BEAM MEASUREMENTS AND MANIPULATION OF THE ELECTRON BEAM IN THE BESSY-II TRANSFER LINE FOR TOPPING UP STUDIES

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Abstract

The BESSY-II storage ring based synchrotron radiation source will be upgraded to allow for continuous topping up operation. In order to achieve a high injection efficiency between the booster synchrotron and the storage ring, the transfer line will be equipped with novel beam size monitors and collimators. This paper describes the collimator design and first beam measurements of the transverse emittance. The transverse emittance is measured using the quadrupole scan technique. The data taking and the analysis procedure is given together with results and comparison with simulations.

MOTIVATION

Nowadays, more and more synchrotron light sources operate in topping up mode already (for example [1]). BESSY is planning to implement topping up mode operation for the BESSY-II [2] facility in the near future. In this mode lost electrons are continuously replaced. This leads to a constant heat load on optical components and increases the average brilliance. The disadvantage is the potential risk of injecting beam with open beam shutters. Radiation safety requires an injection efficiency close to 100 %. At BESSY-II the injection efficiency is at best 80 %. The unfavorable distribution of particles was suspected to be partly responsible for that. In order to get a better understanding of the injection process the particle distribution was studied during the acceleration in the fast cycling synchrotron [3] and in the transfer line [4] at the extraction energy of 1.72 GeV. The measurements and results for the transverse emittance and the energy spread will be presented and compared to the theoretical expectations. The injection efficiency can be improved by cutting away the transverse tails of the particle distribution [5]. Therefore, a set of collimators was installed at strategic locations in the transfer line. The collimators are combined with novel screens.

TRANSFER LINE

Layout

The layout of the transfer line between the booster synchrotron and the storage is depicted in Fig. 1. The lattice is modeled on the lattice of the storage ring in order to provide proper matching of the beam from the transfer line into the storage ring. Scraper collimators have been installed at two locations with appropriate phase advance with respect to the injection septum. At another location a first stage halo collimator was installed.

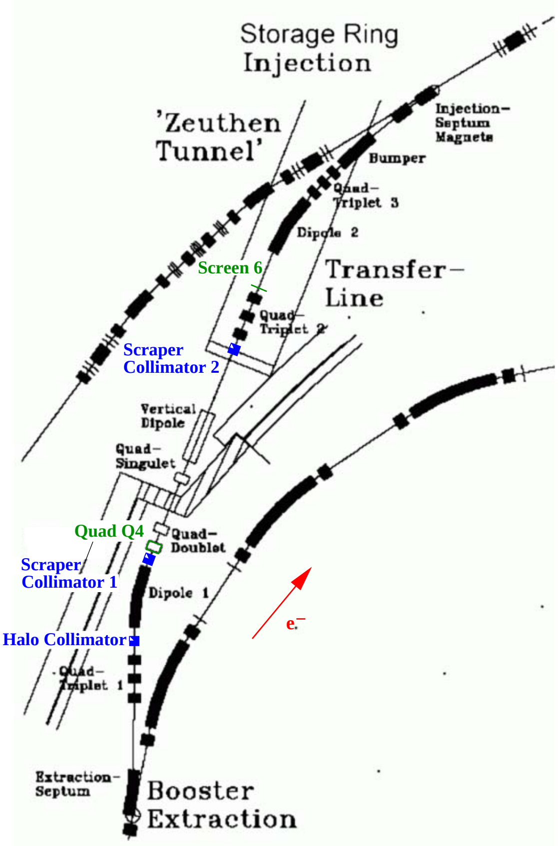

Figure 1: Layout of the transfer line between booster and storage ring, beam collimators (blue) and quadrupole scan elements (green) are highlighted.

Linear Beam Optics

The linear optics of the transfer line is shown in Fig. 2. The starting conditions of the Twiss-parameters are the results of optics measurements in the booster synchrotron: At the time of extraction, when the energy reached 1.72 GeV for the first time, tunes were measured as a function of the two quadrupole families in the synchrotron and

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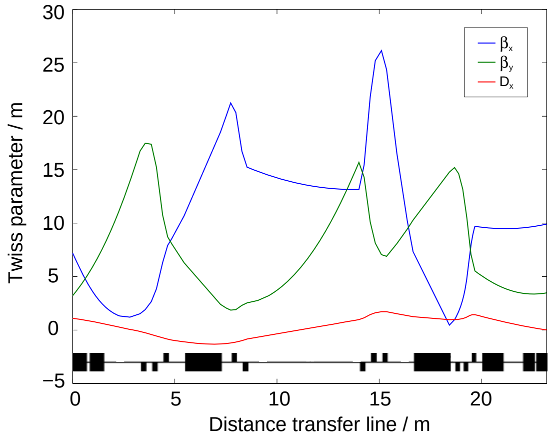

