Test Results using Iris and Airy Disc for the BPM Alignment of SCSS (SPring-8 Compact SASE Source) Prototype Accelerator

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SCSS, a prototype accelerator was constructed at SPring-8 site. The amplified beam with 49 nm wavelength was observed in June 2006. The BPM positions must be measured very precisely for the SASE. Thus we measured the inside of the BPM not the outside. The disc which has iris in the center is inserted in the BPM cylinder to see by the laser. We measured so called Airy disc using He-Ne laser and CCD camera. The image of iris becomes disc if the Fresnel number is less than about 0.5. Four BPMs are used and the distance between first and fourth is fifteen meter. The cover glass on the CCD device is removed because of the interference protection. The diameter of the BPM and laser light are 20mm and 9mm, respectively. Thus the large CCD which size is 19mm x 19mm is used. The BPMs are fixed on the X-Z stage which resolutions are 0.1micron. Thus we aligned four BPMs on the straight line within 0.05mm using these system.

1. INTRODUCTION

SPring-8 a large synchrotron radiation facility has produced a large number of results in the fields of materials science, the life science and in industrial use. The synchrotron radiation which SPring-8 produces is very bright, and has a broad wavelength range. On the contrary, a laser light is coherent. Since the synchrotron radiation and a laser are complementary lights with different characters, "the next light source" in the SPring-8 site becomes X-ray Free Electron Laser (XFEL). Starting from 2006 construction of XFEL(Fig.1.) with a full length of about 800m which makes acceleration energy 8GeV possible, it will be completed in 2010, and aims at the X-ray lasing. From the beginning of 2005, the research group has started construction of the prototype accelerator of 60m in the total length as the proof experiment. It succeeds in amplifying the soft Xray with the wavelength of 49nm to the maximum outputs 110kW at June 2006. One of the key technologies in XFEL is the alignment of BPMs between IDs. We tried the alignment method using laser and airy disc to align four BPMs in the prototype accelerator. The test results are shown in this paper.

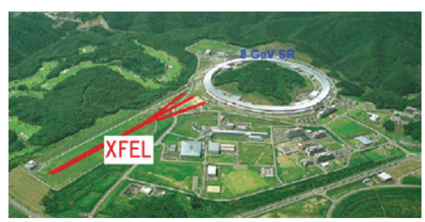

Fig1. XFEL in the SPring-8 site.

2. BPM ALIGNMENT

2.1. Prototype Accelerator

The arrangement of a prototype accelerator is shown in Fig.2. The final energy is 250 MeV. The number of insertion device is two. There is a HeNe laser beside the Chicane part. The BPMs with iris are also denoted by the double circles. The image is focused on the CCD camera by reflecting mirror (yellow line). The important point is that the four BPMs are on one line. The distance from the laser to CCD camera is about 20m.

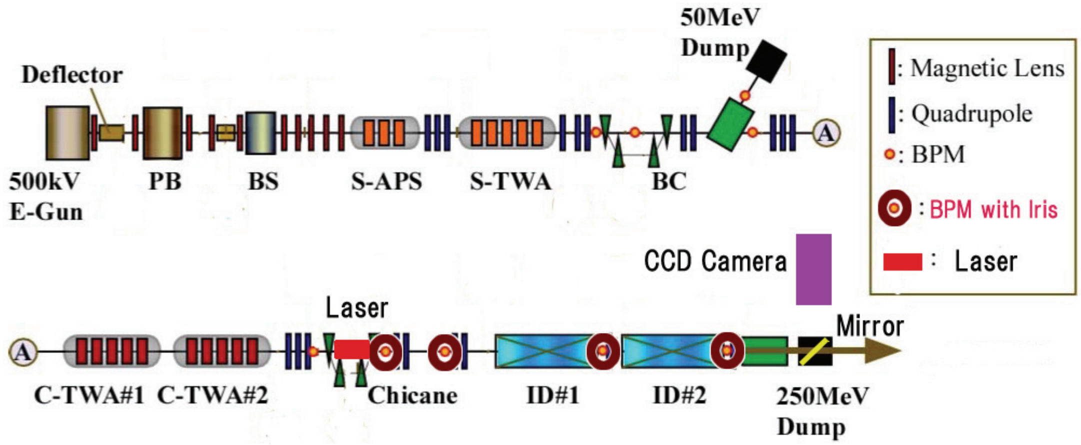

Fig.2. Arrangement of prototype accelerator.

