ALIGNMENT METHOD for 50m DISTANCE USING LASER and CCD CAMERA

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1. INTRODUCTION

SPring8 storage ring is 8GeV synchrotron radiation source, which circumference is 1436m with 48 double-bend achromatic cells. This ring has also four long straight sections. Before modification three girders were put as other section. A long undulator (27m) was installed at one straight section and three free spaces were made at other sections in the summer of 2000 as shown in Fig.1. This modification is reported in this proceedings [1]. The length between the two reference points QL1 and QL12 is 44m. The misalignment tolerance of quadrupole magnets QL6 and QL7 is ± 0.2mm horizontally and ± 0.1mm vertically as shown in Fig.2.

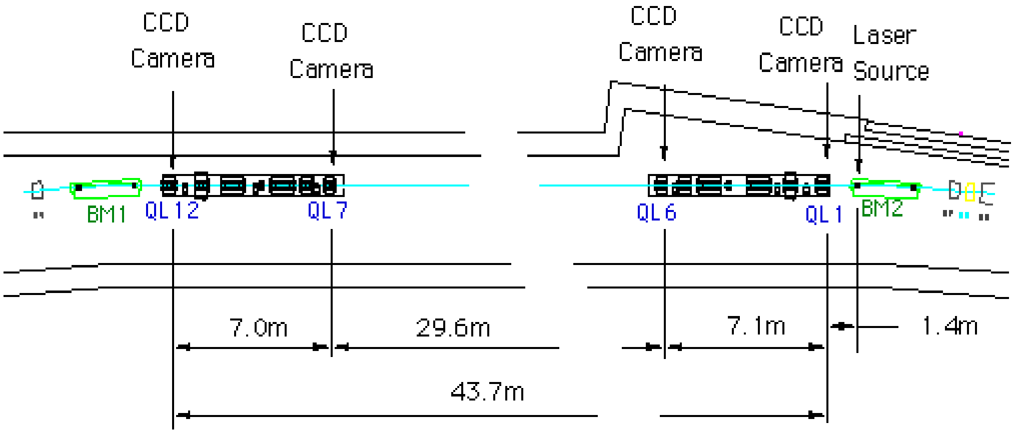


Fig.1. Long straight section after modification.

Misalignment tolerance

rms displacement error(μm)

	ΔX	ΔY	ΔZ
Magnet	25	25	
Girder	200	100	500

rms rotation error(mrad)

	θx	θy	θz
Total	0.1	0.1	0.2

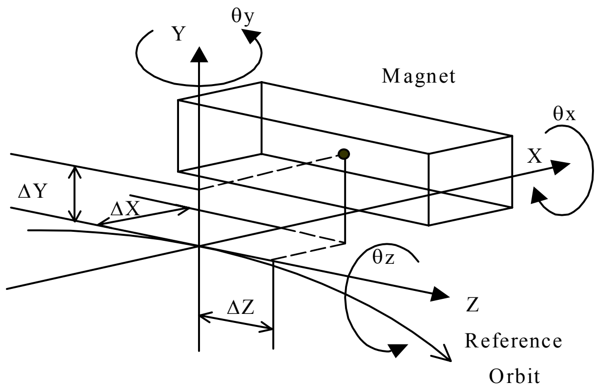


Fig.2. Coordinate system and alignment tolerance of quadrupole

It was rather difficult to align by using telescope. Thus we made a new laser and CCD camera system. We had already used a laser and CCD camera system when we align the multipole magnets on a girder in a whole ring. [2] The diameter of laser light was about 3mm and the size of CCD was 2/3 inch. However the distance was long this time. Thus we used large CCD device. However, the light is refracted by the temperature gradient. In particular, this gradient increases in the pipe. There is no dispersion problem in the vacuum. However the in-air instrument for compensation of the dispersion by using two wavelengths is developed.[3,4]

