SINGLE DIPOLE KICKER INJECTION INTO THE SESAME STORAGE RING

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Abstract

SESAME (Synchrotron Radiation Light Source in Allan, Jordan) consists of an 800 MeV injector (original from BESSY I, Berlin, Germany) and a 2.5 GeV storage ring. Extraction out of the Booster is done by means of a bumper, a delay-line kicker, and a direct driven in-vacuum septum. This paper will present the injection procedure into the storage ring. Simulations of the injection process are compared to the results obtained during commissioning.

INTRODUCTION

In general injection into a storage ring is achieved by moving the stored beam by closed bump towards the septum. The bump is achieved by means of three or four kicker magnet. The injected beam enters the storage ring with a small offset to the bumped beam and does betatron oscillations around the stored beam before being damped and becoming part of the stored beam. Ideally the orbit of the stored beam is not effected outside the kicker region and remains unchanged for any beamline, in practice the action of the kickers cannot completely be compensated for the complete kicker pulse, respectively a not completely closed bump enhances the injection process. As a result also the stored beam performs small betatron oscillations which might disturb the synchrotron radiation in beamlines in topping up operation. To overcome this problem a pulsed multipole magnet had been proposed, which would not affect the stored beam in its centre but would allow kicking the injected beam being off centre towards the centre if an appropriate location is selected. This scheme is in use or under examination at several SR sources [1,2] and has also been investigated for SESAME. The additional advantage is being achieved with only one magnet. For SESAME still not having a full energy injector the stored beam is allowed to oscillate during the injection process, thus injection with one dipole magnet only might be feasible, kicking the injected beam in and the stored beam a bit out and having both damped together. This would further simplify the magnet. All options have been investigated and the injection with the dipole kicker has been realized.

THEORY

After injection the beam oscillates with large amplitude, depending on the distance from closed orbit and injection angle. Following notations given in [2], let's look at the motion of injected particle in normalized phase space. Coordinates in this space are defined as,

$$X = \frac{x}{\sqrt{\beta}}, \quad P = \frac{\alpha x + \beta x'}{\sqrt{\beta}} \tag{1}$$

The motion of particle around the ring becomes a motion around the circle (Fig. 1). Radius of this circle is the square root of Courant-Snyder invariant.

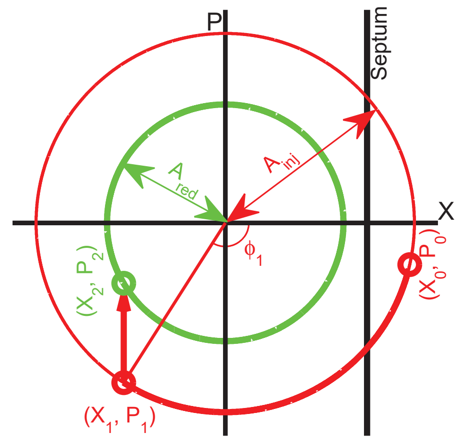

Figure 1: Motion of injected particle in normalized phase space.

The beam is injected with coordinates X_0, P_0. It will oscillate with amplitudeA_{inj} and would hit the septum wall after some turns. To avoid this, the amplitude of the oscillation is reduced by a kicker magnet moving the beam from coordinates X_1, P_1, to X_2, P_2 with reduced radius A_{red}. The location of the kicker has to be chosen as compromise between low kicker strength (large X_1 in case of multipoles)and low final amplitude. Using some geometry relations it is possible to find relationships between reduced amplitude A_{red} and the kick angel (θ) of pulsed magnet.

$$\theta = \frac{A_{inj}|\sin\phi_1| - \sqrt{A_{red}^2 - A_{inj}^2\cos^2\phi_1}}{\sqrt{\beta_1}} \tag{2}$$

As possible locations the first eight straight after the injection septum was investigated. Injection feasibility with dipole, quadrupole, sextupole and nonlinear kicker was studied. Injection with single dipole magnet was chosen because of simplicity of the magnet and price of solution. Here we will present only injection scheme with dipole magnet.