2.2. BPM Center

It is very important how to measure the center of BPM. There are two methods to detect the center. If using outside the BPM, then the mechanical error becomes larger than 10 micro meter. In this case, the pipe for reference line is needed. On the other hand the mechanical error may become small if using inside the BPM. However the mechanics of sensor target for in and out is needed. In this case the reproducibility should be less than several micron. We chose the second case.

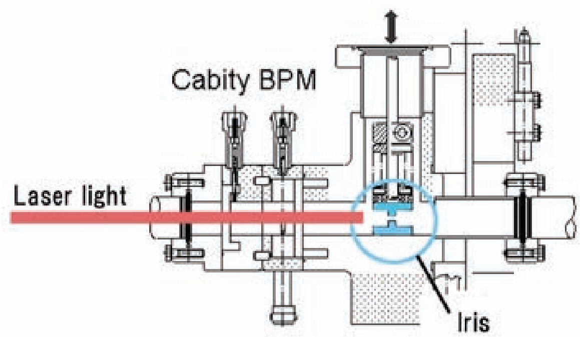

Fig.3. BPM with Iris.

2.3. Airy disc

The radiation from closed circle is so called Airy disc at the Fresnel zone. The images from iris which diameter is 3 mm are shown in Fig.4.

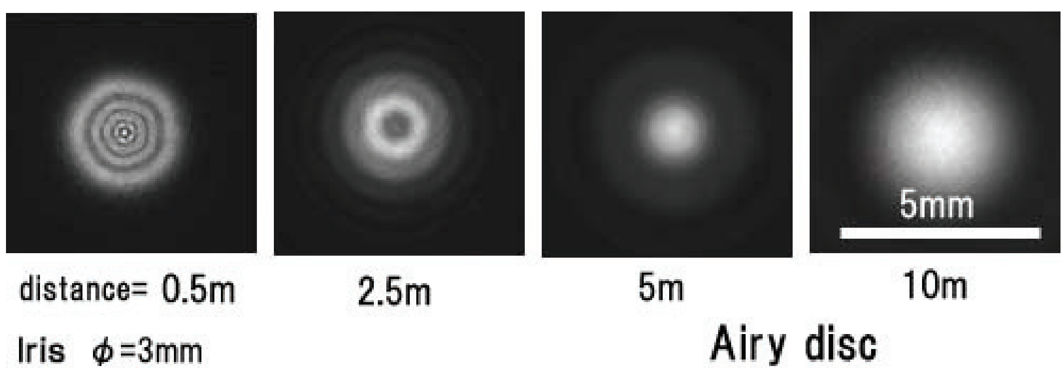

Fig.4. Images from the closed circle.

Fresnel number N_F is given by

$$N_F = \frac{a^2}{\lambda Z}$$

where iris radius a, wavelengthλ and distance Z. The N_F at the distances 0.5m, 2.5m, 5m, and 10m are 7, 1.4, 0.7 and 0.35, respectively in Fig.4. The image at the near point from iris is complex interference pattern. However at the far point (N_F <0.5) the image becomes so called airy disc. The diameter of airy disc is about 1.2Zλ/a.

3. APPARATUS

3.1. HeNe Laser

The parameters of laser are shown bellow.

laser tube	Uniphase 1137P
wavelength	633 nm
output power	7 mW
Beam diameter	0.81 mm
Beam divergence	1mrad
Pointing stability	< 0.02 mrad

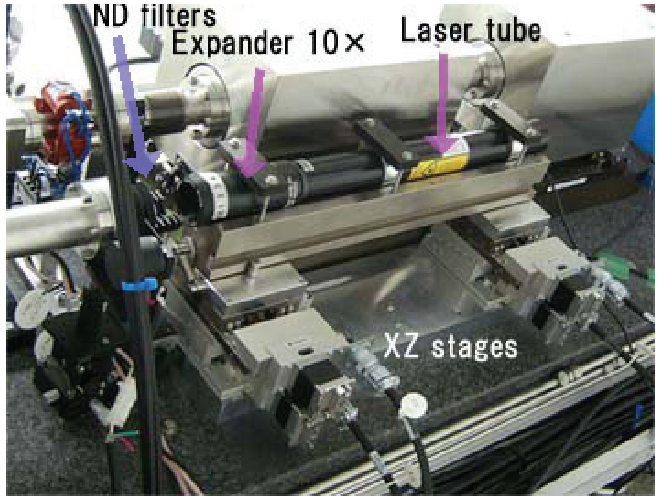

Fig.5. HeNe Laser, expander and ND filters

The expander magnifies the beam ten times. ND filers are used to reduce the laser power. The support of laser is on the two XZ stages. The resolution of these stages is 0.25 micro meter for X axis and 0.125 micro meter for Z axis.

