MEASUREMENT OF THE LNLS ELECTRON STORAGE RING BEAM TRANSVERSE ACCEPTANCE

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Abstract

We describe a simple method to determine the parameters of the beam transverse acceptance in a storage ring at the position of a kicker. Basically the injection capture efficiency is measured as a function of the beam initial conditions in phase space. We use the kicker to scan the initial angle coordinate and use steering of the injected beam to scan the initial position coordinate. We present and discuss the results of the measurements performed on the Brazilian Synchrotron Light Source (LNLS) UVX electron storage ring.

1 INTRODUCTION

Various performance parameters of a storage ring depend directly on the size of its transverse acceptance. Parameters such as injection efficiency and beam lifetime can be seriously compromised if the acceptance is too small. Not surprinsingly a lot of effort is put in acceptance optimization during a storage ring design phase, e.g. refs. [1,2]. However, direct acceptance measurement is not common in normal operation mode. In most beam dynamics experiments, where the distribution in phase-space is observed, the beam is driven close to ressonance conditions and turn-by-turn beam position monitors are employed [3,4]. These monitors require non-trivial hardware development specially in the case of small storage rings where the revolution period is short. The overall aperture can also be accessed by measuring beam lifetime as a function of scraper position [5]. In this report we describe a simple way to assess the phase-space distribution of the transverse acceptance in a storage ring without using turn-by-turn BPMs. The linear optics is supposed to be known. We measure the injection capture efficiency for various beam initial conditions in phase space. A fast injection kicker is used to scan the angle coordinate and orbit steering at injection point is used to scan the position coordinate at the kicker location.

We present in this paper an experimental application of the proposed method to the Brazilian Synchrotron Light Source (LNLS) electron storage ring, a 1.37 GeV machine dedicated to the production of synchrotron radiation.

2 THEORETICAL DESCRIPTION

The Hamiltonian that describes transverse electron motion in a storage ring in linear approximation is given by

$$H = \frac{1}{2}x'^2 + \frac{1}{2}K(s)x^2$$

where (x,x') are conjugate phase-space coordinates and K(s) is the quadrupole gradient function. The trajectories described by this equation follow ellipses in phase-space as a function of the longitudinal azimuth s. The acceptance is defined as the maximum phase-space area where particles can survive in the accelerator. It can be determined by physical limitations, such as the vaccum chamber size or the kicker aperture; or by dynamical effects associated to non linear magnetic fields. To achieve good performance of an accelerator, the acceptance must be much larger than the beam emittance. Furthermore, it must accommodate the large amplitude oscillations of the injected beam during the injection process.

The method we are proposing for the acceptance measurement consists in scanning the initial conditions of the injected beam in phase space at the azimuth of a kicker and looking at the injection capture efficiency, or the fraction of the charge delivered by the booster that is captured by the storage ring. The injection efficiency reflects the position of the injected beam with respect to the acceptance. The kicker's azimuth is taken as the initial position for beam motion in the storage ring. This reference kicker is used to deflect the beam in its first passage through it, thus the angle coordinate can be scanned and a slice of the acceptance can be probed (Figure 1).

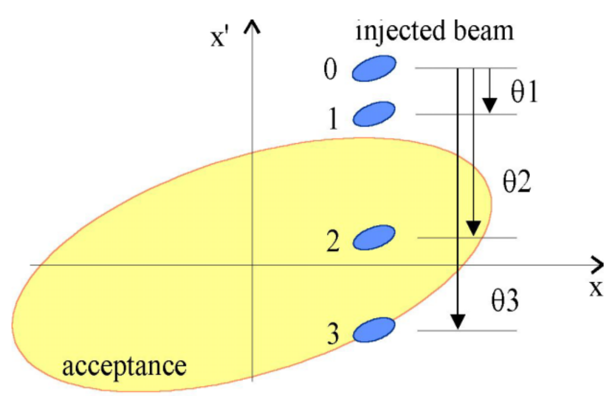

Figure 1: Phase-space at the azimuth of a kicker at the first passage of the injected beam. Angular scanning of the acceptance for a fixed position. The small ellipse 0 shows the beam before the kick. Ellipses 1, 2 and 3 show the beam after the kicker deflections θ1, θ2 and θ3, respectively. The corresponding injection efficiencies should be zero, maximum and small respectively.

The transverse position of the beam at the kicker can be varied by steering the injected beam at the end of the transport line. The injection efficiency can also reveal some structure of the acceptance border if the injected beam distribution is sufficiently small and well known.

Many difficulties may arise in this experiment. One is the limitation in the kicker strength since ideally we should be able to cross the acceptance height. To minimize this problem it is desirable to have the kicker at a high betatron function place. A small α (the Twiss function, $\alpha = -\beta'/2$) is also convenient since the ellipse is more upright. There are also many sources of systematic errors such as variations in the injected beam conditions from pulse to pulse, errors in the kicker and current monitor calibrations, etc.

