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ELECTRON BEAM PROBE DIAGNOSTIC FOR BESSY II STORAGE RING

Abstract

A low energy electron beam can be used to characterize the high energy ultra-relativistic bunches. This technique allows one to obtain the bunch transverse profiles as well as the bunch length within a non-destructive single shot measurement.
In this paper the bunch length measurement technique based on the interaction of the low energy electron beam with an ultra-relativistic bunch is described. Results of numerical simulations of measurements related to BESSY II are presented. A possible setup of such diagnostic system for BESSY II and in future for BESSY VSR is proposed.

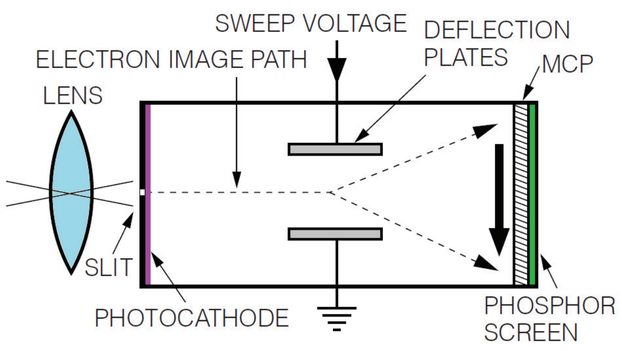
Introduction

The bunch length can be measured, for example, using a standard method with a streak camera which analyses a synchrotron light from a dipole magnet or using a low energy electron beam crossing the electron bunch trajectory in the accelerator. Both methods are non-destructive, i.e. does not affect the bunch, and therefore they can be used during the standard routine operation at user facilities or at others accelerators where destructive diagnostic methods cannot be used. Each method has its own advantages and disadvantages.

Streak Camera

A light pulse hits the photocathode causing it to emit a bunch of the photoelectrons. The time structure of this bunch is identical to the structure of the light pulse. These electrons are accelerated and then deflected by a ramped transverse electric field between the deflection plates. Afterwards the number electrons are multiplied by the microchannel plate (MCP) and imaged on the phosphor screen. The resulted transverse profile of the screen image will represent the temporal profile of the light pulse. The minimal achieved resolution by the available commercial streak cameras is in the order of 200 fs.

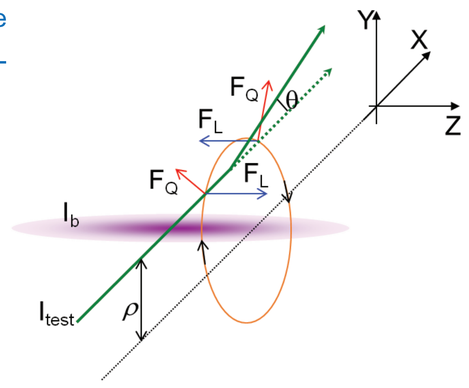
Streak Camera layout



Electron Beam Probe

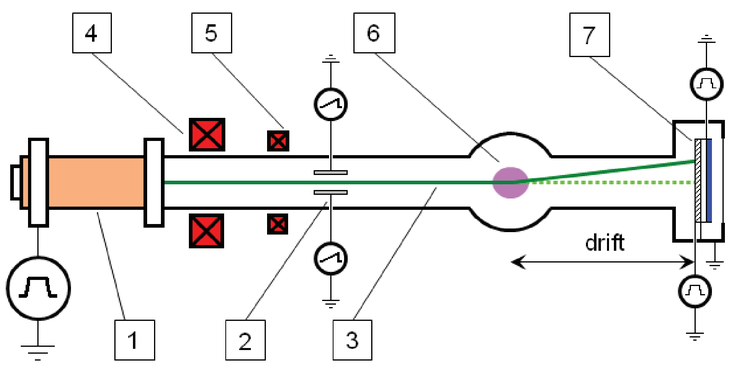
Electron beam probe diagnostic is based on interaction of the low energy electrons with the strong electric and magnetic fields of the relativistic bunch. Measuring the result of such interaction the bunch length or transverse bunch profile can be obtained. The vertical θ_y deflection angle can be described by the following equations:

$$\theta_y(\rho,x)=\frac{2\rho r_e}{\gamma\beta}\int_{-\infty}^{+\infty}\frac{n(z)dz}{\rho^2+(x+\beta z)^2}\left(1-e^{-\frac{\rho^2+(x+\beta z)^2}{2\sigma_\perp^2}}\right)$$



where ρ - impact parameter, r_e - the electron radius,
γ, β - relativistic parameters of the probe beam,
$n(z)$ - the bunch longitudinal distribution,
x - the relative electron position in the probe beam and $\sigma_\perp$ - the transverse size of the bunch.

Electron Beam Probe layout



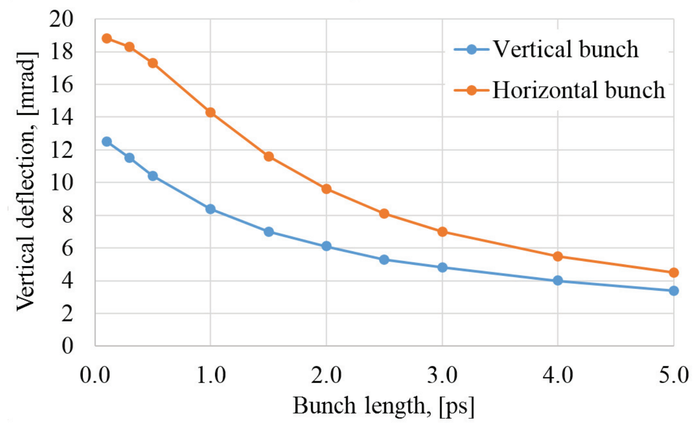
A Probe electron beam (3) is generated and accelerated in the electron gun (1) up to about 100 keV energy. The beam is focused by the lens (4) and adjusted vertically and horizontally by a two-coordinate corrector (5). Time correlation in the beam is introduced by horizontal deflecting plates (2). After interaction with the ultra-relativistic bunch (6) the beam is projected on the observation screen (7). The horizontal axis on the screen will correspond to the time and the vertical axis will contain information about the bunch length.

