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BEAM DIAGNOSTIC BEAMLINES AT HEPS STORAGE RING

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Abstract

High Energy Photon Source (HEPS) is a 6 GeV diffraction limited storage ring light source. An ultralow emittance of ~34 pm·rad is designed with a multiple-bend achromat lattice at storage ring. The transverse beam sizes at the dipoles will be less than 10 µm. In order to measure such small beam sizes in both directions, an X-ray beam diagnostic beamline is designed with bending magnet as source point. X-ray pinhole imaging and KB mirror imaging are used compatibly and comparably to capture beam image. A visible light beam diagnostic beamline is designed to measure bunch length with streak camera. During the first phase storage ring commissioning time, both diagnostic beamlines captured the first light.

INTRODUCTION

HEPS will be a 6 GeV diffraction limited storage ring [1] and have an emittance of ~34 pm·rad. Bending angle per dipole is designed small enough to achieve such small emittance. In such case, synchrotron light will travel a long distance before its vacuum pipe can reach a sufficient distance from the beam pipe, which makes beam transverse profile imaging more difficult because the installation space for the first measurement device is limited.

In this article, two beam diagnostic beamlines will be introduced to measure transverse beam sizes and longitudinal bunch length respectively. Both beamlines use the first dipoles after the straight sections as its source points, which sections located at the sectors of injection or RF to avoid taking up ID beamlines. X-ray diagnostic beamline (XBL) is dedicated to capturing beam image and measuring beam sizes using X-ray pinhole and KB mirror imaging. Streak camera (SC) is used at visible light diagnostic beamline (VBL) for bunch length measurement.

X RAY DIAGNOSTIC BEAMLINE

XBL is located at R39 where is the RF region. The source point is in the first dipole (BLG1), 1 mrad angle relative to the straight section extension line to avoid edge radiation of dipole. This small angle also allows the beamline to be led out through the reserved holes in the sawtooth wall to the hutch outside the tunnel. Table 1 lists some designed parameters of the source point. At this source point, β_y is higher about 24.3 m while β_x is 1.3 m, which makes the vertical size larger and relatively easier to measure. This point has almost no dispersion, so the contribution to the horizontal beam size comes mainly from beam emittance.

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Table 1: Theoretical Parameters of the Source Point

Parameters	Value
Energy	6 GeV
Beam current	200 mA
Bending radius	41.4 m
Horizontal Emittance	34.2 pm·rad
Emittance Coupling	10%
Beta function β_x	1.3 m
Beta function β_y	24.3 m
Horizontal beam size	6.7 µm
Vertical beam size	9.1 µm

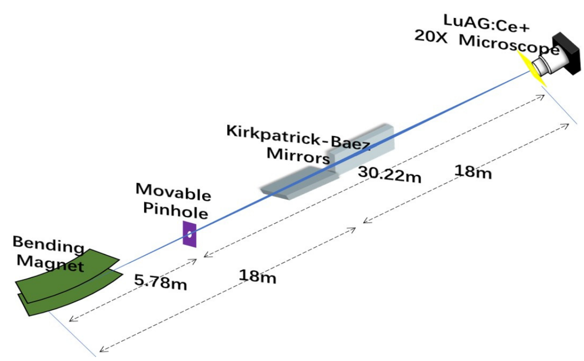

Figure 1: Schematic diagram of X ray diagnostic beamline.

As shown in Fig. 1, pinhole and KB mirrors share the same source point and also the same X-ray camera, and they are both movable by remote control. Pinhole is placed in the atmosphere at 5.78 m from the source and 30.22 m to the scintillator of X-ray camera with the magnification of ~ 5.22. There is a 1mm thick aluminum window and a copper attenuator in front of the pinhole. Pinhole assembly is made of precision machined tungsten sheets laminated together and contains slits of 20 µm, 50 µm and 400 µm both horizontally and vertically. The Pinhole assembly is mounted onto motorized stages, allowing to exchange the optical systems and to align the optics with respect to the beam axis in four degrees of freedom: two linear translations perpendicular to the beam axis, a goniometer rotation around the horizontal axis, and a rotation around the vertical axis.

It is a balance between geometric blurring and the diffraction limit. The optimum aperture that minimize the PSF can be obtained by making the two values equal. A more accurate model to calculate the PSF from the pinhole is to compute the illumination on a screen through the pinhole from a source point using the Fresnel diffraction approximation [2]. When using $20\times20\ \mu m^2$ pinhole for

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calculation, the spatial resolution is about 6–7 μm at the source [3].