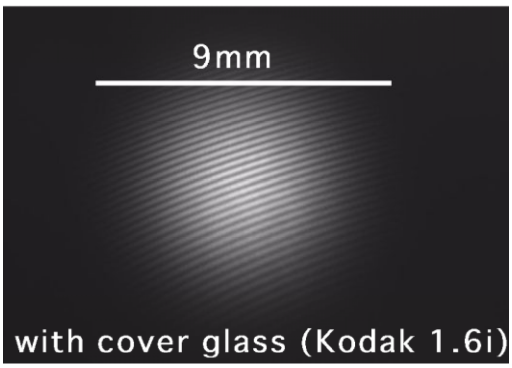
2. APPARATUS

2.1 Laser source

A new He-Ne laser source is almost same as old one. A 633nm He-Ne laser of 2 mW is used. The power is reduced about 1/6 using two ND filers. The spatial filter (MELLES GRIOT) consists of a focusing lens(f=8mm) and a pinhole(ϕ=25μm) for suppression of higher mode. A collimator lens (f=101.5mm) is used to make parallel light beam. The diameter of laser light is about 9 mm. It is possible to adjust finely the position of the laser spot on the CCD device at 45m distance from the laser by using differential bolt.

2.2 CCD camera

The sensitive area of CCD device (KODAK 4.2i) is 18.5mm×18.5mm. Its pixel dimension is 9μm×9μm. The cover glass in front of the CCD surface for protection is removed to suppress the interference. This CCD camera is available now (three years after removing). The older CCD device has low-reflecting coating for 633nm.[2] Figure 3 shows the CCD images of both with and without cover glass. There is interference pattern on the CCD device which has cover glass.



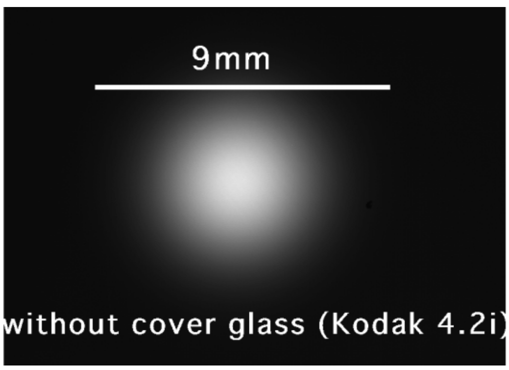


Fig.3. CCD images (left: with cover glass right: without cover glass).

A 1/100 ND filter for good S/N ratio is at the top of the hood. (Fig.4)

The images on the CCD device at the different positions are shown in Fig5. The laser light is so adjusted that the diameter are almost same at the different distances. Since the ADC bit is 8, the maximum count is 256 per one pixel.

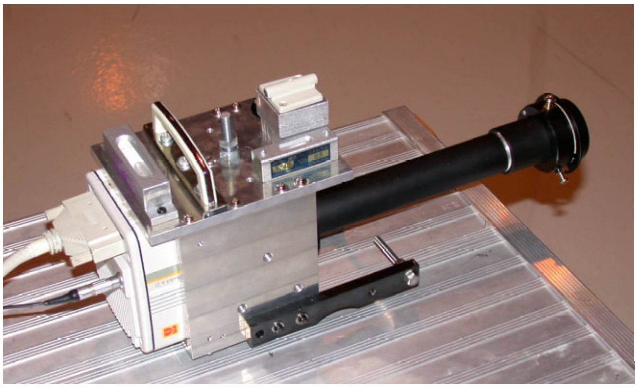


Fig.4 . CCD camera with hood and bubble tiltmeter.

