EXTRACTION BEAM LINE FOR LIGHT SOURCES

M. Aiba, M. Böge, T. Garvey, N. Milas, Á. Saá Hernández and A. Streun
PSI, Villigen, Switzerland

Abstract

Most measurements to determine transverse and longitudinal phase space volume in a storage ring are rather indirect although they are of importance to better understand the machine and the beam physics. Direct measurements may be performed when the beam is extracted to a beam line, where destructive methods are available. However, light sources can tolerate internal beam dumping and thus do not normally have an extraction line. We, therefore, propose a dedicated diagnostics extraction line. Such an extraction beam line had earlier been realized at the KEK-ATF. The idea would be to equip a compact beam line, which fits into an existing tunnel. First investigations of a light source extraction line are presented.

INTRODUCTION

An extraction line in light sources offers the possibility to characterize the beam in a direct and destructive manner, where transverse and longitudinal beam parameters can be measured rather precisely. We have made first investigations to explore the feasibility. Although the parameters of the SLS are employed for these investigations, the idea may be applicable to any light source. Such an extraction beam line had earlier been realized at the KEK-ATF [1]. The idea would be to equip a compact beam line, which would fit into an existing tunnel.

To date at the SLS storage ring, the horizontal and vertical emittances are determined through the beam sizes from a pinhole method and an emittance monitor [2], respectively. The bunch length is measured in several ways using a streak camera, or by scanning the bunch with a short laser pulse in the FEMTO laser beam slicing facility and recording the coherent THz radiation [3]. Momentum spread measurements from the undulator spectra [4] and betatron sidebands [5] are under test, motivated by a campaign for measurements of intra beam scattering effects [6]. It would be interesting to compare the results from the destructive measurements in the extraction beam line to those from these and other methods using the stored beam.

One of the particular interests of having an extraction line at the SLS would be to further verify the small vertical emittance [7] and to calibrate the existing and new emittance monitors [2, 8]. It is challenging to measure the vertical emittance because of the corresponding small beam size, of the order of a few microns, in the storage ring. The extraction line is designed to make the vertical beam size measurable, at least 10 μm or more, by enlarging the beta function to the order of 1 km.

EXTRACTION LINE

Fast extraction equipment can be integrated into the injection straight section. The minimum number of bunches to enable beam diagnostics is one in terms of the bunch charge, that is ~1 nC at the nominal beam current. Strip line kicker technology such as reported in [9] may allow us to extract a single bunch out of a bunch train. Other types of kicker are also under investigation. A possible injection and extraction equipment layout is shown schematically in Fig. 1, and the extraction line follows as shown in Fig. 2. The beam may be extracted outward to leave room for other applications using extracted beams. The layout shown in Fig. 2 is configured to realize the optics parameters required for the measurements discussed below.

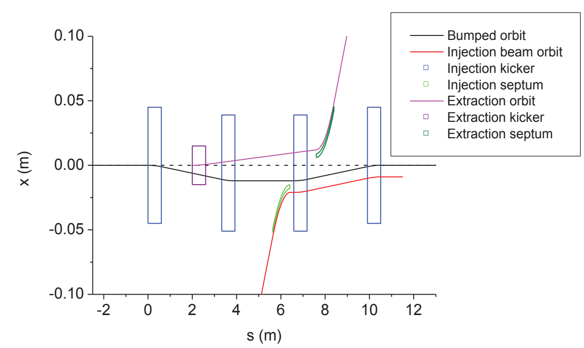

Figure 1: Layout of injection and extraction equipment (schematic). Stored beam, injection and extraction orbits are also shown. Longitudinal location, s=0 corresponds to the entrance of the first injection kicker in this figure as well as in the following ones. A few instruments presently located between the injection kickers have to be moved to other places.

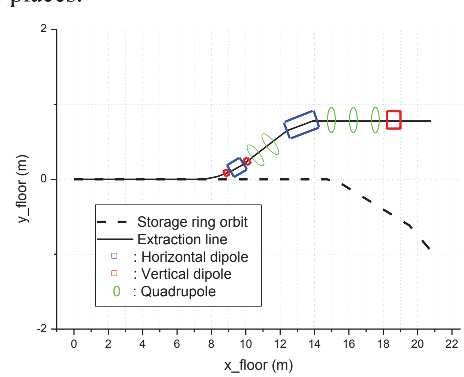

Figure 2: Extraction line layout (schematic). The last part of the line is a drift of ~2 m for the beam measurements.