A pair of KB mirrors is mounted on adjustment mechanics, installed in an independent vacuum chamber. We use 1:1 imaging in the KB system with two cylindrical mirrors. We have previously tested the KB mirror imaging system with both mirrors of 0.3 μrad slope errors at SSRF and successfully measured ~ 20 μm vertical beam size, the calculated PSF of KB mirror monitor is 4.97 μm vertically and 6.08 μm horizontally [4]. At HEPS, vertical focus mirror (VFM) is placed 18 m from the source point and 18 m to X-ray camera, while horizontal focus mirror (HFM) is placed 18.36 m to the source and 17.64 m to the detector (as shown in Table 2). With 2.5 mrad grazing incidence angle, the two mirrors would reflect the X-ray beam respectively 5 mrad horizontal and vertical from the incidence light. The slope errors are designed below 50 nrad RMS for both mirrors, the measured values both at the processing company and at HEPS optical metrology laboratory are equivalent to the design values. In this case, the spatial resolution of KB mirrors should be better than 2 μm after precise adjustment.

Table 2: Parameters of X-ray Optics

	Distance to source[m]	**Distance to detector [m]**	**Magnification**
Pinhole	5.78	30.22	5.22
KB(VFM)	18	18	1
KB(HFM)	18.36	17.64	0.96

A scintillator X-ray camera is located 36 m away from the source point in an optical hutch outside the tunnel. The scintillator is LuAG:Ce glued on quartz substrate. With a 4X magnification microscope objective, the spatial resolution measured by the supplier is 3 μm, it becomes 0.8 μm when the objective lens is changed to 20X. The two objectives provide effective resolution and field of view for either pinhole or KB mirrors optics.

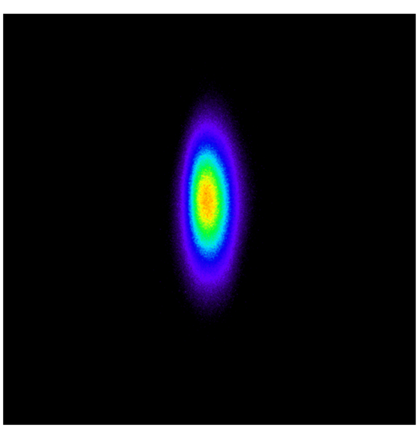

Figure 2: First beam image captured by X-ray pinhole camera.

During the first phase commissioning time of storage ring, when the beam was stored and the lifetime increased to several seconds, light spot can be seen on a 50×50 mm^2 YAG:Ce scintillator installed in the hutch. When the beam current increased to mA level, pinhole and X-ray camera were moved into the light path and adjusted with the light. Figure 2 shows the first beam image captured by X-ray pinhole camera with 4X lens. As expected, vertical beam size is larger than horizontal size because β_y is significantly larger than β_x here. In addition, some contributions are from the vertical dispersion and coupling, as the storage ring correction of alignment and optics is still in progress and has not yet been completed at this moment.

VISIBLE LIGHT DIAGNOSTIC BEAMLINE

Source point of VBL is in the first dipole (BLG1) after the injection kicker at R03. The main function of VBL is to measure bunch length with streak camera. The first in-vacuum mirror is installed at 6.2 m from the source, the angle of visible-UV light reaching the mirror is ~ 4 mrad in both horizontal and vertical direction, limited mainly by the gap of magnets. A water-cooled thin absorber with 2 mm height made by Glidcop is installed in front of the first mirror, to prevent the mirror from deforming due to the heat load of X-ray. Reflected by the first mirror, the light enters the atmosphere through a quartz window. Another four in-air mirrors are used to direct light into the laboratory where streak camera placed, all the mirrors are aligned in advance using a laser. The total path length of the beamline is about 17 m.

VBL also observed the light when the beam was stored and the lifetime increased to several seconds, as shown in Fig. 3. The central dark region caused by the thin absorber can be observed clearly.

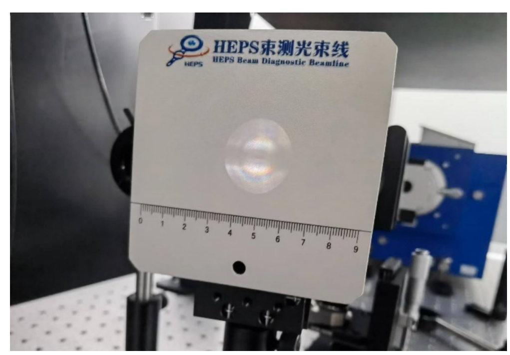

Figure 3: First visible light observed at VBL laboratory.

