Measurements for 2.4 GeV Beam by Diagnostic Beamline in PLS

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Abstract

From 1999, the Pohang Light Source (PLS) is operated at 2.4 GeV beam energy that is higher than the operation energy of 2.04 GeV in 1998. The transverse beam sizes for several beam currents have been measured at 2.4 GeV by the diagnostic beamline of the PLS. The current dependence of the beam sizes is not found in the lower current limit, and the increment of the transverse beam size is observed as the beam energy increases. The emittance of 11.9 nm rad at 2.4 GeV is obtained, and the ratio of 2.4 GeV emittance to 2.04 GeV one is in good agreement with the expected value of 1.38 from the theory after removing the longitudinal instability by the longitudinal feedback system. Also, the vertical coupling of the 2.4 GeV beam is matched with the 2.04 GeV one with the longitudinal feedback system.

1 INTRODUCTION

In the PLS, there are a visible light diagnostic beamline for the temporal dynamics and a X-ray diagnostic beamline for the beam structure. The diagnostic beam line was constructed in 1998, the beam size and the emittance had been measured at 2.04 GeV [1]. In 1999, the PLS was operated at 2.4 GeV, and the beam size and the emittance were measured again and compared with the 2.04 GeV case.

2 X-RAY BEAMLINE

The synchrotron radiation of diagnostic beamline comes from the second bending magnet of No. 1 cell. The whole beam fan from a bending magnet is 42 mrad. A total of 14 mrad is used for the diagnostic beamline, among them 8 mrad used for visible beamline and 2 mrad for X-ray beamline.

The sychrotron radiation in the X-ray beamline passes through a slit which has a 15 mrad acceptance angle and comes to a vacuum mirror chamber. Mirrors in the chamber consist of one flat deflecting mirror and two spherical mirrors to form an 1:1 iamge system by the Kirkpatric-Baez optics [2]. The distances from the source to the horizontal and the vertical focusing mirror are 10.581 m and 10.911 m, respectively. The whole distance from the source to the image is 21.492m.

The synchrotron radiation in the chamber comes to a 250-nm nikel coated plat deflecting mirror with 3^o angle to the mirror plan. In this mirror, most of hard X-ray over 0.8 keV are absorbed and cooled by water cooling system. Less than 10 % of the initial radiation power comes to two 250-nm nikel coated spherical mirrors and the absorbed power is cooled by the conduction. After the mirror chamber, the synchrotron radiation deflected by 6^o to the horizontal direction. The angle of each mirror can be changed by a step motor.

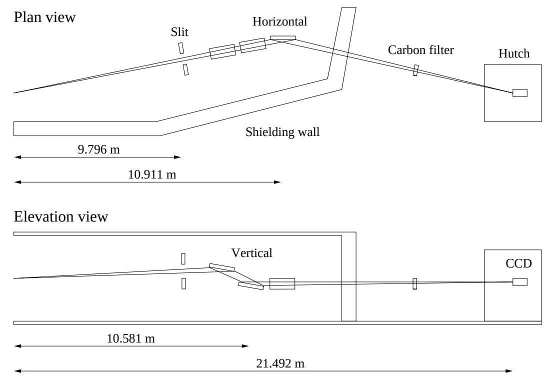

Figure 1: Layout of X-ray beamline

Then, the synchrotron radiation passes through a carbon filter. Photon energy below 200 eV cannot pass through a 5μm thin filter, and a carbon filter has a strong absorption edge over 284 eV. As a result, soft X-ray from 200 eV to 284 eV can only pass through three mirrors and one filter which behave as the band pass filter [3].

Finally, the synchrotron radiation hits the scintilator in the bellows at the end of the beamline. The length of the bellows can be changed by a step motor to focus the image. With the steering of the mirror angle in the mirror chamber and the change of the bellows length, we can get a focused image.

Horizontal and vertical beam images are captured by a CCD camera (Sony XC-75). The determination of the beam size is done by LBA-300PC (ver. 1.10) program which can analyzes the CCD image. Fig. 1 is the layout of X-ray beamline [4].

3 EXPERIMENT RESULT

3.1 Beam sizes at 2.4 GeV

The beam size is measured for various beam currents at the 2.4 GeV beam energy. After the injection, measurements start from 128.8 mA and continue to 93.0 mA for about the 10-hour period. The horizontal beam size is 203.3 μm and the vertical beam size is 49.9 μm at 2.4 GeV. Fig. 2 shows beam sizes with respect to the beam current at 2.04 GeV and 2.4 GeV. It shows that the beam sizes are not changed by the beam current change. Fig. 3 shows the length of the single bunch in terms of the beam current at 2.04 GeV [1]. Spots are mesurement values and the a dotted line is