3.2. BPM with Iris

Fig.6. shows the BPM with iris on the XZ stage. The up and down motion of iris is derived by air pressure. The resolutions of XZ stage are 0.1 micro meter in both directions. The part of iris cylinder is silver-soldered to the cavity BPM so that these center axes coincide with each other.

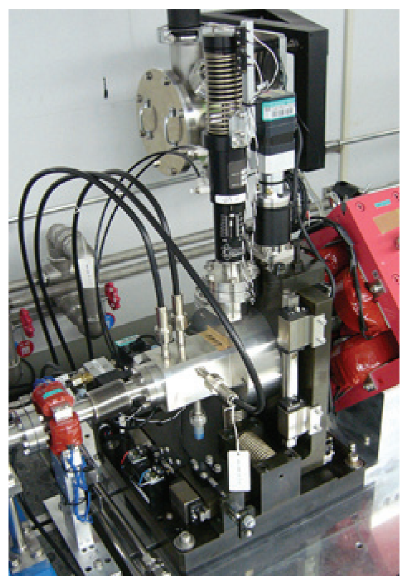

Fig.6. BPM with iris on the XZ stage.

3.3. CCD Camera

The specifications of Kodak 4.2i are as follows. This camera has a mechanical shutter and a 12 bit ADC in the body. The flame glauber board is in the PC. The size of 1 pixel is 9 micro meter square. Total pixel number is 2K x 2K. The cover glass in front of CCD device is removed to reduce the interference. (Fig.7.) ND filter which decreases to 1/100 is used to improve the S/N ratio.

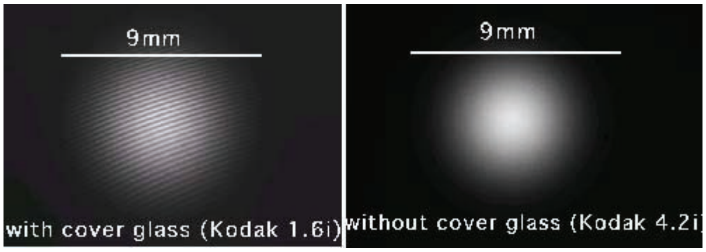

Fig.7. The effect of cover glass.

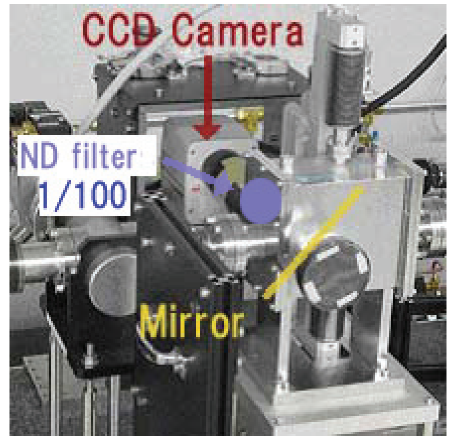

Fig.8. Beam pipe, mirror and CCD camera.

3.4. Calculation of center

Fig.9. shows the image of the airy Disc. Fig.10. shows the count of each pixel. The second peak can be seen. Ten counts are set as the back ground level. Fig.11 is given by subtracting back ground level from the initial count. If the subtracted count becomes negative, the count is replaced by zero.

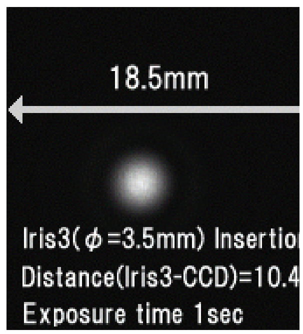

Fig.9. Airy image.

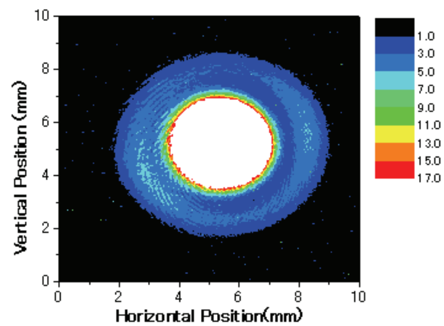

Fig.10. Counts of each pixel.