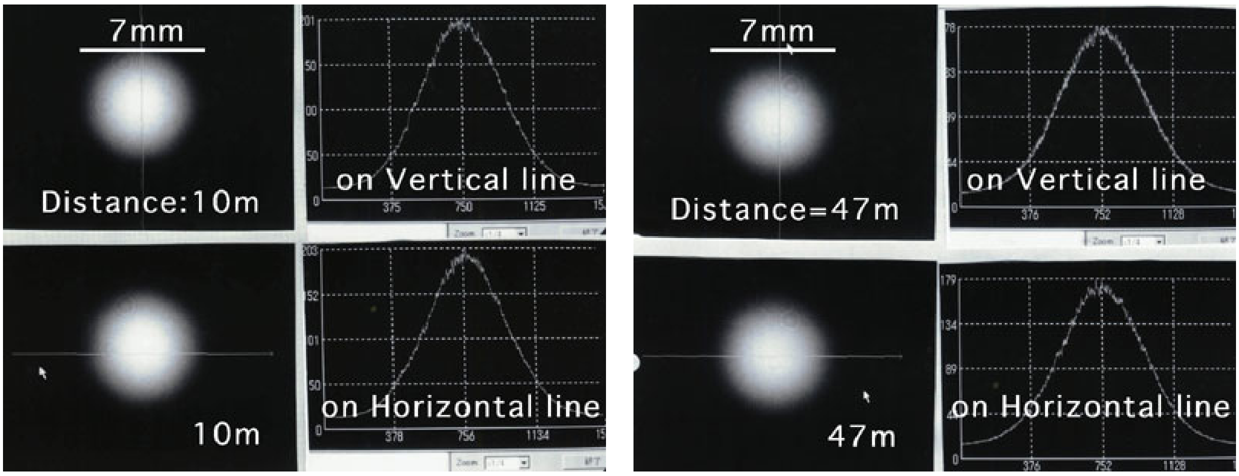


Fig.5. CCD images and intensity distributions on the vertical and horizontal line at 10m and 47m distances.

The feeble interference pattern is due to the dust on the ND filter. This CCD device is not cooled down. Thus the back ground level is not so low. In this case the B.G. level is about 13 count at the normal temperature as shown in FIg.6. Discrimination level is set at 17 count.

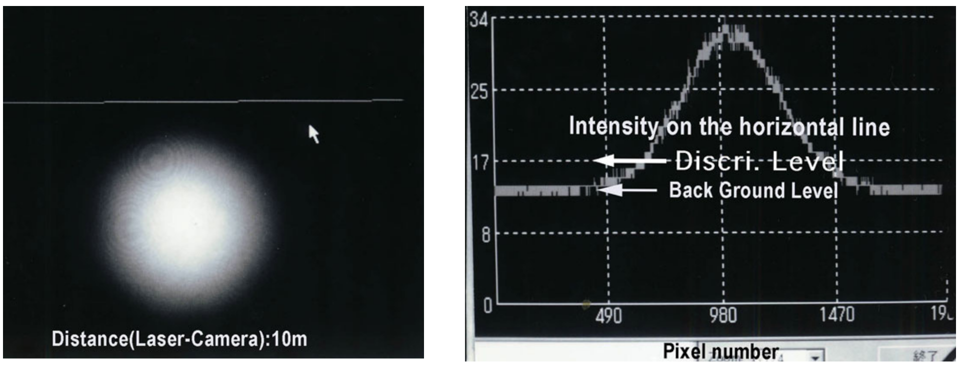


Fig.6. Background of CCD image

The exposure time of CCD device is 0.5 sec per one sec. The flame glaber board (IC4-DIG16 Imaging Technology ITOCHU TECHNO-SCIENCE CO.) is operated under Windows 98. The transfer time of 2K× 2K 8 bit data is about 0.5 sec. Two-dimensional counts are summed up ten times, and then this distribution is projected to two one-dimensional distributions. Horizontal and vertical distributions are shown in Fig.7. After subtracting discrimination level from the projected distribution the number of center channel is obtained by average. It takes 12 seconds to obtain the averaged center positions. The counts is very large, so that the resolution is much smaller than the pixel size (9μm).