Simulations

Particle tracking simulations were performed in analytical fields for an axially symmetric ultra-relativistic bunch. Space charge forces of the probe beam were not taken into account.

The maximal deflection angle of the probe electrons versus the bunch length for horizontal and vertical bunch orientations with:

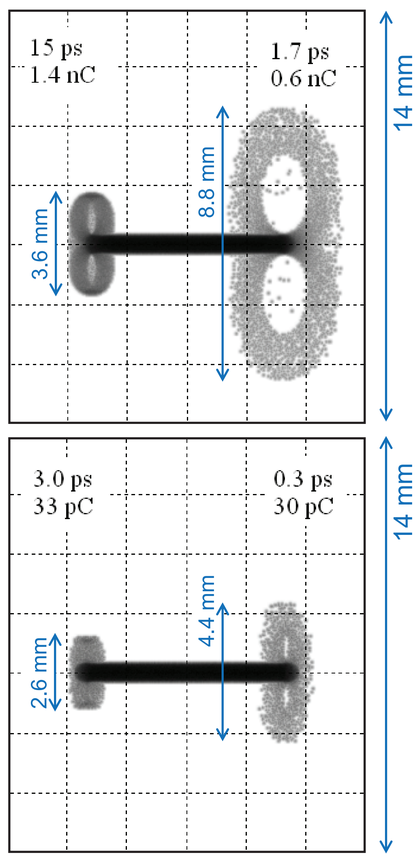
- bunch charge of 144 pC,
- vertical bunch size 17 μm,
- hoizontal bunch size 170 μm.



Horizontal bunch orientation is preferable as it produces higher deflecting angles to the probe electrons, which in turn is increasing the method resolution.

Standart operation mode at BESSY VSR: two bunches with 15 (left) and 1.7 ps (right) length, 1.4 and 0.6 nC charge respectively and with 2 ns delay between them. The drift length after interaction is 10 cm and image grid size is 2x2 mm. The longer bunch gives as a result a smaller size of the image despite the larger bunch charge in this case: about ±1.8 mm for 15 ps long bunch and ±4.4 mm for 1.7 ps long bunch.

Low alpha operation mode at BESSY VSR: two bunches with 3 (left) and 0.3 ps (right) length, 33 and 30 pC charge respectively, 2 ns delay between them and the drift length after interaction is 40 cm. The energy of the probe beam was decreased to 50 keV to have higher deflection angles. The resulted vertical deflections of the probe beam are about ±1.3 mm for 3 ps long bunch and ±2.2 mm for 0.3 ps long bunch.



The bunch length measurements errors for all sets of bunches at BESSY II and for future BESSY VSR are presented in Table:

- Err1 assumes the bunch transverse size error of ±20%.
- Err2 assumes the deflection angle measurement error of ±1 mrad.

Better knowledge of the transverse bunch size at the interaction point will significantly improve the resolution of this method. Also with the good optical readout system the angle resolution can reach ±0.2 mrad, which will greatly reduce the Err2.

Bunch length measurement errors:

	Bunch type	Length, ps	Charge, nC	Err1, ps	Err2, ps
BESSY II	Bunch train (1x300)	15	0.7	±3.0	±1.0
	Camshaft (x1)	27	4.0	±5.0	±1.0
	Slicing (x3)	27	4.0	±1.0	±0.1
	Bunch train (1x300)	3.0	0.04	±1.0	±1.0
	Booster (1x5)	60	1.0	±10	±2.0
BESSY VSR	Long bunch (2x75)	15	1.32	±3.0	±1.0
	Long bunch (2x75)	1.1	0.144	±0.3	±0.2
	Short bunch (x1)	1.7	0.64	±0.5	±0.3
	Camshaft (x1)	27	8.0	±5.0	±1.0
	Slicing (x3)	3.7	4.0	±1.0	±0.1
	Long bunch (2x75)	3.0	0.036	±1.0	±1.0
	Short bunch (2x75)	0.3	0.032	±0.5	±1.0

Conclusions and Outlook

- Two non-destructive bunch length measurement techniques have been discussed.
- Electron Beam Probe diagnostic has been comprehensively studied.
- The resolution depends on the transverse bunch size and the readout optics resolution.
- There are several advantages of EBP compare to the streak camera:
  - it is the single shot measurement,
  - it does not require synchrotron light,
  - it has lower costs for the case of sub-picosecond bunch length ranges.
- More detailed and sophisticated analysis of the electron beam image on the screen may allow this technique to get even the full longitudinal profile of the bunch like the streak camera.

- D. Malyutin, A. Matveenko “Electron Beam Probe for the bunch length measurements at bERLinPro”, IPAC’16, Busan, Korea, May 2016, paper TUPOW034.
- P. V. Logachev, D. A. Malyutin, and A. A. Starostenko, “Application of a low energy electron beam as a tool of nondestructive diagnostic of intense charged-particle beams”, Instruments and Experimental Techniques, Vol. 51, No. 1, pp. 1–27, 2008.

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