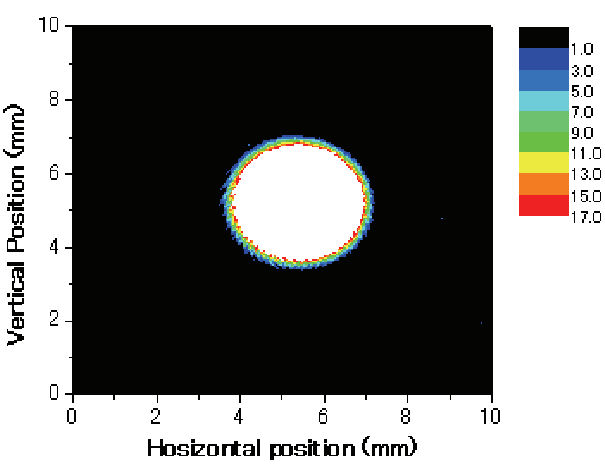

Fig.11. Counts after background subtraction.

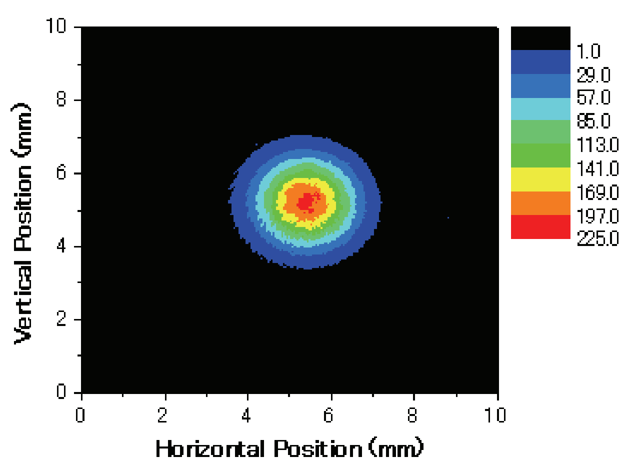

Fig.12. Contour which max counts is 225.

The counts of Fig.12. are same as those of Fig.11. The max counts are different from each other. These counts are projected to calculate the center position.(Fig.13.) In this case the center position can be determined with the accuracy of 0.6 micro meter. The resolution is estimated by Eq.(1).

$$\text{Resolution} \approx \frac{\text{fwhm}}{\sqrt{\text{Total Counts}}} \sim 0.6\mu\text{m} \qquad (1)$$

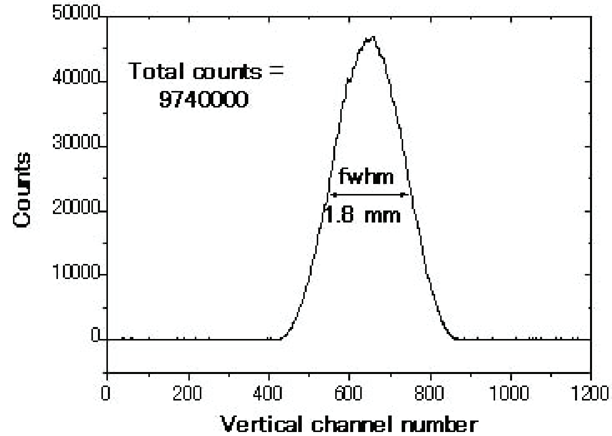

Fig.13. Distribution of projected counts.

4. EXPERIMENTAL RESULTS

4.1. Calibration between Cavity center and Iris one

The calibration was done as the following:

1) The wire is set through the cavity BPM as shown in Fig.14. Search the center position as measuring output signal from cavity BPM. The diameter of Cu wire is 0.05mm, and rf frequency 4 to 6 GHz;

2) Pull out the wire and insert the iris. Set the wire again. Search the center position as 1);

3) Table I shows the value rf center minus iris center. Horizontal difference is small. However, the iris center is lower than the cavity one.

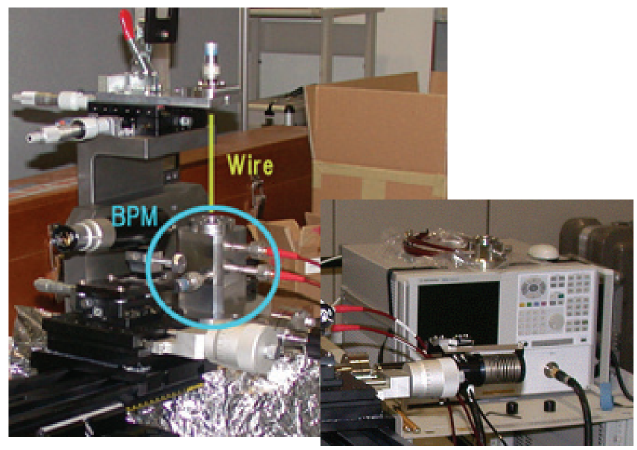

Fig.14. Calibration of iris center.

