PERFORMANCE OF THE IRIS DIAPHRAGM LASER ALIGNMENT SYSTEM OF THE SPRING-8

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INTRODUCTION

The storage ring of the SPring-8, with a circumference of 1436 meters, has forty-eight cells of Chasman-Green lattice. The multiple magnets of 10 quadrupoles and 7 sextupoles are mounted on three common girders of 4 or 5 meters in length.

The magnets on common girders have tight alignment tolerances. To align these magnets a laser CCD camera system was developed in 1995 [1]. This system, without optical lens or targets, measures the centre of laser beam directly. It is precise while the shortcoming is time consuming, because it should be very careful when set the camera's posture to get good positional reproducibility of camera when camera is moved among measurement points. With this system the magnets on common girder were aligned within 20μm (σ).

To upgrade this system, as well as for the promising use in future project of SPring-8II, we proposed a new laser system which uses iris diaphragm as target and fixes the position of CCD camera, and illustrated in IWAA2012 [2]. New system aims short measurement time and high accuracy of 10μm (2σ) in 10 meters range. At present, performances of it are examined. Resoults shown that the new system has reached the aim of our intention.

LASER-IRIS ALIGNMENT SYSTEM

When plane wave, with wavelength of λ, is incident on an iris with a radius of a, on the orientation of wave propagation, we get a diffraction pattern. When distance

$$z >> \frac{a^2}{\lambda} \tag{1}$$

The diffraction pattern is known as airy pattern (figure 1).

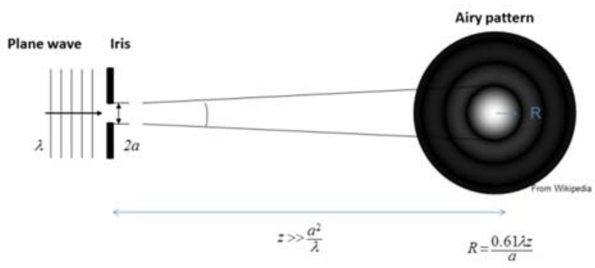

Fig. 1 Airy pattern of an iris

Airy pattern possesses a main lobe and concentric rings around it. The main lobe is called airy disk which holds 84% of power. The radius of airy disk is

$$R = \frac{0.61\lambda z}{a} \tag{2}$$

it is proportional to the distance and inverse proportional to the radius of iris.

Laser-iris alignment is by measuring the centre of airy disk to determine the position of the iris.

Alignment using laser-iris was first investigated in 2003 at the SPring-8 for the SCSS, and executed in 2006 [3][4]. To precisely align the centres of BPM, we inserted retractable irises into vacuum chamber which have a physical aperture of 20mm and introduced He-Ne laser beam into the chamber. Airy disk at the downstream of undulators were measured with the camera. Distance between laser and camera was about 20 meters. Laser-iris system was verified a feasible method for alignment.

IRIS DIAPHRAGM LASER ALIGNMENT SYSTEM

An iris diaphragm laser alignment system is proposed and developed. The system consists of a laser source, a CCD camera and four iris diaphragm targets as shown in figure 2.

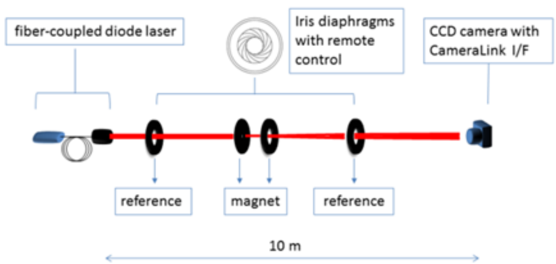

Fig.2 Iris diaphragms laser alignment system. It consists of laser source, CCD camera and iris diaphragm targets.

The iris diaphragm that in measurement closes to minimum caliber while other three keep opening at maximum aperture to let laser beam pass. The aim of this system is an accuracy of 10μm (2σ) in 10 meters range.

Figure 3 shows actual system. It is composed of a laser head, CCD camera and image acquisition PC, four iris diaphragm targets and a target controller.

Fig.3 Iris diaphragms laser alignment system developed in the SPring-8.

The laser head consists of 3.5mW fiber-coupled diode laser of λ0.633μm, collimator and 6× beam expander. Output laser beam has a size of 4.7mm in diameter.

We first used an 8× expander and the beam size was 6.2mm correspondently. Figure 4 shows the pointing stability of the laser beam for eight hours, measured in the storage ring tunnel. Distance from laser to camera is eight meters. The stability of room temperature in tunnel was within 0.1°C. As the result, fluctuations of the laser beam in transverse directions are under ±2μm (σ).