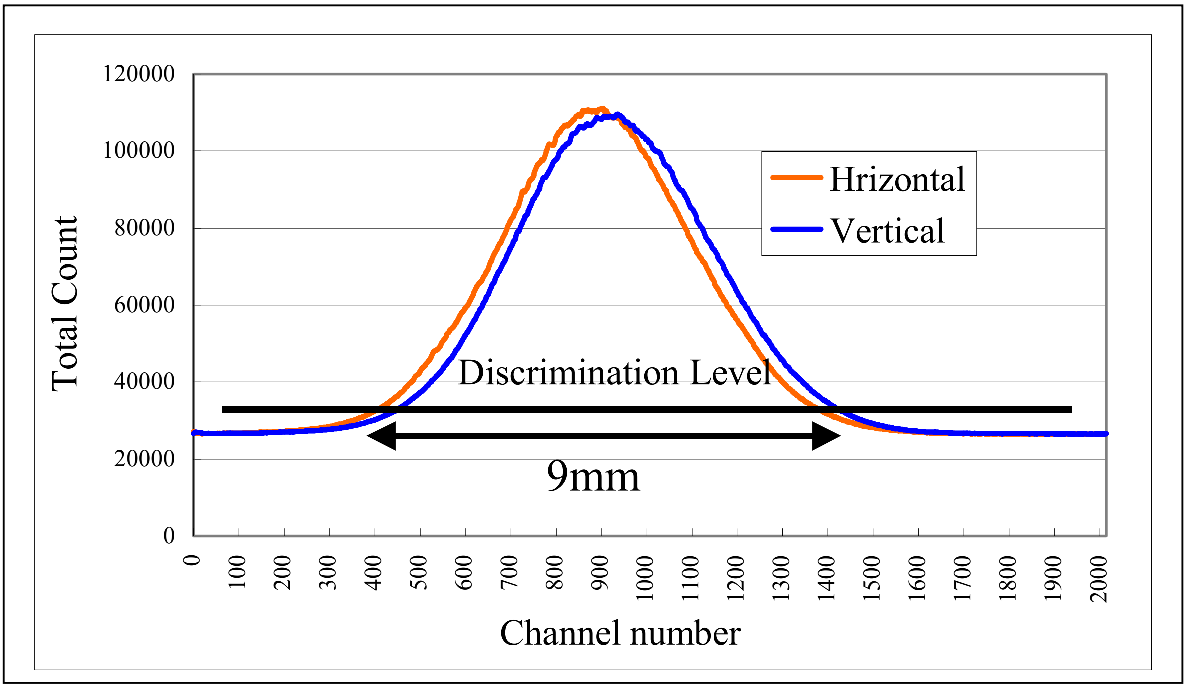


Fig.7. Projected distributions of the laser light and discrimination level.

The bottom of the CCD camera is shown in Fig.8. The spherical target is put on the stage shown in Fig.9. The target radius for laser tracker, optical target and CCD camera is 37.5mm.

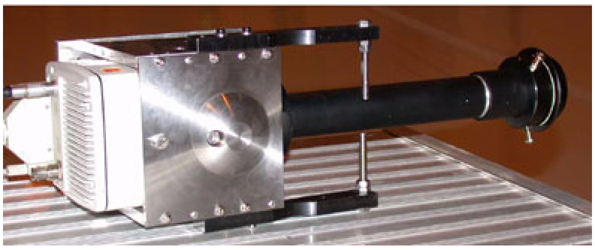


Fig.8. The bottom of CCD camera.

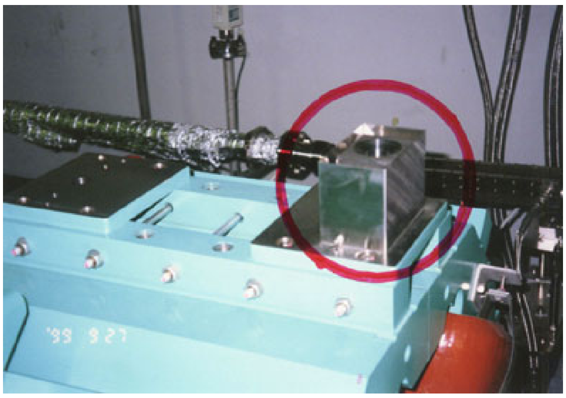


Fig.9. Stage for the spherical target.

