

## DEVELOPING AN IRIS DIAPHRAGM LASER ALIGNMENT SYSTEM FOR SPRING-8 STORAGE RING MAGNETS

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### INTRODUCTION

The SPring-8 storage ring is Chasman-Green lattice of 48 cells. Each cell consists of 2 bending magnets, 10 quadrupoles and 7 sextupoles mounted on three common girders of 4 or 5 meters (fig.1).



Fig.1 Magnets arrangement of a cell of the storage ring

The magnets on common girders have critical alignment tolerance. To align these magnets the laser CCD-camera system was developed in 1995[1]. With this system the magnets were aligned for accuracy of 20 $\mu\text{m}$  (rms). As the devices of this system become old we need to replace it with a new one. For the more, the Spring-8II in planning requires magnets' centres to be aligned with a tolerance less than 20 $\mu\text{m}$  because of strong field. That, except for other error sources, demands an alignment system to have accuracy of several micrometers. Therefore, the new laser system should have the possibility to be used in future accelerator.

An iris diaphragm laser alignment system is proposed and under developing. The test result shows that it is a practical method for the alignment of straight line in short distance range.

### LASER ALIGNMENT WITH IRIS

When plane wave of wave length  $\lambda$  is incident on an iris of radius  $a$ , on the orientation of wave propagation, we get a diffraction pattern. For small distance  $z$ , the pattern varies along propagation, when  $z \gg a^2/\lambda$ , the diffraction pattern becomes a main lobe and some concentric circles around it, it is known as the airy pattern.

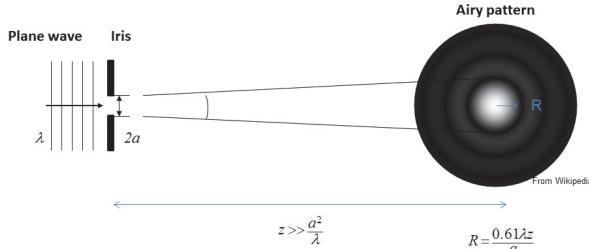


Fig. 2 Airy pattern of an iris

The intensity distribution of airy pattern along radius is

$$I(r) = \left[ \frac{2J_1(\frac{2\pi}{\lambda z}ar)}{\frac{2\pi}{\lambda z}ar} \right]^2 \quad (1)$$

where,  $J_1$  is first kind Bessel function of

$$J_1(x) = \frac{i^{-1}}{2\pi} \int_0^{2\pi} e^{ix\cos\phi} e^{i\phi} d\phi$$

while,

$$z \gg \frac{a^2}{\lambda} \quad (2)$$

The main lobe is called airy disk, which possesses 84% of power. The radius of airy disk is

$$R = \frac{0.61\lambda z}{a} \quad (3)$$

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

From eq.(3), the divergence angle of wave behind the iris is

$$2\theta = \frac{1.22\lambda}{a} \quad (4)$$

Monitoring the centre of the airy disk can determine the position of iris. And, instead of plane wave we use laser. Figure 3 is images of diffraction patterns along laser propagation.

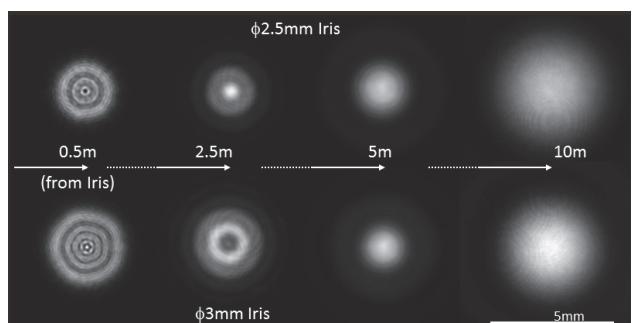


Fig.3 Diffraction pattern of an iris along laser propagation

Alignment using laser-iris was initially proposed by Dr. T. Shintake in 2003 for the SPring-8 compact SASE source (SCSS)[2](fig.4), it was verified a feasible method for alignment by authors.