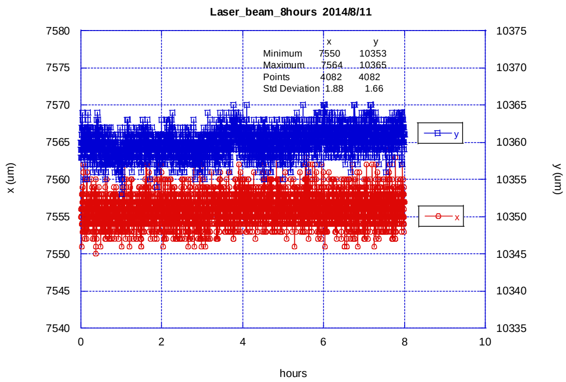

Fig. 4 Pointing stability of the laser beam, fluctuation in transverse directions are under ±2μm (σ) for 8 hours.

8× expander is testified a little large for a 12mm aperture of targets. Because the image was seen diffraction patterns which produced from the targets. The expander is changed to 6× afterward. Correspondingly, beam size is reduced from 6.2mm to 4.7 mm.

The CCD camera has a sensor size of 15x15mm^2 with pixel size of 7.4μm (figure 5). There are total of 4M pixels. Frame rate of image acquisition is 15fps with Cameralink interface.

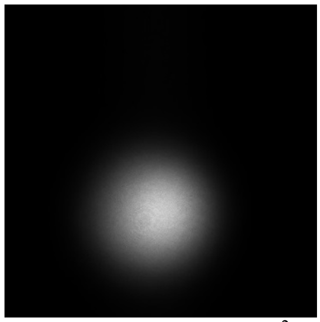

Fig.5 Size of CCD sensor is 15x15mm^2 with pixel size of 7.4μm and total of 4Mpixels.

About the system resolution, it is tested using a precise automatic stage on which the camera is set. Distance from laser to camera is 2 meters. The stage moves the camera in 1μm step and camera reads the deviations. Figure 6 shows the deviations measured by camera against the movement of the stage. Quantities of camera indications are 1μm in a confidence level of 90%. It verifies the resolution of camera is under 1 μm.

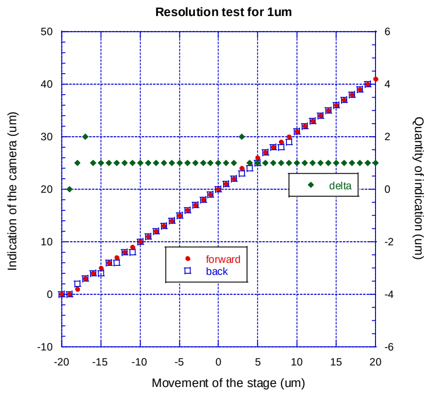

Fig.6 Resolution test of the camera. The camera is moved in 1μm step and the camera measures the deviations. Quantities of camera indications are 1μm in a confidence level of 90%.

The key component of iris diaphragm alignment system is the target. As shown in figure 7, commercial iris diaphragm consists of blades, base plate and blade actuating ring.

Fig. 7 a commercial iris diaphragm

The centre reproducibility was examined for several makers, and good piece has a reproducibility of about 2μm (σ) as shown in figure 8. Reproducibility becomes worse when iris is not used in minimum caliber. It is not good enough for high precision alignment.

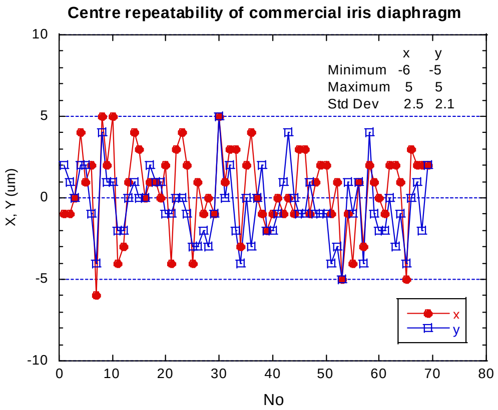

Fig.8 Example of the centre reproducibility of commercial iris diaphragm.

Because the commercial iris diaphragm is not precisely processed, especially the rotation parts are not smooth, we have developed a new piece as shown in figure 9. The SPring8 iris diaphragm consists of blades of 11 pieces, base plate, centring balls and driving gear wheel. The centring ball fixes the position of actuating ring radially and makes its rotation smooth. The gear wheel is actuated by an actuator which is not shown in the figure.

The iris diaphragm is embedded into the centre of a ϕ75mm ball and has variable caliber from ϕ1 to ϕ12mm (figure 10).

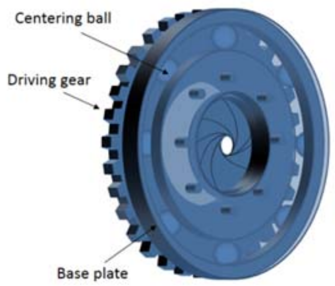

Fig. 9 Schematic figure of SPring8 iris diaphragm. It consists of blades of 11 pieces, base plate, centring balls and actuating gear wheel.