Transverse Emittance Measurement

Since the transverse particle distribution in an electron storage ring is almost Gaussian, it is not essential to measure the beam sizes over ~π phase advance, as one does in a linac, in order to determine the beam emittance. Therefore, we apply an emittance measurement based on beam sizes along a drift, where the beta function is well defined once we know the initial alpha and beta functions. The emittance together with Twiss parameters are found simultaneously from the beam sizes measured at at least three locations by fitting data to the following equation:

$$\sigma^2 = \varepsilon\left[\beta_0 + 2\alpha_0(s-s_0) + \gamma_0(s-s_0)^2\right], \quad (1)$$

where ε is the beam emittance, α, β and γ are the Twiss parameters, σ is the beam size measured as a function of the longitudinal location, s. The subscript, 0, represents the initial location, which can be the most upstream measurement point. (The fitting parameters are ε, β_0 and α_0 since $\gamma_0=(1+\alpha_0^2)/\beta_0$.)

In order to make the beam size measureable with a screen, it should be at least 10 μm or more in size, and thus the beta function must be greatly increased, especially in the vertical plane. A setting of quadrupoles with modest strength is found, where the beta functions are on the order of 100 m and 1 km in the horizontal and vertical planes, respectively (Fig. 3). Horizontal and vertical phase advances can be varied independently in the vertical emittance measurement in order to survey over various coupling phase. The vertical emittance will be resolved down to 0.2 pm, which is the quantum limit [10] at the SLS at the nominal beam energy of 2.4 GeV. It is noted that the beam optics are not necessarily matched, by adjusting the quadrupole strengths, to the design optics as far as the beta function is large enough to enable the beam size measurement.

To exclude the contribution from energy spread to the beam size in the emittance measurement, the obvious condition must be satisfied:

$$\beta\varepsilon >> \eta^2\delta^2, \quad (2)$$

where η is the dispersion function and δ is the relative momentum spread.

A large beta is useful to fulfill this condition, however increasing the beta function also tends to increase the dispersion function. The vertical dispersion is zero in the design but the spurious dispersion in the ring propagates to the extraction line. It is found, as shown in Fig. 4, that the initial dispersion and angular dispersion (η') result in similar propagation to the measurement drift. Therefore a mechanical shift of the entire beam line, which introduces the same amount of dispersion when the beam orbit is also shifted by a pair of dipole correctors (the small vertical dipole pair at the beginning of the line shown in Fig. 2), is an efficient correction in the vertical plane. A shift of a few mm would be enough due to the fact that the spurious dispersion in the ring is corrected to 1~2 mm rms [7].

Dispersion free steering, on the other hand, may not be straightforward because the possible momentum change in the ring is limited to ~0.5%, making a precise dispersion measurement difficult.

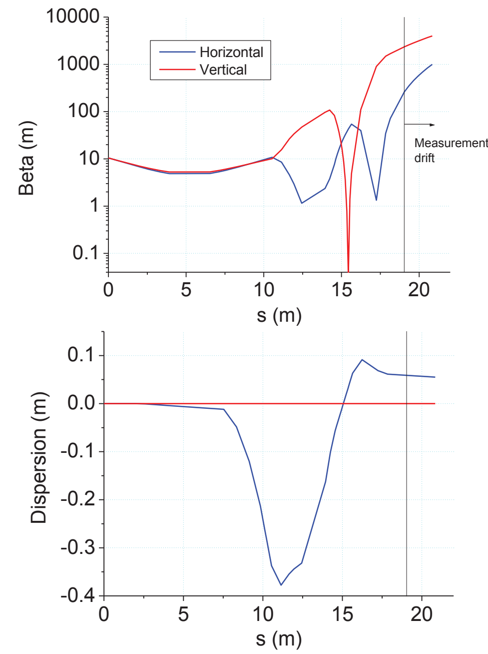

Figure 3: Optics parameters for transverse emittance measurement. (Top) Beta functions in a semi-logarithmic scale. (Bottom) Dispersion functions.

Since the horizontal emittance is approximately 5 ~ 7 nm, which is about three orders of magnitude larger than the vertical emittance, the tolerance of the horizontal dispersion is rather loose. A rough dispersion closure, ~20 cm, fulfills the condition. The extraction line is then not necessarily an achromatic lattice, which would be more complex. The layout shown in Fig. 2 provides a residual dispersion <10 cm with the beta function more than 100 m. The spurious dispersion in the ring is in the order of a few mm and has negligible impact. (The horizontal design dispersion is zero in the straight section.)

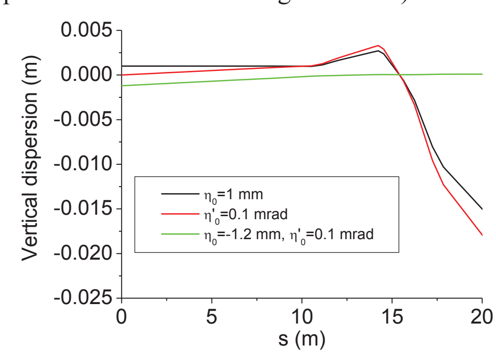

Figure 4: Propagation of spurious dispersion, η_0 (black), and angular dispersion, η_0' (red), from the storage ring to the extraction line. The angular dispersion can be compensated by the dispersion (green).