Streak Camera

The SC is OptoScope SC-10 from Optronis. Before entrance to SC, SR light is focused by a 300 mm lens, filtered by a 550 nm narrow band filter. The entrance slit of SC is set to 30 μm. Fast (horizontal) sweep unit uses a synchroscan frequency of 41.65 MHz, which is synchronized to the 166.6 MHz master oscillator frequency of the storage ring, providing sweep speed of 25 ps/mm, 50 ps/mm, 100 ps/mm and 200 ps/mm. An additional slow (vertical) unit is used to spread the overlapped streaks of one or several bunches in a single image. Injection signal is used as its trigger input, both the injected bunch and the stored bunch can be captured after the accurate delay adjustment is completed.

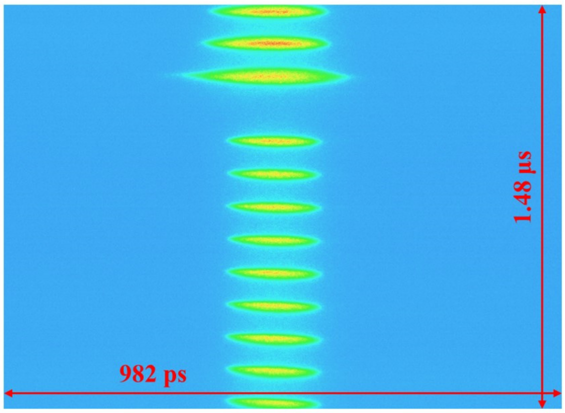

Figure 4: Bunches image captured by SC at slow sweep range of ~1.48 µs at 35 bunches top-up injection

As shown in Fig. 4, 12 bunches can be seen from the SC image. At this moment, a total of 35 bunches had been injected into the storage ring with an interval of 120 ns, and top-up injection was still on progress. Slow sweep unit was set at 100 ns/mm so the total scan range is ~1.48 µs, which is approximately one-third of the revolution period of ~4.55 µs. It is clear that the third bunch is longer, which is the bunch that has just been injected represents the length of bunch injected from the booster, the two bunches above it are previously injected bunches, and the nine bunches below are waiting to be injected that has lower bunch current.

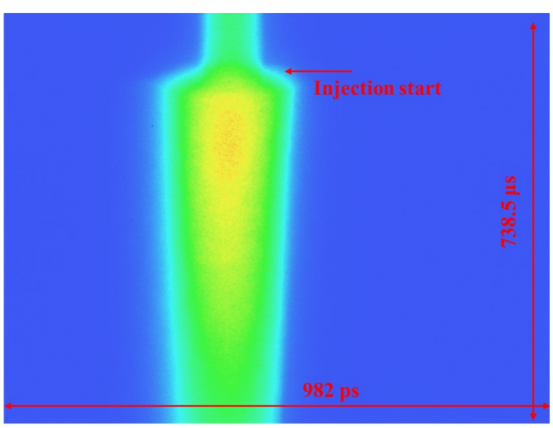

Figure 5: Transient longitudinal motion of a single bunch with SC setting at ~738.5 µs slow sweep range

In order to observe the injection transient longitudinal motion, slow sweep was set to 50 µs/mm, so the vertical scan range is 738.5 µs, which is about ~1/6 of the longitudinal synchrotron period of ~ 4.5 ms. Only one bunch was injected in the ring, when a new injection started, this bunch was kicked away by injection kicker. As shown in Fig. 5, the upper area represents the previously injected beam which has remaining but damped oscillations with shorter bunch length. From the red arrow mark to the lower end, a longer bunch from booster is injected and starts synchrotron oscillation in the ring. The current slow sweep setting makes the image unable to observe a complete synchrotron oscillation period, however, a larger sweep range will lead to a longer delay which makes it impossible to observe the initial state of injection. A more detailed study including bonding images with different time delays to obtain a complete longitudinal synchrotron oscillation image is needed.

CONCLUSION

This paper presents the design and preliminary results of two beam diagnostic beamlines at HEPS storage ring. XBL is dedicated to measuring the transverse beam sizes and beam emittance. X-ray pinhole imaging and KB mirror imaging are used compatibly and comparably to capture beam image. During the first phase commissioning time of storage ring, as the storage ring correction of alignment and optics is still in progress and has not yet been completed at this moment, just pinhole was moved into the X-ray path, first beam image was captured by X-ray pinhole camera with 4X lens. At VBL, first visible light was also observed at the laboratory. SC was used to measure bunch length, the injected bunch and the stored bunches at 35 bunches top-up injection mode were captured at 100 ns/mm slow sweep setting. Transient longitudinal motion of a single bunch was observed when slow sweep was set at 50 µs/mm.

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