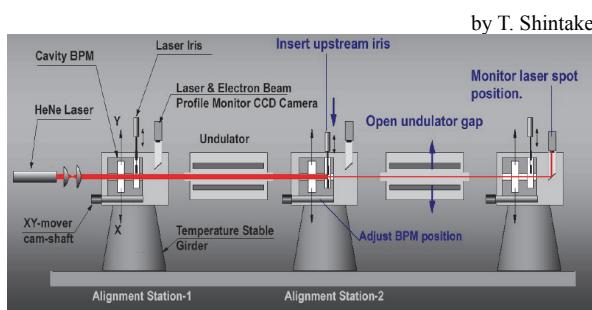


Fig.4 Alignment concept of the SCSS

To precisely measure the centres of BPM, retractable iris is made the same body with the BPM and mechanically co-axis with it. In the alignment we introduced He-Ne laser to vacuum chamber, which has physical aperture of 20mm in diameter. Gap of the undulator can be opened to pass laser beam. Distances between irises and CCD camera were from 5m to 19m and of we used  $\phi 2$  to  $\phi 5$ mm irises for this system [3].

For the distance range of laser iris system, figure 5, which plots equations (2) and (3), shows the dependence of airy disk size on distance, as well as the shortest distances to get the airy disk.

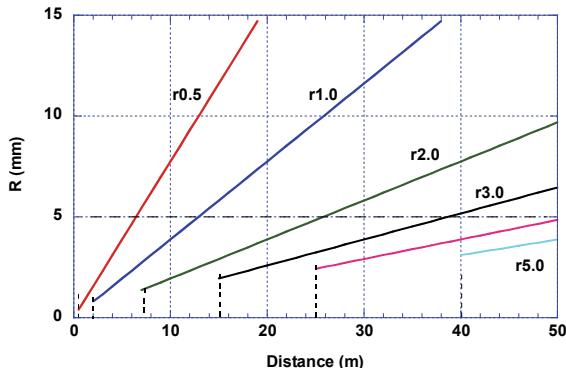


Fig.5 Radius of airy disk against distance, Dot line indicates the shortest distances the airy disk appears.

If the size of image in front of the camera is limited to  $R=5$ mm for a system, an iris of  $r1.0$ mm covers distance for about 13 meters; for a  $r2.0$ mm iris it is 25m. Iris larger than  $r3.0$ mm could be used for a range more than 40 metres. On the other hand, larger iris needs long distance to get airy disk. One solution is to use varied sizes by

$$a = 0.61\lambda z / R_{const}$$

to keep the images same dimension.

To investigate the feasibility of laser-iris using in the alignment of SCSS, some verifications were done in 2003. We made a 20-m test bench, and set up several stations for laser, irises and camera in 5m intervals. We took images and profiles of the beams, measured sensitivities and linearity of the devices. Figure 6 gives the sensitivity test for an iris 3mm in diameter. Spot size of laser beam is expanded to 9mm, three time of the iris. Distance from iris to camera is 10m and 5m respectively. Iris is moved

transversely in 10- $\mu$ m steps. As the results, the shifts of the images are well in correspondence of movement of the iris. For the linearity test, as shown in figure 7, iris was moved across the laser by half width of the beam, as it can be seen, even for this large displacement, linearity of the image is fairly good.

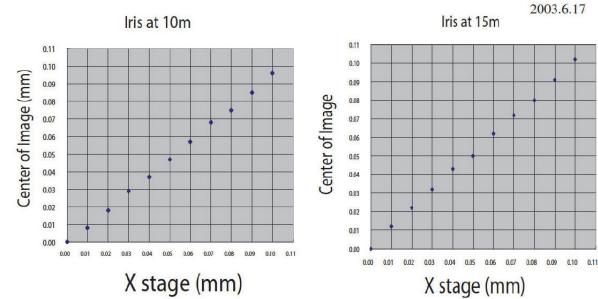


Fig.6 Sensitivity test of laser-iris, iris is moved transversely in 10- $\mu$ m steps.

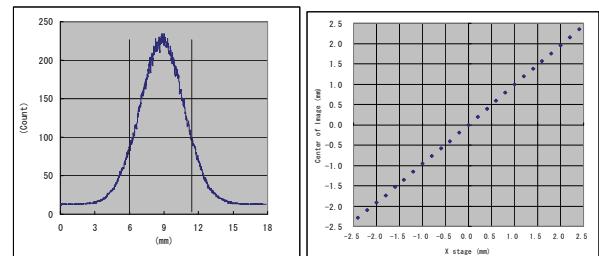


Fig.7 Linearity test of laser-iris, iris goes across the laser by half width of the beam.

## IRIS DIAPHRAGM LASER ALIGNMENT SYSTEM

Succession to the iris system used in the SCSS, when renew the laser system for the storage ring, we are developing an iris diaphragm laser alignment system. It is composed of a fiber-coupled diode laser source, four iris diaphragms and the CCD camera as illustrated in figure 8. The diaphragm at the point of measurement is closed to the minimum to form an iris, and other three diaphragms are opened to let laser beam pass.