ISBN 978-3-95450-122-9

Longitudinal Emittance Measurement

Momentum spread measurements will be realized with the usual approach, i.e. a spectrometer. The opposite condition to the emittance measurement minimizes the systematic error:

$$\beta\varepsilon << \eta^2\delta^2 . \tag{3}$$

It makes sense to employ a spectrometer with a vertical dipole given the small vertical emittance. The vertical optics parameters for the momentum spread measurement are shown in Fig. 5.

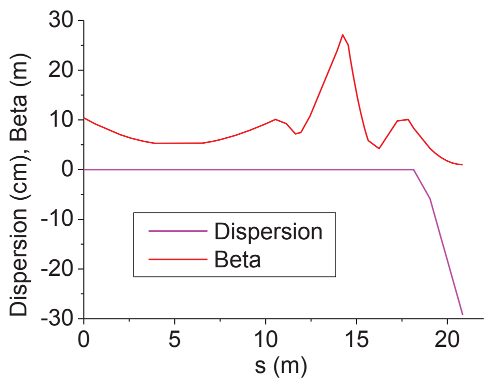

Figure 5: Vertical optics parameters for the momentum spread measurement. The vertical beta and dispersion functions are less than 1 m and ~30 cm, respectively, at the measurement location (at the end of beam line).

This measurement allows us to measure not only an rms momentum spread but also a momentum profile that would be interesting when the profile is non-Gaussian, for example, with the 3rd harmonic cavity and/or collective effects.

A reliable measurement of bunch length can be performed on the stored beam using a streak camera and therefore is not required in the extraction line. A streak camera together with the spectrometer dipole, however, would allow us to perform the same measurement for the extracted bunch. Finally, a transverse deflecting cavity and a longer beam line, if equipped, would provide a direct image of the longitudinal phase space [11].

Table 1 summarizes the SLS beam parameters to be measured with the extraction line together with expected resolutions.

Table 1: SLS beam parameters and expected resolution. The last row, λ, is the bunch length, where typical resolution of streak camera is listed.

Parameters	Values	Resolution
ε_x	5.5 – 7 nm	~100 pm
ε_y	>0.2 pm	~0.2 pm
δ	$\sim 10^{-3}$	$\sim 5\times 10^{-5}$
λ	<~50 ps	1 ps

APPLICATIONS

The extracted beam may be used not only for the beam characterization but also for other applications. When the extraction kicker is able to produce a longer pulse, two bunches can be extracted.

This capability offers, for example, a test bed for studies of long range wakefields in an accelerating structure. The bunch charge of the two bunches are independently variable, and the bunch spacing is discretely variable with the granularity corresponding to the fundamental rf frequency, 2 ns (500 MHz) in case of the SLS. The two extracted bunches are usable also for tests of diagnostics that measure more than one bunch.

An interesting usage of the extraction line would be on-line beam monitoring, that is, extracting one of bunches during the user operation from time to time and measuring the beam parameters.

SUMMARY

First investigations of a light source extraction line revealed that transverse and longitudinal beam parameters can be measured with sufficient resolution. It would be interesting to compare the results from direct measurements of the extracted beam with those based on the stored beam. Such an extraction line offers not only the capability of beam characterization but also applications using the extracted beam. Further studies may be needed to look into issues, which are not covered here, such as alignment tolerances and cost estimation.

ACKNOWLEDGMENTS

The authors would like to thank C. Gough, M. Paraliev and many other colleagues for valuable discussions.

REFERENCES

[1] http://www-atf.kek.jp/atf/
[2] Å. Andersson, et al., Nucl. Instrum and Methods A, Vol. 591, 3, pp.437-446 (2008)
[3] A. Streun, et al., Proc. EPAC’06, pp.3427-3429 (2006)
[4] E. Tarazona and P. Elleaume, Rev. Sci. Instrum. 67, 3368 (1996)
[5] T. Nakamura, et al., Proc. of PAC’01, pp.1972-1974 (2001)
[6] F. Antoniou, et al., Proc. PAC’12, pp.1951-1953 (2012)
[7] M. Aiba, et al., Nucl. Instrum. and Methods A, Vol. 694, 1, pp.133-139 (2012)
[8] N. Milas, et al., TIARA report, TIARA-REP-WP6-2012-015 (2012)
[9] F. Marcellini, et al., Proc. PAC’09, pp.1739-1741 (2009)
[10] T. O. Raubenheimer, SLAC-PUB-4937 (1991)
[11] H. Euteneuer et al., Proc. EPAC’88, pp.1149-1150 (1988)