	Horizontal	Vertical
Iris 1	2.5 μm	-43.5μm
Iris 2	-2	-24.5
Iris 3	-0.5	-46.5

Table I: Difference between the center of rf cavity and that of iris.

4.2. Diameter and brightness of Airy disc

Fig.15. shows the laser image and airy disc. The distance from iris to camera, iris diameter and the design diameter

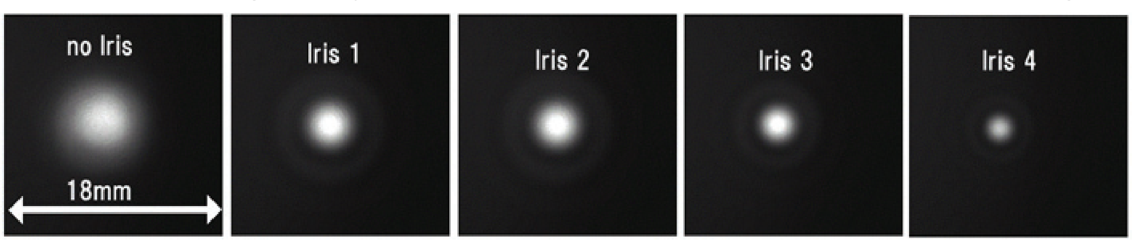

Fig.15. The images of the laser and airy discs.

of the airy disc are summarized in Table II. Fig.16. shows the distribution of the airy disc. The diameters of these distribution agree with the design values.

Iris No	distance (Iris-CCd)	Iris diameter	Airy disc diameter design	Airy disc diameter measured
1	19m	5.0 mm	5.8 mm	5.7 mm
2	16.5	4.5	5.7	5.7
3	10.4	3.5	4.6	4.6
4	4.5	2	3.4	3.4

Table II : Iris number and distance, diameters of iris and airy disc.

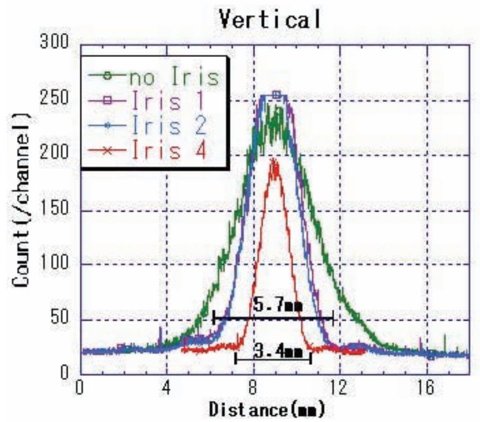

Fig.16. Intensity distribution of airy disc.

4.3. Reproducibility of Iris insertion and pull up

Since the iris is inserted and pulled up many times the reproducibility is much important. The situation is shown in Fig.17. Fig.18. shows the center of airy disc during measurement cycle (insert iris – measuremen t(~10sec) - pull up iris - insert iris - measurement - pull up iris - - - -). Fig.19. shows the center during measurement cycle (insert iris – measurement (~10 sec) - measurement stop - measurement - - -). The cycle time of both cases is about 22 sec. The fluctuations of Fig.18. are larger than those of Fig.19. However the standard deviations in the case of Fig.18 are less than 1 micro meter.

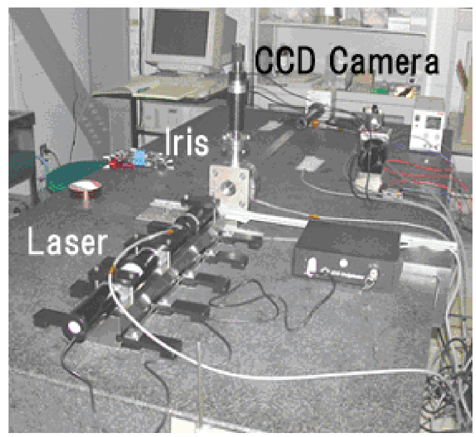

Fig.17. Test of reproducibility of iris up and down.