In order to monitor the stability of the laser light another 2/3 inch CCD device was used. This small CCD camera is put on the BM1 in Fig.1. and used when the large CCD is not on the line of sight. The half spherical lens which radius is 10mm was used to cover the 9mm laser beam. The refractive index of the lens is very large n=2.4.(Fig.10.) This lens is made from $SrTiO_3$.(Earth Chemical Co., Ltd.) and attached on the CCD surface.

Fig.10. Half spherical lens (n=2.4) and CCD camera (HAMAMATSU PHOTONICS K.K.) with this lens.

3. ALIGNMENT FOR LONG STRAIGHT SECTIONS

3.1 Laser, camera and pipe

Laser source was put on the bending magnet and the CCD camera was put on the target stage to align the magnet. The laser source was put on the BM2 when aligning the magnet QL6 and was put on the BM1 when aligning the QL7 as shown in Figs.1 and 11.

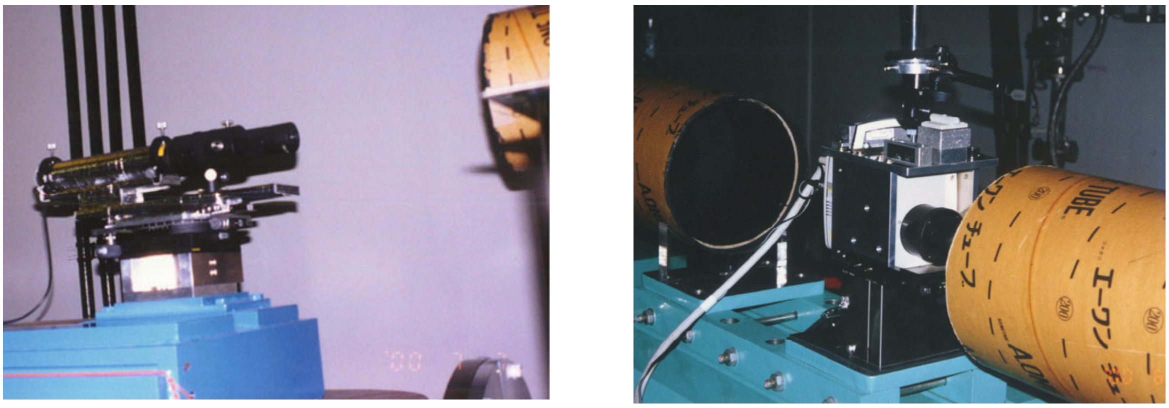


Fig.11. Laser source on the bending and CCD camera on the quadrupole magnet.

This alignment work was carried out with other works together, such as baking because the period for modification was short. Thus the pipe was used to suppress the fluctuation of laser light as shown in Fig.12. The pipe is made of paper which thickness is 5 mm. The length of one pipe is 4m and the diameter is 20 cm. There are two diaphragms at both ends to stop the small angle scattering.

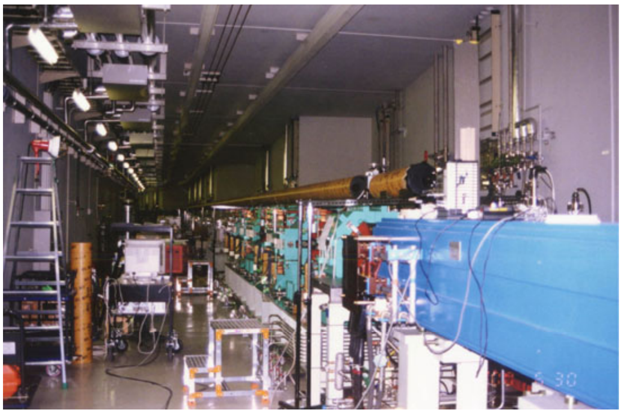


Fig.12. Pipe in the tunnel during the alignment work.

3.2. Stability of the laser and camera system

Figure13 shows ten-hours stability and fluctuation of the system in the tunnel. The temperature is very stable unless there is heat source because the tunnel is made of 1m concrete wall. The fluctuation becomes two or three times smaller if using pipe. However the vertical position shifts 0.7mm as shown in the figure.