3 EXPERIMENTAL RESULTS

The LNLS UVX electron storage ring is a 1.37 GeV machine used as a synchrotron radiation source. Injection into UVX takes place from a 500 MeV synchrotron booster. Three kickers are used to produce a closed bump in the stored beam orbit during injection of a new beam from the booster. (See figure 2). The experiments are performed at the injection energy (500 MeV). We choose kicker AKC03 for our experiments according to the criteria of maximum betatron function. AKC03 is also the optimum place due to the fractional betatron phase advance from the injection point. The phase advance is close to 90 degree, which makes the position at AKC03 very sensitive to the angle at the injection point. Some relevant optical parameters for our experiment are shown in Table I.

Table I: Optical parameters at LNLS UVX kickers.

	β_x (m)	α_x	μ_x (2π)
Injection point	14.056	-0.112	0.018
AKC03	14.075	0.118	5.251

The kicker AKC04 has also been used at a fixed value to allow the injected beam to reach AKC03 at optimum position. The timing of the kickers have been adjusted so that the incoming beam sees the kicker pulse close to the falling edge. This is to ensure just one kick per kicker on the incoming beam.

Figure 3 shows the results of several angular scans using the kicker AKC03. Each scan corresponds to a different initial position in phase space at AKC03. We consider the beam with a Gaussian distribution in x'. For each scan we fit a curve that is a convolution between the gaussian beam and a square function representing the angular width of the scanned acceptance slice. See figure 4. In this model we are assuming that the beam size is small. This approximation should be worst when probing the extremities of the acceptance where the beam distribution in x should also be taken into account.

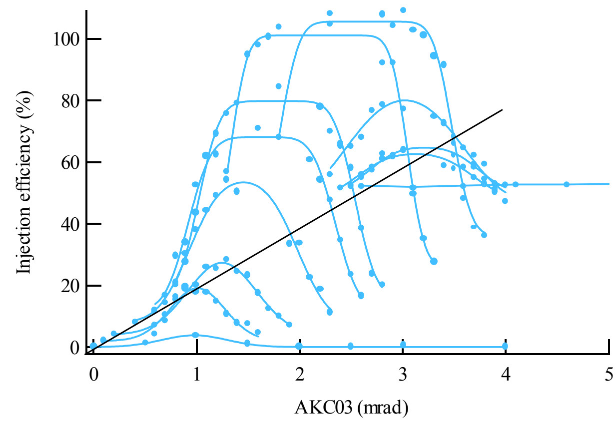

Figure 3: Angular scans using the kicker AKC03. Each scan corresponds to a different initial angle, and hence, to a different position in phase space at AKC03.

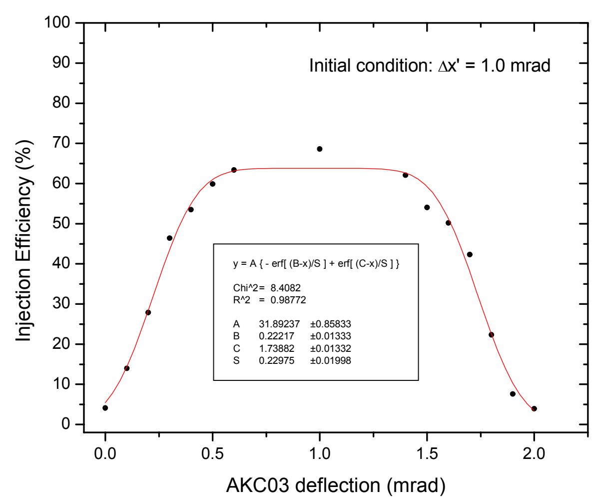

Figure 4: Fitting the measured data with a convolution between the gaussian beam and a square function representing the angular width of the scanned acceptance.

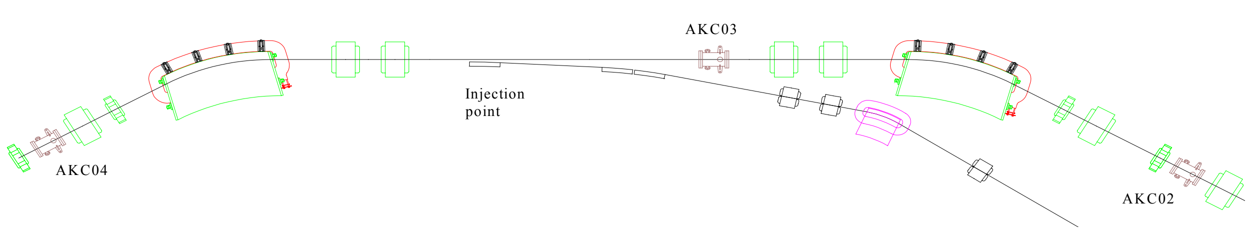

Figure 2: Schematic view of the LNLS UVX superperiod showing the three kickers and the injection point.