Fig. 10 Iris diaphragm target which can be opened to 12mm caliber with a remote controller.

The displacements of iris centre are adjusted in three directions, using a laser displacement sensor for the longitude, and the laser beam for the transverses. Displacement in transvers w.r.t centre of the ball is 2 μm.

Test of the central reproducibility are executed for a hundred times in close-measure-open cycles for each target. The reproducibility are well under ±1μm (σ). An example is given in figure 11.

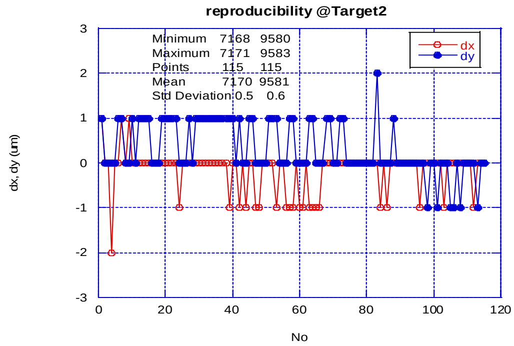

Fig.11 Central reproducibility of SPring8 iris diaphragm. It is well under ±1μm (σ).

To estimate the measurement accuracy of the system, laser beam fluctuations are measured. The distances from four targets to the camera are 2, 3.5, 5 and 6.5 meters respectively. As shown in figure 12, fluctuations of laser beam are 0.9, 1.3, 1.7 and 1.9 μm (σ) correspondingly. Data lengths are cut according to relative distances of the four points for visual contrast.

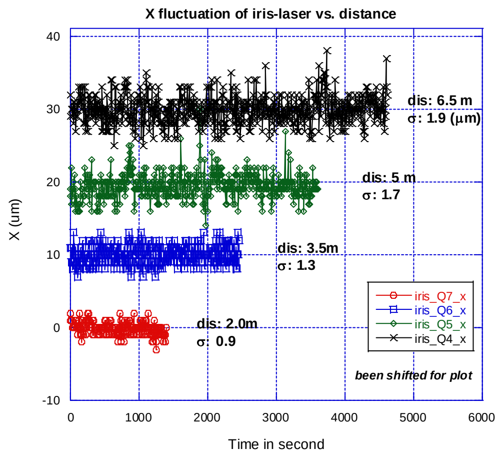

Fig.12 Fluctuations of laser beam from the four targets, all of them are under 2μm (σ).

It is the time to value the measurement accuracy of the iris diaphragm laser alignment system. By sum up the errors of target centre displacement, iris centre reproducibility, laser beam fluctuation of reference points and that of measurement point as bellowing, measurement uncertainty of this system is estimated as ±7 μm (2σ).

$$\Delta = 2 + 2\sqrt{(0.7^2 + 2^2 + 1.5^2)} = 7\ (\mu m)$$

To verify the estimation, we did repeated measurements for the positions of magnets on a common girder. The positions of four magnets were measured 10 times, re-setting targets every time. As the result, measurement reproducibility was within ±7μm w.r.t. the average (figure 13), which agrees with the error estimation.

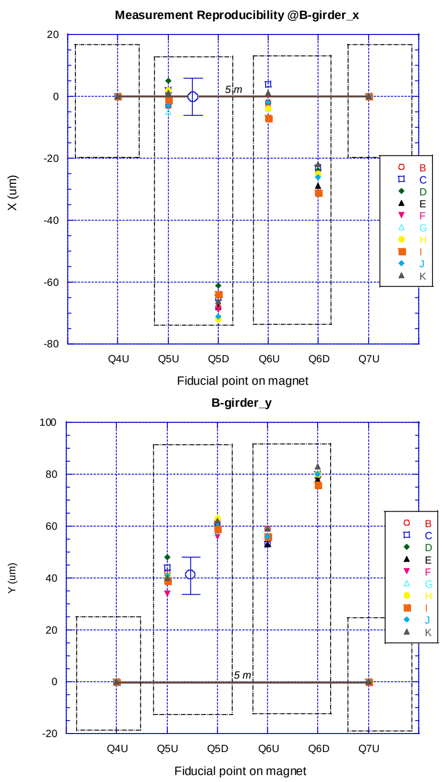

Fig. 13 10 times measurements for the positions of four magnets. Reproducibility of measurement is ±7μm, which agrees with the error estimation.

According to the test results, the iris diaphragm laser alignment system has a measurement uncertainty of ±7μm (2σ) in 8 meters range. It reaches the aim of our intention at first, 10μm (2σ) in 10 meters.

CONCLUSION

An iris diaphragm laser alignment system is developed. The system consists of a laser head, CCD camera and four iris diaphragm targets which are operated remotely. Performances of this system were tested, and it is verified that the system has a measurement uncertainty of ±7μm (2σ) in 8 meters range. This reaches the aim of our intention at first, 10μm (2σ) in 10 meters.

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