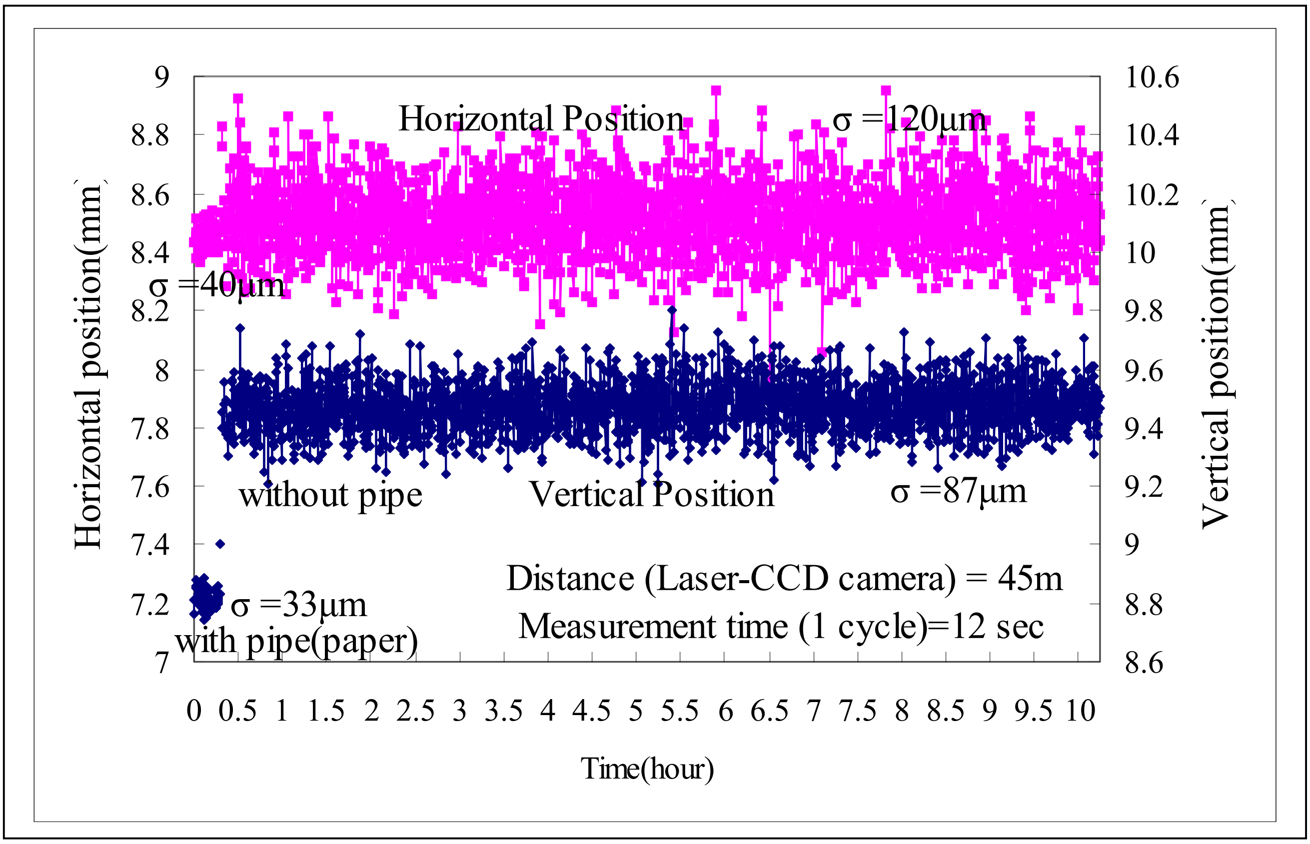


Fig.13. Long term stability of the laser and CCD camera system in the tunnel.

3.3. Check of the alignment

An alignment telescope (Taylor Hobson) was used to check the result without pipe. This telescope was put on the bending magnet same as the laser source(Fig.14).

