SIMULTANEOUS MEASUREMENT OF EMITTANCE AT THE STORAGE RING AND THE EXTERNAL BEAMLINES OF ELSA*

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Abstract

The Electron Stretcher Facility ELSA consists of several accelerator stages, the last one being a storage ring providing a beam of polarized electrons of up to 3.5 GeV. To ensure a high duty cycle, a slow extraction via a third integer resonance is applied at ELSA. The resonance extraction causes a variation of the emittance in the external beamline. A system for simultaneous measurements of the emittance in the storage ring and the external beamlines has been installed. First results including a comparison of both emittances will be shown.

INTRODUCTION

At the Electron Stretcher Facility ELSA, a slow extraction via a third integer resonance ensures a high duty cycle. This extraction mode generates nonlinear particle motions. Due to this nonlinear behaviour, the emittance, which is a constant quantity in the stretcher ring, is changed during the extraction. Simultaneous measurements in the stretcher ring and in the external beamline to investigate the influence of the actual setting of the extraction optics on the emittance are required. At the stretcher ring, the beam profile can be measured by a synchrotron light monitor.

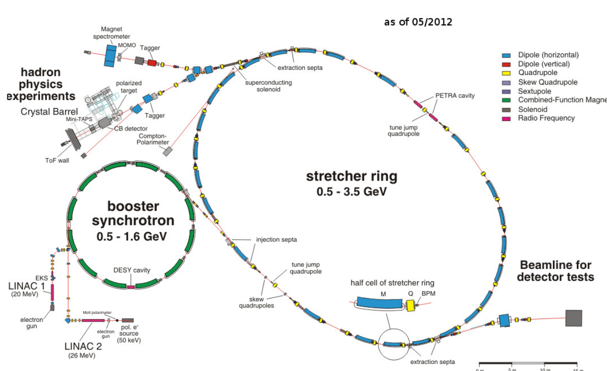

Figure 1: Electron Stretcher Facility ELSA.

MAD-X Simulations were carried out to determine the dispersion and the beta function at the position of the synchrotron light monitor, and using the relation

$$\sigma_x(s) = \sqrt{\epsilon_x \cdot \beta_x(s) + \left(D_x(s) \cdot \frac{\Delta p}{p}\right)^2}, \qquad (1)$$

the emittance ϵ_x can be calculated.

At the external beamline, the dispersion function has to be measured. For this purpose, the RF-frequency is varied and the shift of the beam at different monitors of the external beamline allows to compute the dispersion function. Furthermore, the emittance can be determined by a quadrupole scan and in the vertical plane by the multi screen method [2]. The resulting emittance of these measurements is based upon the average over many cycles. To investigate the evolution of the emittance during one cycle, an additional time resolved measurement is desired. Using the dispersion function and the beta function obtained by the quadrupole scan, the emittance can be derived immediately from the beam profile measurements. Thus, the time resolution of the emittance measurement is only limited by the frame rate of the synchrotron light monitor readout. In the following, the individual measurements and the setup will be shown.

DIAGNOSTICS

At ELSA, a system of different optical diagnostic tools is available. For nondestructive beam profile measurements at the stretcher ring and in each external beam line, synchrotron light monitors are installed. Additionally, different chromox screen monitors are available at the external beam lines (see. Fig. 2). A new framegrabber enables

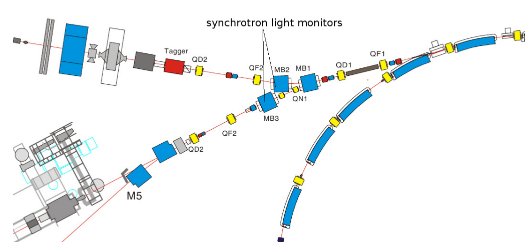

Figure 2: Synchrotron light monitors at the external beamline [3].

a synchronous measurement and analysis of two arbitrary monitors. These measured profiles and the associated fits are implemented in the control system of the accelerator and provide an online diagnostic of the beam shape. Additionally, the averaged values over one cycle are included.