INJECTION BY DIPOLE KICKER

In this scenario the stored beam is disturbed by the kicker. The beta function in all possible locations is approximately the same 13.5 m and the septum sheet at 19.5 mm is the limiting aperture. Each candidate location was examined with

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Eq. (2), and kicker strength was chosen as a compromise between amplitudes of stored and injected beam (Fig. 2). The

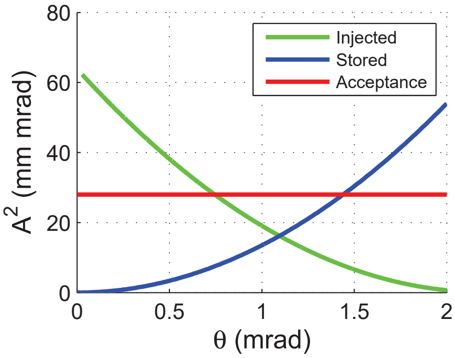

Figure 2: Normalized amplitudes of the injected and stored beam as a function of kicker strength at straight 5.

5th straight after septum was chosen as the best matching with respect of kicker strength and A_{red}. According to the simulations 1 mrad. kick was adequate for injection and also amplitude of stored beam remains well beyond the acceptance of machine. Figure 3 shows the trajectory of injected beam with and without kicker for 1 mrad. kick at straight 5. Figure 4 shows phase space of injected and stored beam for first 4 turns, at septum location. Injection efficiency is 99%. Injection efficiency tolerances for injection timing, injection angle, quadrupole position and tilt errors, and fractional strength error of magnets was studied and found to be acceptable. Another advantage of the straight 5 was that it would be possible to do on axes injection in the first steps of commissioning.

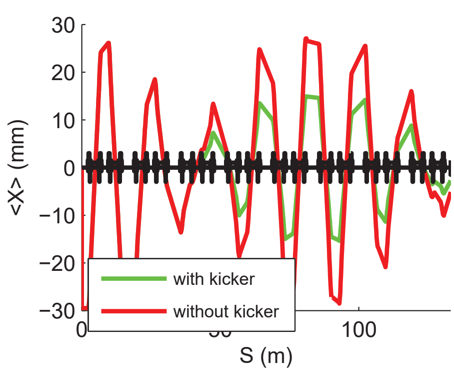

Figure 3: Trajectory of injected beam with and without kicker.

EXPERIMENTAL RESULTS

In the early stages of commissioning it was noticed that the accumulation rate was very poor at the design tune. Changing horizontal tune from the design tune (7.23) to 7.44 (optimized tune) and increasing kicker strength to 1.8 mrad significantly increased the accumulation rate. A closer look to the parameters of injection revealed that the length of

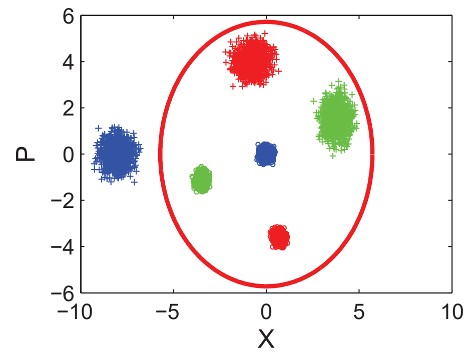

Figure 4: Normalized phase space of injected and stored beam for 1 mrad. kick at location 5. First 3 turns after injection are shown. Circles are the injected beam and crosses stored. Color code: Blue - first turn, Red - second, Green - third.

the kicker pulse is approximately 1.2 µs instead of 0.8 µs as expected. This means that both injected and stored beam will see at least two kicks.

The impact of a second kick can be qualitative understand by looking into normalized phase space (Fig. 5). A second kick for the injected beam (red) will increase the final amplitude for both working points. In case of the design tune (top plot) where the phase of the beam in the second passage of the kicker is close to π, the increment is smaller. It should be noted, that a second kick to the injected beam in both cases can be avoided by injecting at the falling part of the kicker pulse, but for this case the peak of the pulse had to be larger than the needed kick for the injection.

Concerning the stored beam (blue), the second kick in case of the design tune will continue to increase the amplitude and in case of a stronger kick can be moved out of acceptance. In case of the optimized tune (Fig. 5 bottom), the second kick to the stored beam is compensating the first one and the limiting criterion for the kicker strength will be the amplitude of the beam after first kick. For more detailed analysis of the injection process multi-particle simulations for the stored and injected beam were done for the longer kicker pulse length using elegant [3]. According to this simulation, the injection efficiency in case of 1 mrad kick is more than 90 % for the design tune, (Fig. 6). Unfortunately this was not confirmed by experiment. Reason is most probably the fact, that the final amplitude and beam size of the stored beam is bigger than expected and close to the acceptance of the machine, which might be smaller due to the orbit distortions and other effects. More detailed experimental and tracking studies are foreseen for better understanding of the process. As can be seen from Fig. 6 in case of optimized tune injection efficiency is very sensitive to the arriving time of the injected beam and rather limited to the falling edge of the pulse. Taking into account, that the duration of the pulse from the booster is 100 ns, it is obvious that increasing the kicker strength above 1 mrad should improve the injection. According to tracking studies, kicks up to 2 mrad are safe