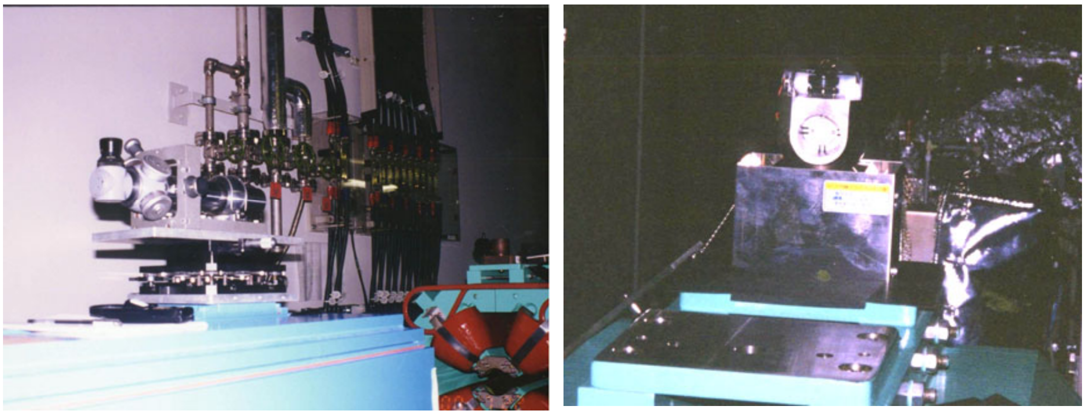


Fig.14. Alignment check using telescope and optical target.

3.4 Alignment result

The results of these alignment are summarized in Table 1. We could not check in the B zone because the tall undulator was installed after the alignment. Paper pipe was used at alignment work, but the measurement results of "Final results" and "Check" are without pipe. It seems that some magnets were aligned higher because of refraction in the paper pipe. However these misalignment are within the tolerance.

Table 1. Alignment results of long straight section.

		at Alignment Work(μm)				Final results (μm)								Check(μm)	
Laser position		QL6 side		QL7 side		Laser =QL6 side				Laser =QL7 side				(Telescope)	
Zone	Magnet	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY
		Jul.5_17:		Jul.7_14:		Aug.19_20:		Aug.19_21:		Aug.19_15:		Aug.21_22:		Jul.20,Aug.19	
A	QL6	9	-4	-1	11	8	46	11	50					10	40
	QL7			9	2			116	77	91	42	96	39	80	60
		Jun.28_16:		Jun.27_19:											
B	QL6	-9	-10	-22	-1									-10	
	QL7			-3	-22										
		Jun.30_13:		Jun.30_9:		Aug.8_11:		Aug.8_14:		Aug.8_15:		Aug.9_10:		Aug.2	
C	QL6	14	2			6	11	-2	9			-48	-16	0	15
	QL7			9	-9			42	24	26	-6	24	9	20	10
		Jul.4_11:		Jul.3_17:		Aug.12_11:		Aug.12_14:		Aug.12_16:		Aug.12_19:		Jul.15.	
D	QL6	-1	34	-21	-8	-58	33	-50	37	-78	9	-22	54	-30	50
	QL7	10	-11					-30	16	-48	18	-46	25		

3.5 Alignment in the girder

The alignment of the quadrupole magnets in the girder was carried out using laser and CCD camera system same as the former technique.[2] The line of laser light and CCD camera is 50cm higher than the magnetic center. After this alignment the optical tool as shown in Fig.15 was inserted to measure the mechanical center at near the both ends of the magnet poles after removing the coating of the pole surface. The circular surface is attached on the two quadrupoles and two springs on the other two quadrupoles.

