COMMISSIONING OF THE ANKA INECTOR

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Abstract

The commissioning of the 500-MeV injector for the 2.5-GeV ANKA light source at Forschungszentrum Karlsruhe was completed in February 2000. The whole injector consisting of a 53-MeV racetrack microtron pre-injector, a 500-MeV 26.4-m circumference booster synchrotron with a 1-Hz repetition frequency, and two transfer lines has been constructed and commissioned by the company Danfysik with assistance from the University of Aarhus. At present, the injector provides a more than 50-ns long electron pulse with an average current in excess of 10 mA and an emittance of 150 nm. Additional accelerator parameters and beam properties of the injector will be presented.

Table 1: Design and achieved parameters

	Design	Achieved
Microtron energy	53 MeV	53 MeV
Max. booster energy	500 MeV	500 MeV
Circumference	26.4 m	26.4 m
Max. dipole field	1.00 T	1.00 T
Rf frequency	499.65 MHz	499.65 MHz
Tunes (hor./ver.)	1.776/1.173	1.82/1.23
Chrom. (hor./ver.)	-0.29/-2.69	2.36/-11.4 (53 MeV)
Mom. comp. factor	0.27	0.246
Hor. emit. (500 MeV)	150 nm	150 nm
Ver. emit. (500 MeV)	<10 %	1.9 nm
Repetition frequency	1 Hz	1 Hz
Cir. current (53 MeV)	>15 mA	35 mA
Extr. current	>7.5 mA	12 mA
Pulse length of extr. electron pulse	56 ns	53 ns

1 INTRODUCTION

The ANKA injector is a 500-MeV electron injector for the 2.5-GeV ANKA synchrotron which presently is being commissioned at Forschungszentrum Karlsruhe, Germany [1]. The complete injector, which has been manufactured and commissioned by Danfysik A/S with assistance from the University of Aarhus, includes a 53-MeV racetrack microtron pre-injector, a 500-MeV booster synchrotron, a transfer line between the microtron and booster synchrotron, and a transfer line from the booster synchrotron to the ANKA synchrotron. The booster synchrotron has a four-fold symmetric lattice with only one family of horizontally focusing quadrupoles, while vertical focusing is provided by the edge focusing at the end-faces of the dipole magnets. A scheme only feasible for dipole magnets, having a rather small bending radius. No sextupole magnets has been included in the lattice because the head-tail instability is of little significance for circulating currents below ~40 mA. The main parameters of the injector are outlined in table 1 together with the parameters achieved during the commissioning. Here the main results of the commissioning will be presented while the detailed design of the injector and the commissioning results of the microtron have been published previously [2,3].

2 BOOSTER OPERATION AT 53 MEV

In order to store as many electrons as possible in the booster synchrotron, the microtron beam is injected over several revolution periods of the booster synchrotron, a so-called multi-turn injection [2]. With this scheme a current of more than 35 mA can be stored during the first milliseconds after injection, suggesting that the injection process is capable of injecting the microtron beam over 5-7 revolution periods of the booster synchrotron. Initially, however, substantial beam losses (more than 75 percent) occurred during the first ~50 ms after injection even though the rf voltage was decreased to avoid a large energy spread from the matching of the 3-GHz-bunched microtron beam in the 500-MHz bucket of the booster synchrotron. It turned out that the beam loss was caused by a significant beam loading in the rf cavity due to the low rf voltage. The problem was solved by implementing a fast feedback loop in the rf system which successfully reduced the beam loading [4]. The tune dependence of the injection process has been investigated by recording the circulating current as a function of the tunes. The result is plotted in the tune diagram in figure 1, clearly demonstrating the negative effect of resonances on the circulating current. In addition, the figure reveals that the present working point at (1.82,1.23) is at a position with less space between the resonances as compared with the position of the design working point at (1.776,1.173). The displacement of the working line can be explained by a 0.4 degrees discrepancy between the actual angle between the beam axis and the dipole field boundary and the design angle of 22.5 degrees.

By recording the tunes shift when the rf frequency is changed, the horizontal and vertical chromaticities of the booster synchrotron have been determined to 2.36 and -11.4, respectively. The significant disagreement with the design values of -0.29 and -2.69 is attributed to a sextupole component in dipoles magnets, arising from a curvature of the field boundary at the end-faces.