Figure 2: Twiss-parameters for transfer line.

the findings agree very well with the predictions of the theoretical linear model [3]. Due to the simple FODO-lattice this approach leads to a perfect knowledge of all relevant lattice parameters including the momentum compaction factor α. Knowing this parameter and if the beam is in equilibrium the momentum of the beam dp/p can be changed by varying the RF frequency df_{rf}/f_{rf}, according to $dp/p = -1/\alpha\, df_{rf}/f_{rf}$. This was used to measure the dispersion function at all screens along the transfer line. The results are in fair agreement with the model expectations. In preparation for the emittance measurement the dispersion at Screen 6 was measured with orbit displacements as function of beam energy variation and found to be $D_x|_{Screen6} = (1.8 \pm 0.1)$ m.

EMITTANCE MEASUREMENTS

Booster Synchrotron

The horizontal beam size during the acceleration of the beam in the synchrotron was measured by imaging visible dipole synchrotron radiation onto a gated CCD-camera. The result is shown in Fig. 3. For each data point 20 images were captured, the background was subtracted and a Gaussian distribution function was fitted to the horizontal projection of the intensity distribution. The final RMS-width is corrected for the finite resolution of the imaging system $\sigma_{res} = 0.8$ mm. At $t = 0$ the beam is injected from the 50 MeV microtron. Within 33.7 ms the energy is ramped up to 1.72 GeV and at 44 ms the maximum of 1.9 GeV is reached. The energy variation is sinusoidal due to the white circuits employed. Since the dispersion function amplitude is in the order of 1 m at the dipole where the horizontal beam size is observed, the measured spot size contains a rather large contribution from the energy spread. A longitudinal many particle tracking code was used to calculate the energy spread of the beam during the acceleration. The results are similar to the behavior of the transverse emittance [6]. At first and up to 20 ms the adiabatic damping dominates the total beam size and shrinks it below the values given by the radiation equilibrium. In the longitudinal dynamics this equilibrium is reached already at the extraction time due to the faster damping. The transverse emittance follows much slower and reaches the radiation equilibrium only at maximum energy and at later times. The result of the calculation is shown as a line in Fig. 3 and agrees quite well with the measurement. Therefore, at 1.72 GeV the energy spread is given by the equilibrium value of $\sigma_\epsilon = 5.7 \cdot 10^{-4}$ [7] and the transverse emittance is 40% smaller than the equilibrium value of $\varepsilon_{nat} = 1.3 \cdot 10^{-7}$ m rad.

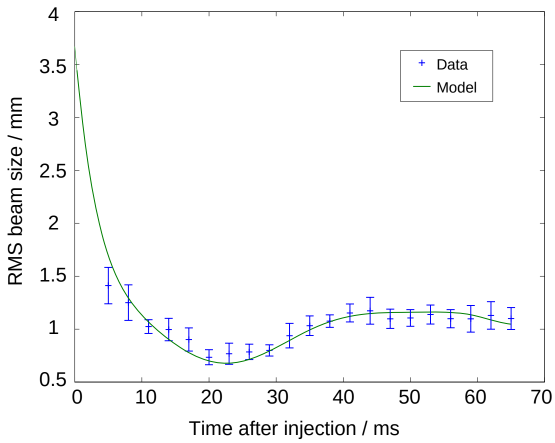

Figure 3: Development of RMS beam size during acceleration in the booster synchrotron.

Transfer Line

As a cross-check the emittance of the beam in the transfer line was measured using the quadrupole scan technique [8]. With this method the quadrupole current I_q is changed and the horizontal beam size is monitored. The transfer Matrix M_{ij} between the quadrupole magnet and the screen station (here quad Q4 and Screen 6, see Fig. 1) is known. Therefore the measured beam size σ_{S6} can be expressed in terms of the transfer matrix and the initial beam conditions at the quadrupole according to

$$\sigma_{S6}^2 = M_{11}^2\langle x^2\rangle + 2M_{11}M_{12}\langle xx'\rangle + M_{12}^2\langle x'^2\rangle + M_{13}^2\sigma_\epsilon^2. \tag{1}$$