MEASUREMENT OF THE DISPERSION FUNCTION

As given by Eq. 1 the determination of the emittance demands the knowledge of the dispersion and the energy spread. The energy spread can be calculated through:

$$\left(\frac{\sigma_E}{E}\right)^2 = \frac{55}{32\sqrt{3}} \cdot \frac{\hbar c \gamma^2}{J_s m_0 c} \cdot \frac{1}{R}. \qquad (2)$$

For ELSA, the energy spread is in the range of 0.05% and 0.09%, depending on the actual beam energy. Out

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of MAD-X simulations, the dispersion function of the stretcher ring is well known. The dispersion function for the external beamline depends on the nonlinear extraction optics and has therefore to be measured. It is determined by varying the RF-frequency and measuring the corresponding shifts of the entire beam at different positions along the external beamline:

$$D(s)\left(-\frac{1}{\alpha}\frac{\Delta\nu_{RF}}{\nu_{RF}}\right) = \Delta x(s). \quad (3)$$

The acquired dispersion at the monitor positions and the transfer matrices are used to derive the dispersion D_0 and its derivative D'_0 at the start of the external beamline (see Fig.: 3):

$$D(s) = m_{11}(s)D_0 + m_{12}(s)D'_0 + m_{16}(s). \quad (4)$$

This parameter set is cruical to compute the dispersion for arbitrary optics in the external beamline.

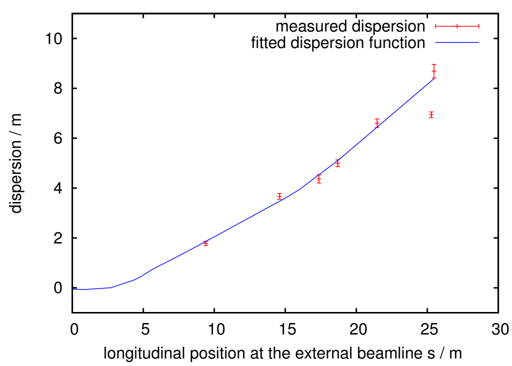

Figure 3: Dispersion at the external beamline.

MEASUREMENT OF THE BETA FUNCTION $\beta(S)$

In order to calculate the emittance at the position of the synchrotron light monitor at the stretcher ring, the knowledge of the beta function of the surrounding quadrupoles is required. The beta function in a quadrupole of the stretcher ring can be determined by measuring the tune shift ΔQ caused by a small quadrupole strength offset Δk applied to the corresponding quadrupole. The strength offset can be applied by a small extra current on the coils of the quadrupole. The transversal tune at ELSA is measured by exciting the beam using a fast pulsed kicker magnet. The Fourier spectrum of the beam reveals the betatron tune from the coherent betatron oscillations [4]. The average beta function $\langle\beta\rangle$ inside a quadrupole can now be calculated using:

$$\langle\beta\rangle = \frac{4\pi}{l}\frac{\Delta Q}{\Delta k}. \quad (5)$$

Figure 4 shows the according measurement of the tune shift in dependence of the quadrupole strength shifts at the corresponding quadrupoles. Using a linear approximation

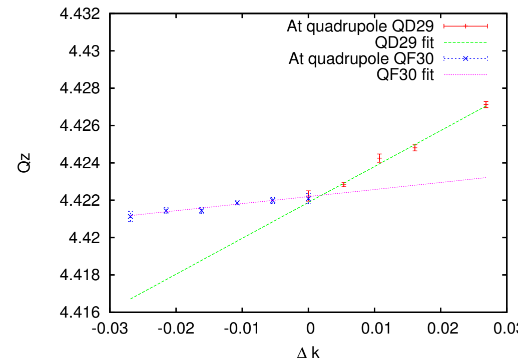

Figure 4: The vertical tune in dependence of the quadrupole strength. The corresponding linear fits are included as well.

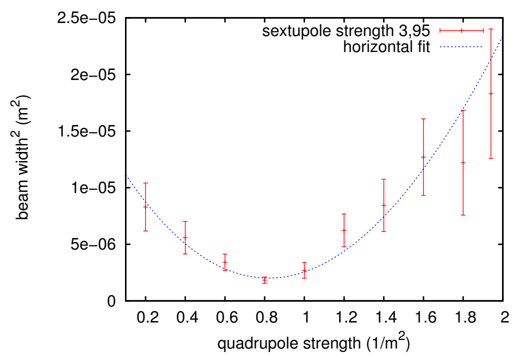

Figure 5: Quadrupole scan [3].

between the two quadrupoles the beta function at the position of the synchrotron light monitor can now be estimated.