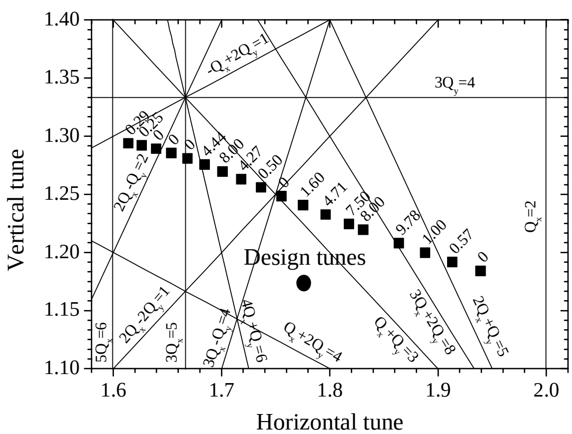

Figure 1: Circulating current in the booster synchrotron 100 ms after the injection (numbers in vicinity of square symbols). All significant non-linear resonances are indicated.

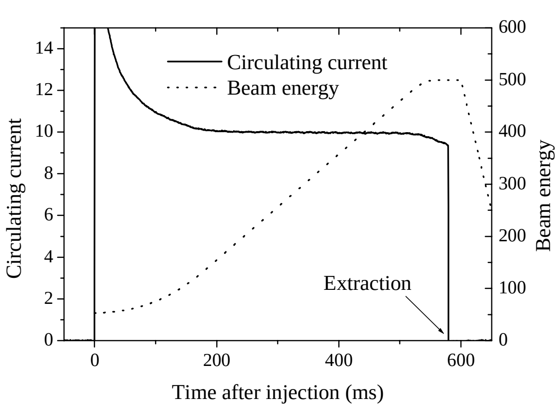

Figure 2: Circulating current in the booster synchrotron during ramping and the associated ramping curve

3 BEAM ACCELERATION

The 1-Hz ramping cycle of the booster synchrotron is performed with arbitrary-waveform supplies for dipoles, quadrupoles, and the horizontal correctors whereas the vertical correctors are operated in dc mode. During ramping the beam is accelerated by means of one rf cavity which is being feed by a 200-W solid state amplifier, providing an accelerating field up to 30 kV [5]. The circulating current in the booster synchrotron during ramping is plotted in figure 2, demonstrating that the beam losses above 200 MeV are very small. However, there is a small drop in the beam current at full energy which is associated with insufficient low level rf power, a consequence of the fast feedback loop [4]. The smooth start of the ramping curve in figure 2 is chosen because it provides more constant tunes during acceleration, making the beam less sensitive to non-linear resonances. The measured tune variation during ramping in figure 3 illustrates the small variation of the tunes throughout the whole ramp.

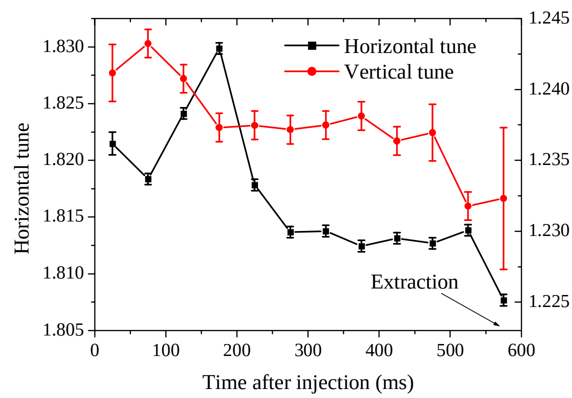

Figure 3: Horizontal and vertical tune variation during ramping.

In addition, a smooth outset of the ramping curve reduces the effect of induced eddy currents in the dipole vacuum chamber which is proportional to the time derivative of the bending field. The eddy currents can be harmful to the beam because these produce a magnetic field with a sextupole component, leading to a modification of the chromaticities which may produce a large tune spread of the beam. The chromaticities are changed by

$$\Delta\xi_x = \frac{1}{4\pi}\oint \beta_x m D_x \mathrm{d}s = K_x m \qquad (1)$$

$$\Delta\xi_y = -\frac{1}{4\pi}\oint \beta_y m D_x \mathrm{d}s = K_y m \qquad (2)$$

where β_x (β_y) is the horizontal (vertical) beta function, $m=\mathrm{d}^2B_y/\mathrm{d}x^2/(B\rho)$ is the sextupole strength, D_x is the horizontal dispersion function, B is the bending field, and ρ is the bending radius. If the modified boundary conditions in the presence of the dipole iron yoke is neglected, the eddy current-induced sextupole strength for a rectangular vacuum chamber is

$$m = \frac{8}{\pi}\frac{\mu_0\sigma}{\rho}\frac{\mathrm{d}B/\mathrm{d}t}{B}\frac{d\,b^3}{\left(a^2+b^2\right)^2} \qquad (3)$$