In this equation the transport matrix elements $M_{11}(I_q), M_{12}(I_q)$ and $M_{13}(I_q)$ depend on the quadrupole current I_q, which is varied during the measurement, and the central moments of the beam distribution, i.e. $\sqrt{\langle x^2\rangle}$ beam size, $\sqrt{\langle x'^2\rangle}$ beam divergence and $\langle xx'^2\rangle$ correlation between size and divergence. The beam energy spread is described with σ_ϵ. At the entrance of the quadrupole the emittance can be obtained according to

$$\varepsilon_x = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}. \tag{2}$$

Two different systems were used to measure the horizontal beam size: with the scraper collimator by knife-edge measurements and with the screen station Screen 6. The two systems are not at the same location as visible in Fig. 1.

Collimator Measurements For each quadrupole setting the collimator is moved horizontally through to the beam and behind the following dipole magnet the remaining transmission is measured. The data for the transmitted current as a function of the scraper collimator position is the integrated beam size and can be described using the error function which describes the integrated beam size σ_x.

Results for three different measurements are shown in Fig. 4.

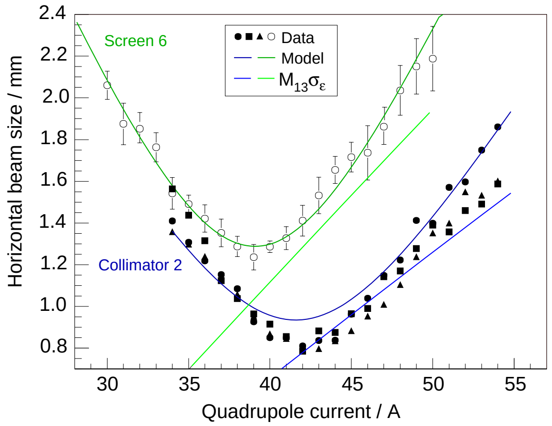

Figure 4: Data and analysis for screen and collimator measurements. In addition to the data, the linear transport matrix reconstruction and the energy spread term is given.

Viewscreen Measurements The second method is based on the monitoring of the transverse beam size by the viewscreen station Screen 6. In a viewscreen station a luminescent Phosphor coated foil can be moved into the beam path. For each quadrupole setting a couple of beam images is captured using a CCD camera. A Gaussian function is approximated to the horizontal projected image data and finally the beam size and error estimates are obtained. In Fig. 4, results for one measurement according to this method are shown, too.

The minimum beam size measured at the scraper collimator location and at the screen station is differs as these screen station is separated by some distance in the lattice of the transfer line. The resulting beam sizes are in agreement with the linear model of the transfer line lattice.

From the resulting beam size measurements with collimator and screen stations, the initial beam parameters at the entrance of the quadrupole can be re-constructed using the transfer matrix formalism. If the energy spread σ_ϵ is known, only the three central moments are necessary to fully describe the transverse distribution at the entrance of the quadrupole. In addition the result of equation 1 with the beam parameters from the screen station are computed at the position of the collimator. One can see that the adapted function describes the measured data on the collimator. Only at the minimum the measured beam size is lower compared to the expectation.

In Fig. 4, the straight lines are the energy spread dependent term $M_{13} \cdot \delta$ at screen and collimator location. The energy spread with the dispersion becomes dominant for high currents. The horizontal beam parameters determine the beam size at lower currents. With the transverse moments the emittance can be estimated to $\varepsilon = (0.82 \pm 0.08) \cdot 10^{-7}$ rad m. From the measurements described above in the booster synchrotron a expected value for the emittance at the extraction time into the transfer line is 60 % of the equilibrium value of $\varepsilon_{nat} = 1.3 \cdot 10^{-7}$ m rad.

CONCLUSION AND OUTLOOK

In the framework of topping up studies beam parameters at extraction time of the booster synchrotron and in the transfer line between booster and storage ring are studied. The initial beam conditions for the transfer line were measured in the booster synchrotron and served as input for the linear optics model and for the emittance measurements in the transfer line. Expectations on a reduced emittance at extraction time due to adiabatic damping can be confirmed by measurements in the transfer line. The emittance in the transfer line is measured using the quadrupole scan technique. Viewscreen monitors and collimator scans are applied for beam size measurement.

In the next steps the scraper collimators will be commissioned. In order to use these devices efficiently, each collimator station will be upgraded with high resolution viewscreen monitors. Materials considered for beam imaging are fused silica wafer coated with thin Al films and Ce:YAG powdered Al carriers.

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