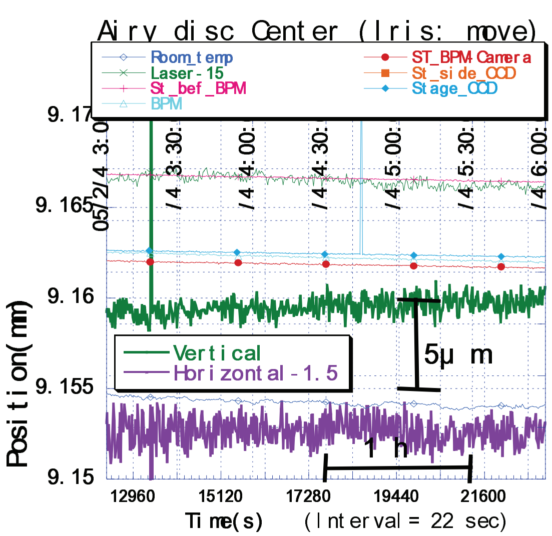

Fig.18. The airy disc center in iris up and down.case.

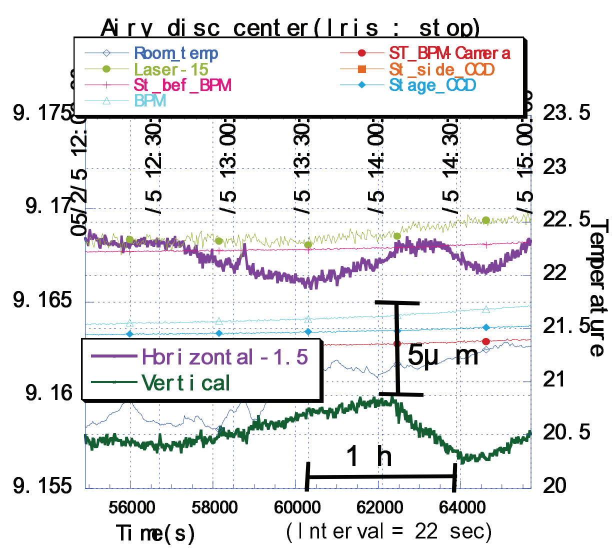

Fig.19. The airy disc center in iris stop case.

4.4. Fluctuation

The center value is given by the averaging centers among ten flames of ccd image. It takes about 15 sec. The standard deviation is estimated averaging four times (~1 min). Fig.20 shows the variation of the standard deviations when each iris goes down. Since the distance between BPM4 and CCD camera is smallest, the standard deviation at BPM4 is also small.

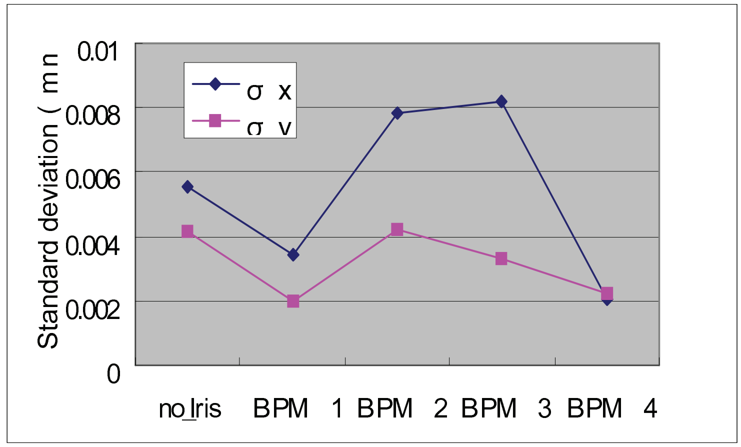

Fig.20. Standard deviation of the center of CCD images.

4.5. Stability

The distance between laser and CCD camera is 20m. Fig.21. shows the drift of center position for 14 hours. These changes are due to the laser, its stage, camera and others. However it is difficult to search the main reason because the change is small. The tilt change of laser (pointing stability is less than 10 micro rad) is reduced ten times because of 10 times expander. If the laser light before the expander shift 2 micrometer, the light after expander shift 20 micrometer.

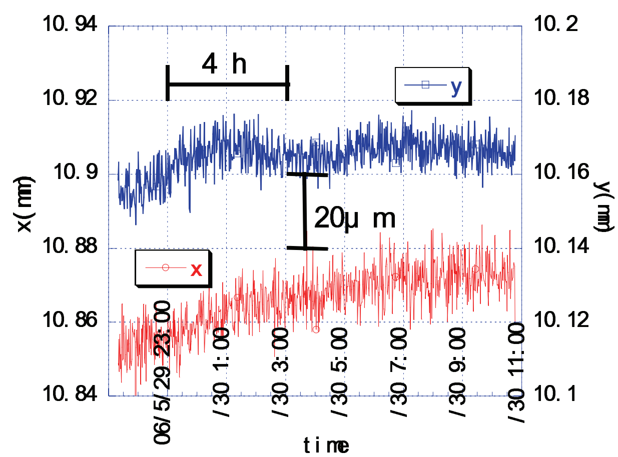

Fig.21. Drift of the center of CCD images.