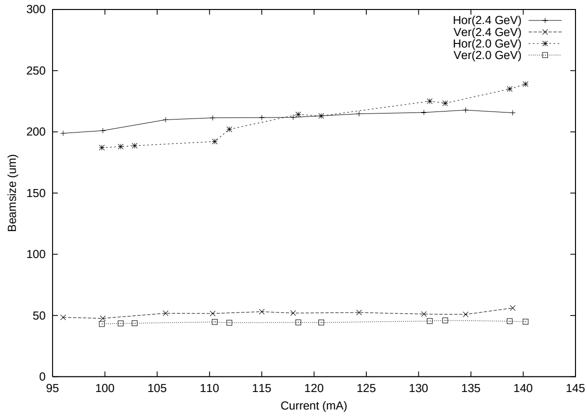

Figure 2: Beam sizes at 2.04 GeV and 2.4 GeV

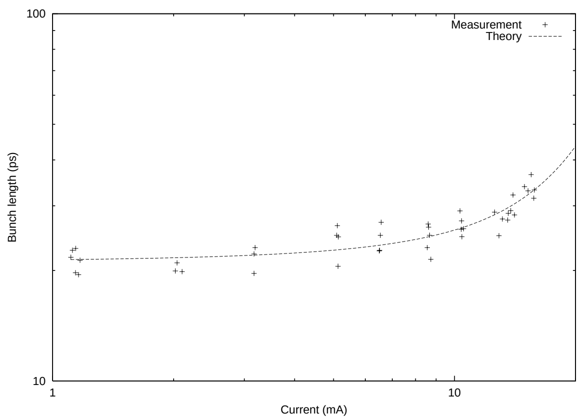

Figure 3: Single bunch length

an experimental fitting such as [5]

$$\sigma_s = \sigma_0 + A\exp(I/t) \tag{1}$$

where $\sigma_0 = 19.545$ ps, $A = 1.6103$ ps, $t = 7.394$ mA and I is the beam current. In the Fig. 3, the bunch length is constant while the beam current goes up to about 5 mA. Over 5 mA, it grows exponentially. The number of bunches in the PLS operation is normally from 350 to 468. Therefore, the bunch length will not change significantly under the normal operation current up to 300 mA. The coupled bunch mode instability is not considered here.

3.2 Comparison with 2.0 GeV case

The 2.4 GeV beam size is compared with the 2.04 GeV case. The horizontal beam size is 187.1 μm at 2.04 GeV and 203.3 μm at 2.4 GeV. Also, the vertical beam size is 43.1 μm at 2.04 GeV and 49.4 μm at 2.4 GeV. The 2.4 GeV beam size is increased by 8.7 % in the horizontal direction and 15.8 % in the vertical direction than the 2.04 GeV case. On the other hand, the horizontal emittance is 12.6 nm rad at 2.04 GeV and 11.9 nm rad at 2.4 GeV, while the vertical emittace is 0.598 nm rad at 2.04 GeV and 0.803 nm rad at 2.4 GeV. Table 1 lists the beam size and the emittance at 2.04 GeV and 2.4 GeV.

Table 1: Beam sizes and emittances at 2.04 GeV and 2.4 GeV before LFS is installed.

Energy (GeV)	σ_x (μm)	η (m)	σ_δ	β_x (m)	ϵ_x (nm rad)
2.04	187.1	0.1706	0.00068	1.7094	12.6
2.4	203.3	0.1706	0.00085	1.7094	11.9
Energy (GeV)	σ_y (μm)			β_y (m)	ϵ_y (nm rad)
2.04	43.1			3.0999	0.598
2.4	49.9			3.0999	0.803

Measured data are compared with the theoretical expectation value. The emittance is given by

$$\epsilon = \frac{C_q \gamma_0^2 \langle H \rangle}{J_u \rho} \tag{2}$$

where C_q is the quantum coefficient 3.84×10^{13} m, γ_0 is the electron energy over the electron rest energy, ρ is the bending radius, and J_x is the damping partition number of the bending plane. The H function is

$$H = \gamma\eta^2 + 2\alpha\eta\eta' + \beta\eta'^2 \tag{3}$$

where α, β, γ are the Courant and Synder twiss parameter, η is the dispersion function, η' is differentiation of η to the distance, and $\langle H \rangle$ is the average value of H to a bending magnet. Eq. 2 shows that the emittance is proportional to γ_0^2 where $\gamma_0 = 1957 \times E[\mathrm{GeV}]$. If the beam energy increases from 2.04 GeV to 2.4 GeV, then the emittance is increased by 1.38 times than the 2.04 GeV emittance. In this measurement, the vertical emittance grows up 1.34 times which is good agreement with the theory. But, the horizontal emittance shrinks down rather than grows up. It means that the measured horizontal beam size at 2.04 GeV is rather larger than desired. This beam size grow-up is due to the instability in the horizontal direction. This is because that, at 2.04 GeV, the radiation damping by synchrotron radiation is lower than the 2.4 GeV case and the effect of instability is much larger [6].