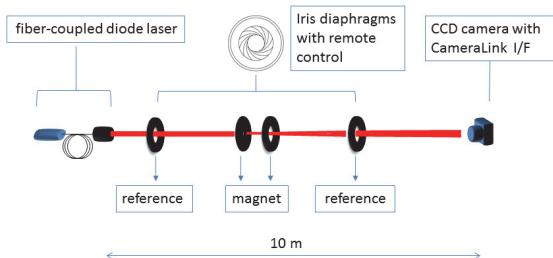


Fig.8 Iris diaphragms laser alignment system, it consists of fiber-coupled LD, four targets of iris diaphragms, and CCD camera.

Using iris diaphragm as the target because it has slight moving leafs and can speedily close to form a small circle (iris) and open to let laser beam pass, with almost no mechanical impact. When operated with motor it is possible to largely reduce measurement time.

It is usual when doing alignment laser beam is always in drift, because of changes of surrounding conditions such as temperature, air pressure and air flow. Figure 9 is a sampling data when measuring laser pointing stability.

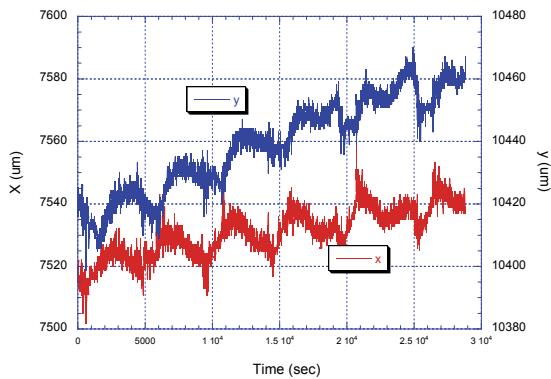


Fig.9 A sampling data of pointing stability

It is a worse case because the air conditioner can not be turn off in the measurement. The former version of laser system omits optical lens of targets and measures laser beam directly. During measurement CCD camera is set among measuring points (fig.10). It is precise because it omits the target induced errors. While for the shortcoming it consumes time. We have to set the camera carefully to get good positional reproducibility of the CCD.

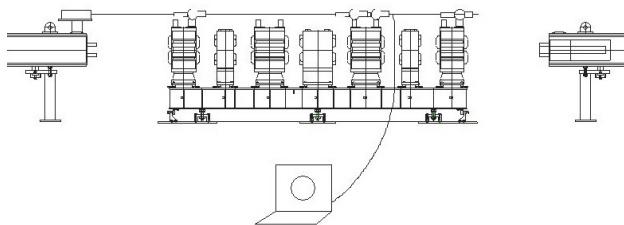


Fig.10 Former method of laser alignment system

By contrast, the system using iris diaphragms as targets and fixing the position of the CCD camera can largely shorten measurement time. The diaphragm can be opened and closed remotely. Time for the measurement, including integral time, will need only 30 seconds.

Figure 11 is the simulation for the two cases. The drifts in figure 9 are reset to zero in 8 minutes or 30 seconds periods because of re-measurement of references. It is clear that short measurement time has an effect on reducing error and therefore increases measurement accuracy.

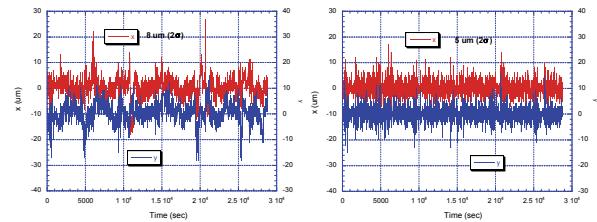


Fig.11 Simulation of the effects of two alignment methods against laser beam drift

At present, an initial system is made while still in developing.

The laser head as shown in figure 12 is composed of 3.5mW fiber-coupled diode laser of  $\lambda=0.633\mu\text{m}$ , a collimator and a beam expander of 8 $\times$  that expand laser beam to 6mm in diameter.

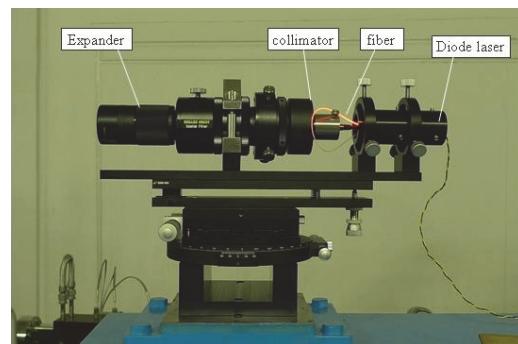


Fig.12 Laser head consists of a 3.5mW fiber-coupled diode laser, a collimator and beam expander of 8 $\times$ .