While this procedure is sufficient for circular accelerators, another procedure has to be used in the external beamline. Here the method of a *quadrupole scan* can be used. The optical functions, especially the beta function, can be obtained by measuring the beam width using a synchrotron light monitor in dependence of the strength of a quadrupole positioned in front of the monitor. Using the elements of the transfer matrix M, the beam width without the part caused by the dispersion at position s can be written as

$$\begin{aligned}\sigma(k)^2 &= m_{11}(s,k)^2(\epsilon\beta_0)\\ -2m_{11}(s,k)m_{12}(s,k)(\epsilon\alpha_0) &+ m_{12}(s,k)^2(\epsilon\gamma_0).\end{aligned} \quad (6)$$

The results of the quadrupole scan and a fit against the data using Eq.: 6 is shown in Fig.: 5 The emittance as well as all twiss parameters at the position of the quadrupole are obtained using Eq.: 6 and the relation

$$\beta\gamma - \alpha^2 = 1 \quad \Leftrightarrow \quad (\epsilon\beta)(\epsilon\gamma) - (\epsilon\alpha)^2 = \epsilon^2. \quad (7)$$

For the real time measurement of the emittance, the knowledge of the beta function at the position of the synchrotron light monitor is indispensable. It can be calculated using the transfer matrices:

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$$\beta(s) = m_{11}(s)^2\beta_0 - 2m_{11}(s)m_{12}(s)\alpha_0 + m_{12}(s)^2\gamma. \quad (8)$$

The results of the quadrupole scan were confirmed by a multi screen measurement [2]. Hereby, the beam width was measured at six different screens along the external beamline. With the knowledge of the transfer matrices, the twiss parameters were determined. The usage of this method is limited to non dispersion dominated beams. At the external beamline, this is only the case for the vertical plane. Nevertheless, the twiss parameters and the emittance could be measured and confirm the results of the quadrupole scan.

TIME RESOLVED EMITTANCE MEASUREMENTS

Using all previously obtained parameters, the dispersion $D(s)$, the beta function $\beta(s)$ and the energy spread $\frac{\sigma_E}{E}$, the emittance can be directly derived from the measured beam width (see Eq. 1). The beam widths are measured by the synchrotron monitors in the exernal beamline and the stretcher ring, both operating at a frame rate of 25 Hz. The captured images of the beam profile are digitalized and processed by a dedicated readout software every 40 ms. The extracted beam widths are used to derive the emittance simultaneously at both monitors. In Figure 6 and 7, the time resolved emittance during one accelerator cycle in both planes is shown.

At the beginning of the cycle, when the injection takes place, a quite high emittance in the horizontal plane is visible. The high emittance, originating from the phase space distribution of the preceeding booster synchrotron, is preserved by the long damping time of $\tau \approx 92$ ms. After the following energy ramping, the equilibrium state is reached and the emittance shows a constant behavior. The errors are dominated by the contribution of the dispersion.

The same effect is observed in the vertical plane, supressed by the coupling factor of the horizontal and vertical phase spaces. The decrease of the emittance at the external beamline is caused by the intensity dependent tune shift in the stretcher ring.

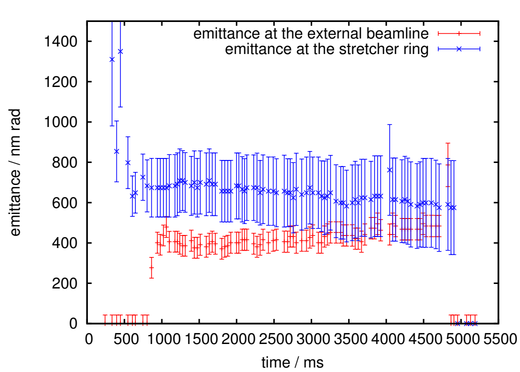

Figure 6: Horizontal emittance.

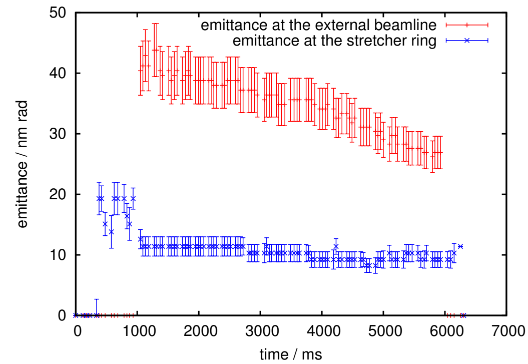

Figure 7: Vertical emittance.

SUMMARY AND OUTLOOK

The installation of the new framegrabber enables a simultaneous readout of two arbitrary monitors with cycle triggered, time resolved beam profile measurements with a temporal resolution of 40 ms. The first simultaneous and time resolved emittance measurements in both transversal planes were successfully conducted. The dependence of the emittance on the extraction parameters is of high interest. Therefore, further investigations are indispensable.

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