 compares the different possibilities under the assumption that the current is 10 mA at 500 MeV. In these calculations a loss of 75% is assumed due to transversal oscillations during injection and acceleration.

	500 MHz Prebuncher	Proposal [mA]	WF [mA]	SF [mA]
Linac	Yes	70	198	54
	No	116	327	88
Microtron	Yes	14	21	14
	No	17	29	16

Table 2. Beam intensity at pre-injector exit

5 INJECTION AND EJECTION

The two types of boosters require different injection and ejection schemes. Fig. 7 shows the closed orbit distortion in the case that only one kicker for the WF and the SF booster is used for injection. The weak focusing booster needs a large aperture.

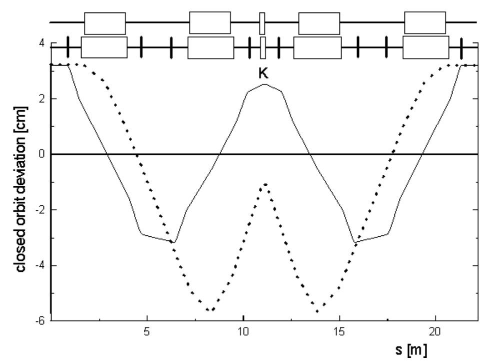

Fig. 7 Kicker bump with one kicker in a WF (dotted line) and a SF (solid line) booster. In the case of the WF booster two kickers are needed.

7 LITERATURE

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