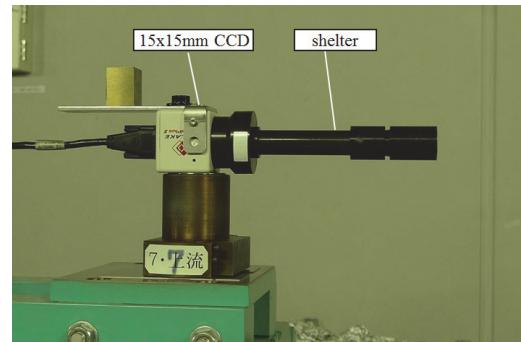


Fig.13 CCD camera with sensor size of  $15 \times 15\text{mm}^2$  and pixel size of  $7.4\mu\text{m}$ , resolution is  $2048 \times 2048$  pixels.

CCD camera presently uses Redlake MegplusII. It has a large sensor of  $15 \times 15\text{mm}^2$  with pixel size  $7.4\mu\text{m}$ . Max frame rate is 15 fps with the interface of cameraLink. To get high accuracy we avoid using focus lens in front of CCD.

The target will be an assembly of iris diaphragm and motor as shown in figure 14. The iris diaphragm has variable aperture from  $\phi 1$  to  $\phi 15\text{mm}$  and is set to the centre of  $\phi 75\text{mm}$  ball. Corresponding to 10-meter measurement range, the iris is used around 1.8mm in diameter.



Fig.14 Iris diaphragm target, four targets will be used simultaneously. The diaphragm in measurement is close to form a small circle of iris, and other three are open.

Measurement stability of the iris diaphragm laser system is tested in the tunnel of the storage ring. Distances from diaphragms to camera are 2, 5, 6, 8 metres respectively. Figure 15 gives the measurement results for two hours, as well as images for each point. Fluctuations of image centres generally become large as the distance between diaphragm and camera increases. All points' uncertainties are under 8 $\mu\text{m}$ . Besides, Centres of the four irises are possible to be calibrated coincided with each other for about 2 $\mu\text{m}$ . Accordingly, the system is expected to have capability of 10- $\mu\text{m}$  ( $2\sigma$ ) accuracy for the alignment of the storage ring magnets on common girders.

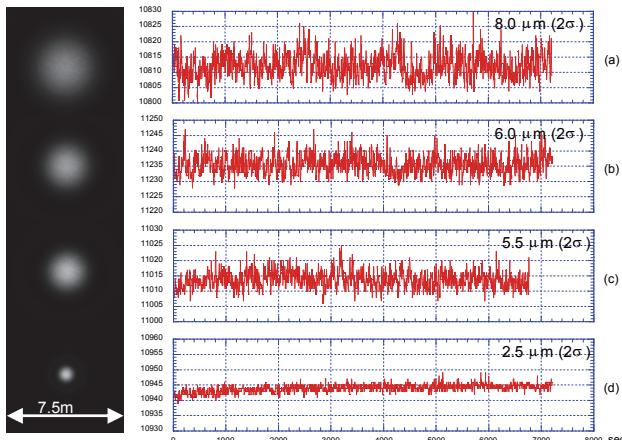


Fig.15 Measurement stability for four typical points, distance from irises to camera are 2, 5, 6 and 8 meters respectively. Maximum uncertainty is 8 $\mu\text{m}$  ( $2\sigma$ ).

## CONCLUSION

Alignment using laser-iris was tested in 2003 and we verified it is a feasible method for alignment of short range and used this system in the alignment of the SCSS.

When renew the laser alignment system for the storage ring magnets of SPring-8, we propose an iris diaphragm laser alignment system. It is under developing.

The new system of iris diaphragm consists of a fiber-coupled diode laser source, four iris diaphragms and a CCD camera. With remote control of the diaphragms this system will much shorten measurement time. It is expected to have capability of 10- $\mu\text{m}$  ( $2\sigma$ ) accuracy for the alignment of the storage ring magnets on common girders.

## ACKNOWLEDGMENTS

The authors would like to acknowledge Mr. M.Hasagawa, Mr. T.Shinomoto of SPring-8 Service Co. Ltd. for their helpful experiments on the devices.

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