To observe the acceptance at AKC03 we must relate the angular variation at injection point to the position and angle variation at AKC03. The transfer matrix between the two points is used for this purpose. The results are shown in figure 5. We can see a small variation in angle whereas a large variation in position is achieved. The measured acceptance limits are then obtained at the kicker position. We define a χ^2 merit function and determine the best-fit ellipse parameters β, α and ε by its minimization:

$$\chi^2 = \sum_{i=1}^{N} \left[\gamma x_i^{\,2} + 2\alpha x_i x_i' + \beta x_i'^{\,2} - \varepsilon \right]^2 \qquad (1)$$

where γ is $(1+\alpha^2)/\beta$.

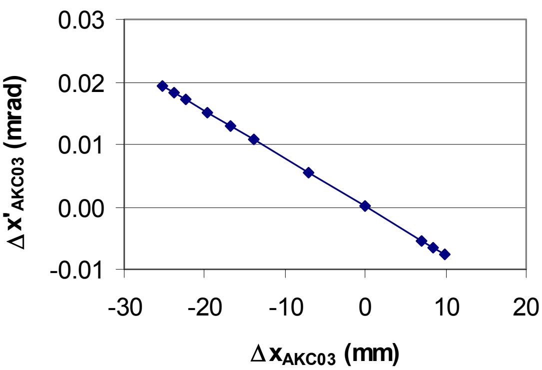

Figure 5: Initial positions for angular acceptance scanning at AKC03.

We note that there is an offset of the ellipse centroid in our measurements. This is due to the fact that we know the variations in position and angle at AKC03 but not the absolute coordinates. Even if the position and angle at the injection point could be measured with high accuracy, the coordinates at AKC03 would still be unkown since the orbit correctors and the misalignment of the magnets introduce deviations in the orbit. However, the coordinate variations are known with high accuracy and an offset in position and angle just introduce a corresponding offset in the ellipse centroid. In this way, we introduce two more unknown parameters in equation (1) in the form of an offset for the ellipse: $x_i \rightarrow x_i + x_0$ and $x_i' \rightarrow x_i' + x_0'$. Figure 6 shows the measured points for the LNLS UVX acceptance in phase space at AKC03 (dots) and the fitted ellipse. The maximum allowed acceptance (limited only by the vacuum chamber) with nominal optics is also shown.

We have found the following values for the acceptance ellipse:

Parameter	Measured	Nominal optics
β_x (m)	20 ± 0.5	14.1
α_x	0.24 ± 0.05	0.12
ε_x (m.rad)	(1.6 ± 0.02) 10^{-5}	-

The errors above were derived from the χ^2 fitting assuming that all measurements are equally good. The systematic errors and relative weight of measured points are not taken into account at this stage. The differences in β_x and α_x are probably due to the inaccuracy of the model near the acceptance extremities since the finite size of the probing beam tends to elongate the measured ellipse. The measured acceptance size, on the other hand, agrees with the fact that we need to introduce a 6.5 mm DC closed bump at injection.

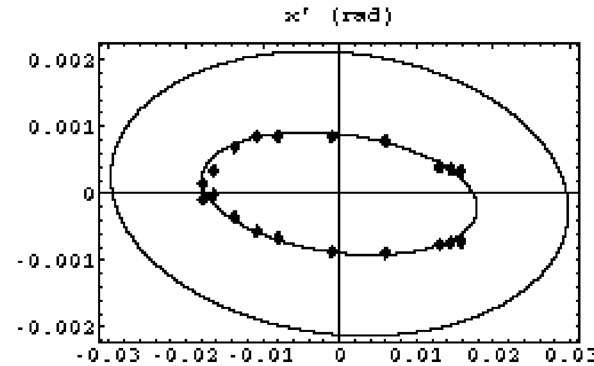

Figure 6: Measured points (dots) for the LNLS UVX acceptance in phase space at AKC03, the fitted ellipse and the maximum allowed acceptance (limited by the vacuum chamber) with nominal optics.

4. CONCLUSIONS

We have measured the phase space acceptance of the LNLS UVX electron storage ring at the injection energy (500 MeV) with a new and simple technique. For the injection capture measurement we need a current monitor and for the phase space scanning we need a fast kicker and beam steering at the injection point. The results for the LNLS UVX show a measured acceptance that is smaller than the maximum value allowed by the vacuum chamber size, as expected. The smaller value is compatible with the empirical implementation of a DC bump at injection. We are currently analysing methods to improve the measurements such as producing a short pulse from the Linac. This could minimize the effect of the beam energy spread on the injection efficiency. The model can also be improved to include the finite transverse beam size. A smooth model for the acceptance border could also reveal some aspects of this border such as the width of the chaotic region if the beam size is well known.

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