4.6. Effect of Gaussian

The intensity distribution of the laser light is not the plane wave but gaussian. Thus the shift value of the image center

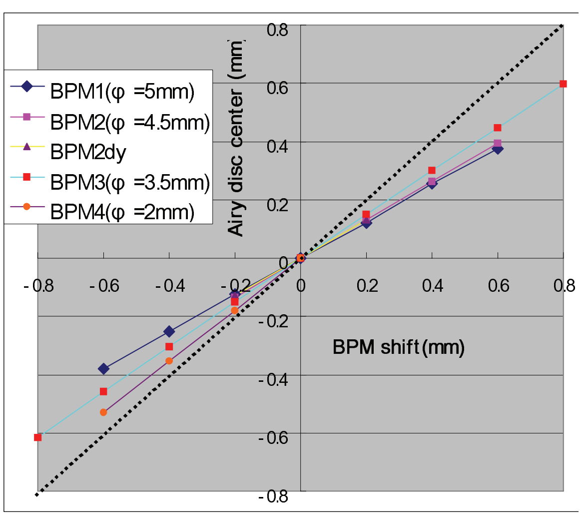

Fig.22. Relation between the iris and airy disc shifts.

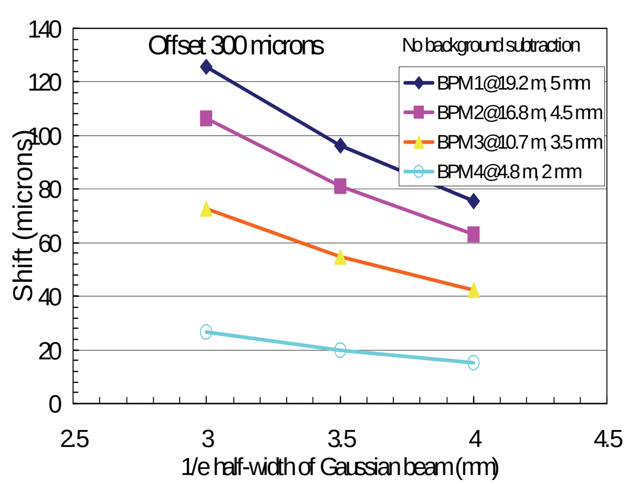

Fig.23. Shift variation against gaussian beam width.

is smaller than the actual shift of the iris. The ratio is 2/3 in iris 1 case as shown in Fig. 22 . Fig.23. shows the calculation of the shift when the offset between gaussian and iris is 300 micrometer.

4.7. Check of Laser and Airy disc System

The measurement by two alignment telescopes was done to check the laser and airy disc system. Fig.24.(left) shows the setting bar with target to measure the horizontal position of the BPM. Fig.24.(right) shows the setting bar to measure the vertical position of the BPM.