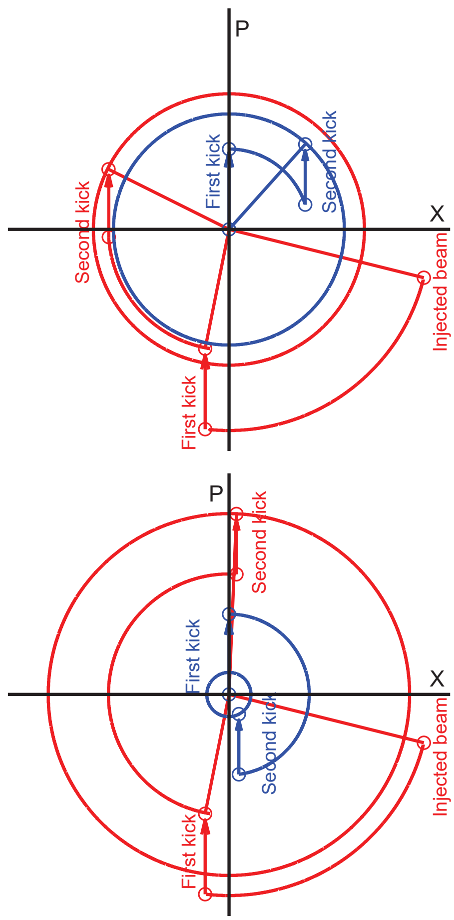

Figure 5: Visualization of injection process in normalized phase space. Top plot: design tune (7.23). Bottom: Optimized tune (7.44). Blue color is for stored beam and red for injected. Scales do not correspond to the real case. Pictures are for illustration purpose.

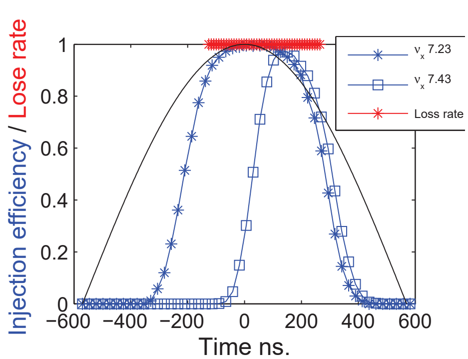

Figure 6: Injection efficiency and loss rate for design and optimized tunes. 1 mrad. kick was used for simulation. Loss rate is calculated as the ratio between number of particle survived after 200 turns and initial number of particles.

for the stored beam and above 2 mrad parts of the stored beam will be lost depending from the arrival time. This was confirmed also by experimental studies. Figure 7 shows the injection rate in dependence of the arriving time of the injected beam for 4 different kicker strengths. The break in the 1.8 mrad line is an artifact of the measurements. The Measurement was done in two steps and the points below 350 ns for 1.8 mrad kick, was not optimized for injection angle. The reference point for the time is arbitrary since the delay in the signal lines compared to the delay of the beam in the transfer line is not exactly known.

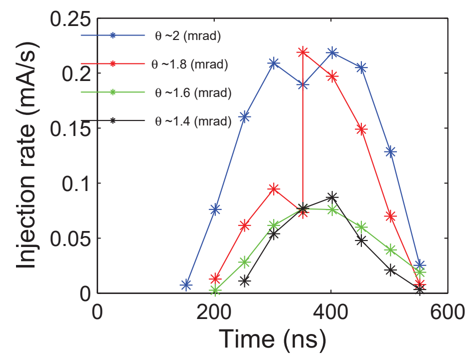

Figure 7: Accumulation rate as a function of injection timing for 4 different kicker strength.

CONCLUSION

Single dipole injection scheme for SESAME storage ring was studied and implemented. Pulse length of the kicker is longer than required, nevertheless >80 % injection efficiency is achieved with optimizing working point. More studies are planed for better understanding of injection problems at design tune.

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