where μ_0 is the vacuum permeability, σ is the conductivity of the vacuum chamber, d is the vacuum chamber thickness, a is the vacuum chamber width, and b is the vacuum chamber height. Besides, a commonly used approximate formula for the eddy current-induced sextupole strength which partly takes into account the effect of the iron yoke is

$$m = 2\frac{\mu_0\sigma}{\rho}\frac{\mathrm{d}B/\mathrm{d}t}{B}\frac{d}{g} \quad (4)$$

where g is the dipole gap [6]. The formulas (1)-(4) suggest the following model for the chromaticity variation during ramping (analog expression for ξ_y):

$$\xi_x = \xi_{inj,x} + \alpha K_x (B - B_{inj}) + \lambda K_x \frac{\mathrm{d}B/\mathrm{d}t}{B} \quad (5)$$

where $\xi_{inj,x}$ is the horizontal chromaticity at the injection energy, α accounts for a linear variation with B of the sextupole field at the end-faces of the dipoles, and λ determines the strength of the eddy current-induced chromaticity shift. For the rectangular dipole chamber of the booster synchrotron, a=26.5 mm, b=70 mm, d=1.5 mm, σ=1.35·10^6 (Ωm)$^{-1}$, ρ=1.67 m, and g=30 mm, yielding λ=0.042 and λ=0.102 for expression (1) and (2), respectively. In figure 4 the model is fitted to actual measurements of the horizontal and vertical chromaticity during ramping, revealing a good agreement with the chromaticities measured at the injection energy. However, the obtained value of λ is in between those found with expression (1) or (2), indicating that the formulas only should by be used for estimations.

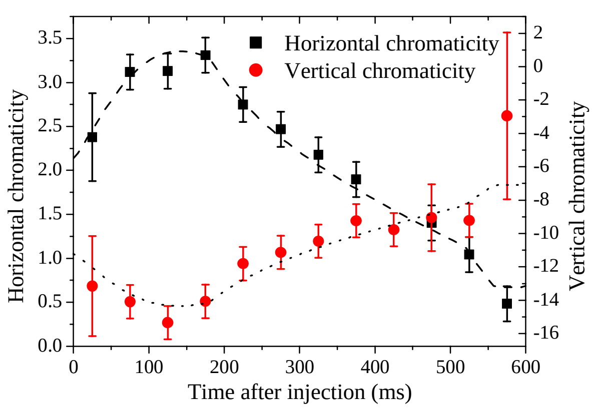

Figure 4: Horizontal and vertical chromaticity variation during ramping. Dashed curve: Model with the parameters $\xi_{inj,x}$=2.1, α =-7.8·10^{-4}, and λ=0.078 (see text). Dotted curve: Model with the parameters $\xi_{inj,y}$=-11.2, α=-8.2·10^{-4}, and λ=0.076 (see text).

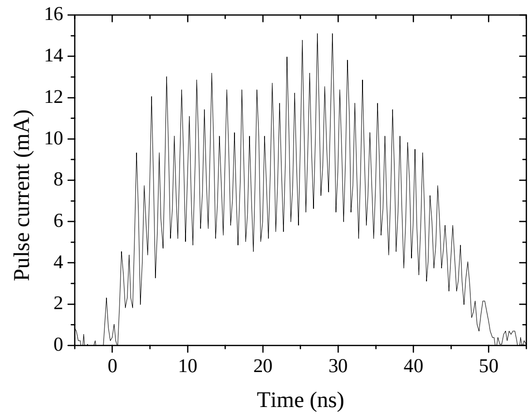

Figure 5: Extracted electron pulse.

4 THE EXTRACTION PROCESS

The electron beam is extracted from the booster synchrotron in a one-turn process, involving a fast kicker, a pulsed septum magnet, and separate windings in four dipoles magnets which displace the closed orbit towards the extraction septum during the last 40 ms before extraction. Initially a closed orbit distortion caused by the stray field of the septum magnets resulted in beam loss during extraction. However, after improved shielding of the septum field and the installation of four ramped horizontal correctors for closed orbit correction at full energy, the extraction process proceeds with close to 100 percent efficiency for a wide range of kicker and bumper settings. Figure 5 shows a measurement of the extracted electron pulse with a pulsed current transformer in the extraction beam line. The revolution period of the booster synchrotron is 88 ns whilst the rise time of the extraction kicker is 20-30 ns, resulting in typical pulse lengths of the extracted electron pulse in the vicinity of 50 ns.

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