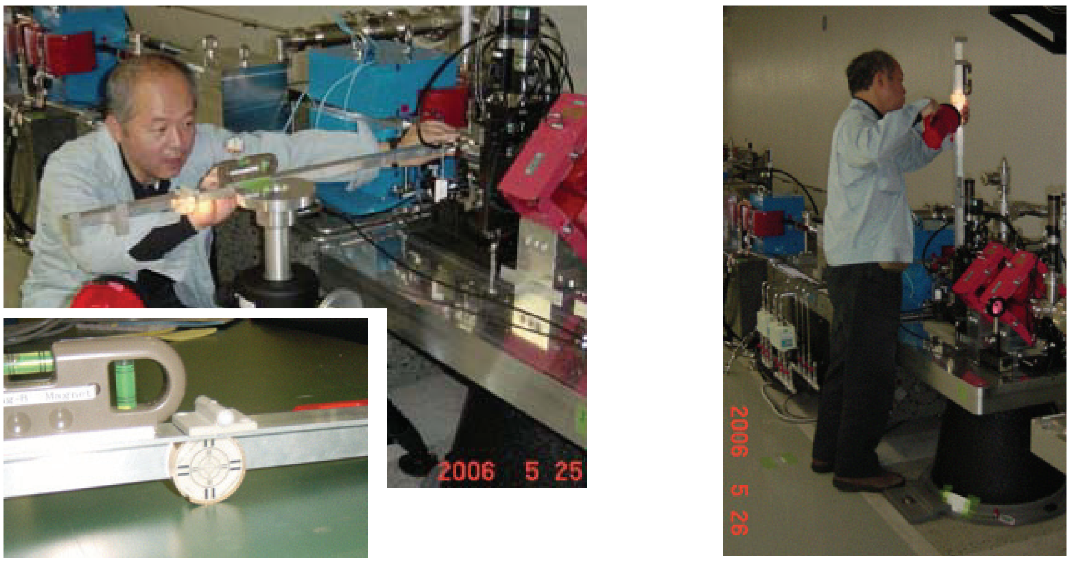

Fig.24. Setting bar to measure the horizontal (left) and vertical (right) position of the BPM

The results are shown in Fig.25. The reference BPMs are BPM1 and BPM4. Diamond blues represent the positions measured by the telescope. Pink squares and orange diamonds represent the positions measured by the laser and camera system. Pink squares are not corrected with gaussian effect, but orange diamonds are corrected. Though these plots are not corrected by the 4.1. calibration of the iris, the differences between the values of two methods are around 0.1mm

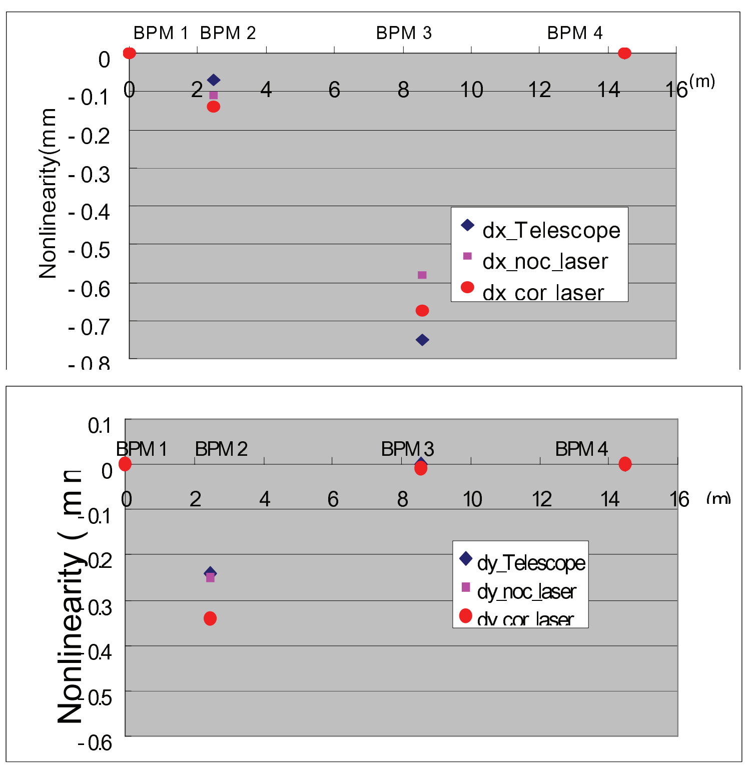

Fig.25. Nonleariy of BPM2, 3 measured by telescopes and laser-airy disc system. (up:horizontal down: vertical).

5. SUMMARY

It is possible to measure the position of Iris inside the BPM chamber (diameter 20 mm) using airy disc for 20 m range. If using red He-Ne laser, it is difficult to be passed through 20mm inner diameter for more than 30m at one time. It is necessary to estimate the accuracy of this Iris-airy disc system. It is necessary to get the flatness of the response in the CCD device. Defect pixels are corrected using next pixel values. Check by the other method is also necessary. For example, WPS, HLS, and so on. It is important to align the vacuum chamber so that the laser light is not blocked. The effect of Gaussian beam must be considered. It is necessary to improve the reproducibility of Iris insertion and pull out. The fluctuation should be improved by searching the reason.

There will be 18 insertion devices in our planed XFEL. Since the wavelength of HeNe laser is 633 nm and BPM diameter is 20mm, it is difficult to be passed through the all BPMs in one laser light with space. Thus if using HeNe laser, several steps are needed to align 19 BPMs on one line. Six BPMs are aligned by one step. In the next step, six BPMs including last two BPMs are aligned. However this method needs many lasers and CCD cameras, moreover the positions of reference BPMs are not both ends but successive two BPMs. Thus the reference line tends to curve. The light of shorter wavelength is needed to be passed through by one path. For example, the light of 325nm by HeCd laser should be examined. In addition, an investigation of new method will also be considered.