3.3 Removal of the horizontal instablilty

In 1999, the longitudinal feedback system(LFS) was installed in the PLS. The LFS detects the phase errors of bunches in the RF cavity, kicks to the proper phase, thus removes the longitudinal instability. The beam size is measured again after the instability is removed by the LFS at 2.04 GeV. Fig. 4 shows beam sizes with and without the LFS at 2.04 GeV, 100 mA current. After the instability is removed by the LFS, the horizontal beam size is 168.8 μm and the emittance is 8.80 nm rad. In the vertical direction, the beam size is 42.2 μm, and the emittance is 5.75 nm rad at 2.04 GeV. The 2.4 GeV emittance is lager than 2.04 GeV

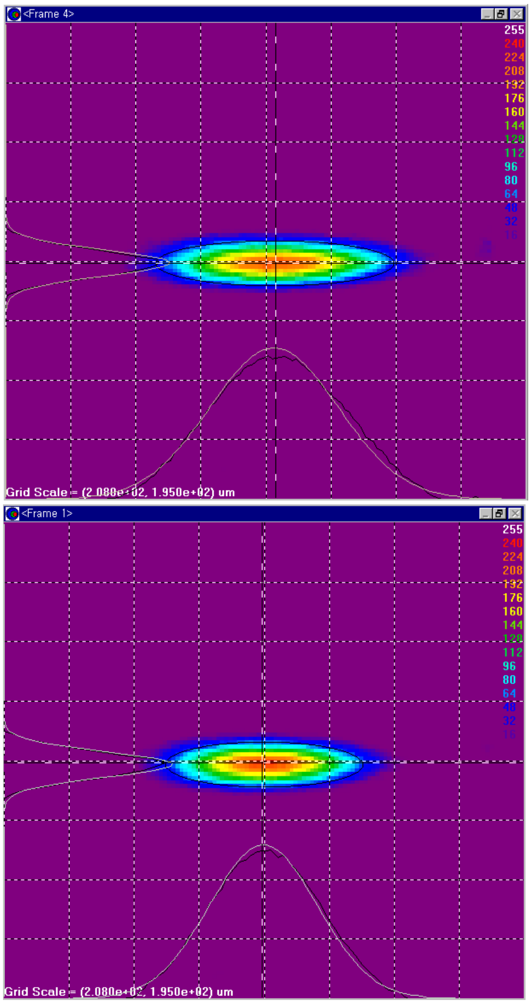

Figure 4: Beam sizes with LFS (lower) and without LFS (upper) at 2.04 GeV, 100 mA current

Table 2: Beam sizes and emittances at 2.04 GeV with LFS and 2.4 GeV

Energy (GeV)	LFS	Beam size hor. (μm)	Emittance (nm rad)	Ratio
2.04	on	168.8	8.80	1
2.4	off	203.3	11.9	1.35
Energy (GeV)	LFS	Beam size ver. (μm)	Emittance (nm rad)	Ratio
2.04	on	42.2	0.575	1
2.4	off	49.9	0.803	1.40

emittance by 1.35 times in the horizontal direction and 1.40 times in the vertical direction. This result is in good agreement with the theoretical expectaion value of 1.38. Table 2 lists the beam size and the emittance at 2.04 GeV with the LFS and 2.4 GeV without the LFS.

3.4 Vertical coupling

The vertical coupling of the emittance is also obtained in this experiment. The coupling is determined not by the energy but by the lattice. Thus, the coupling should be same in the same lattice no matter what the energy is. We obtain 4.70 % coupling at 2.04 GeV without the LFS and 6.76 % coupling at 2.4 GeV. On the other hand, the coupling becomes 6.53 % at 2.04 GeV with the LFS, which is in good agreements for the 2.4 GeV case. This result is another evidence of the beam size blow-up due to the longitudinal instability.

4 CONCLUSION

The emittance is measured at 2.4 GeV by the PLS diagnostic beamline. The diagnostic beamline uses X-ray for the transverse beam size measurement and the visible light for the longitudinal bunch length. An 1:1 image system is consisted by the Kirkpatric-Baez optics in the X-ray beamline and the image of beam is captured by a CCD camera to determine the beam size.

The beam size is measured at 2.4 GeV. In the low current region, the beam size and the bunch length do not change by the beam current change.

The beam size at 2.4 GeV is larger than that of 2.04 GeV in the horizontal and vertical directions. According to the theory, the 2.4 GeV emittance should be 1.38 times larger than the 2.04 GeV case for each direction. It is observed that the horizontal beam size at 2.04 GeV contains the beam size blow-up effect by the longitudinal instability. After the instability is remove by LFS, the emittance ratio of 2.04 GeV to 2.4 GeV is 1.35 in the horizontal direction and 1.40 for the vertical direction, which is in good agreement with the theoretical expectation value of 1.38. Also, the vertical coupling of the emittance at 2.04 GeV with the LFS is matched with the 2.4 GeV one.

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