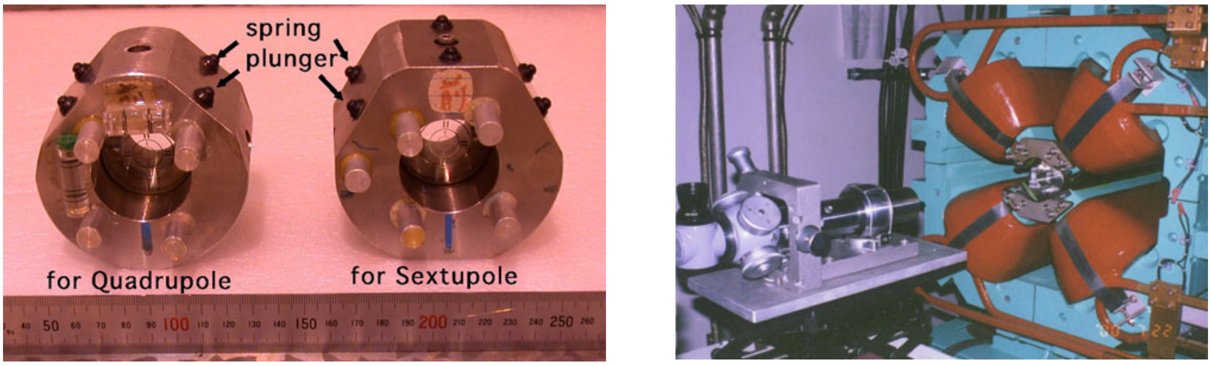


Fig.15.Tool for pole center and measurement of pole center.

The mechanical center was obtained by rotating this tool four times as shown in Fig.16. These graphs also show the twist between

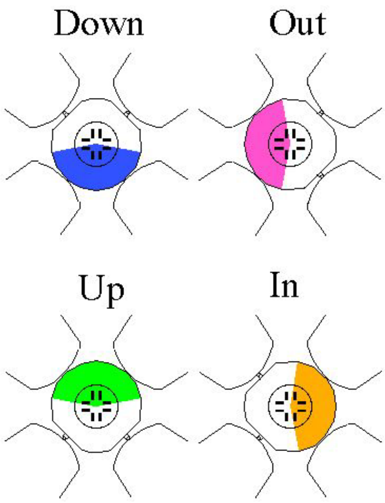
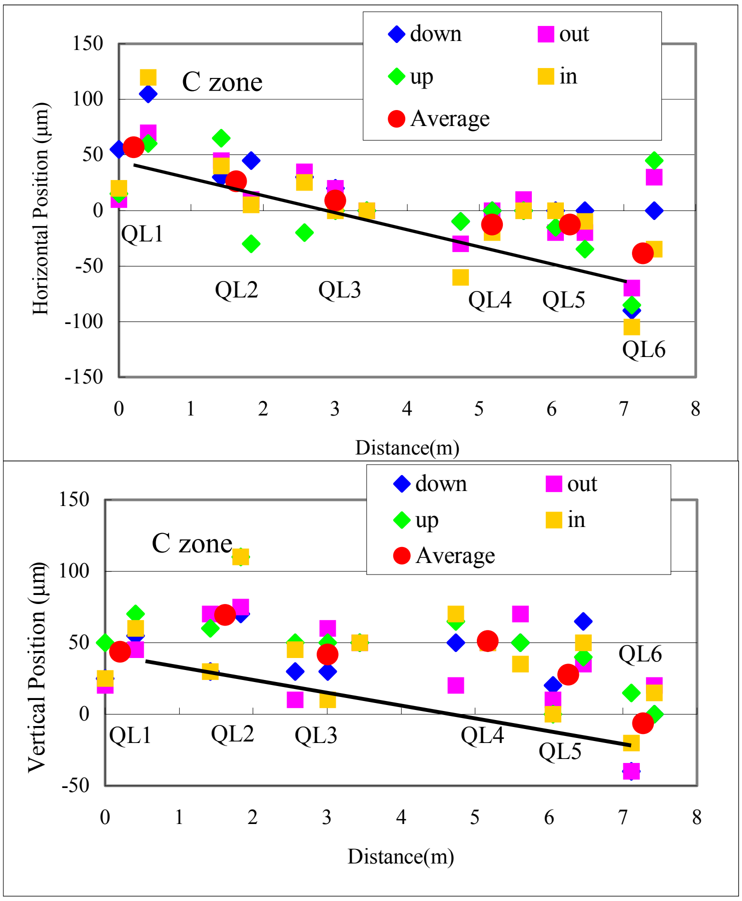


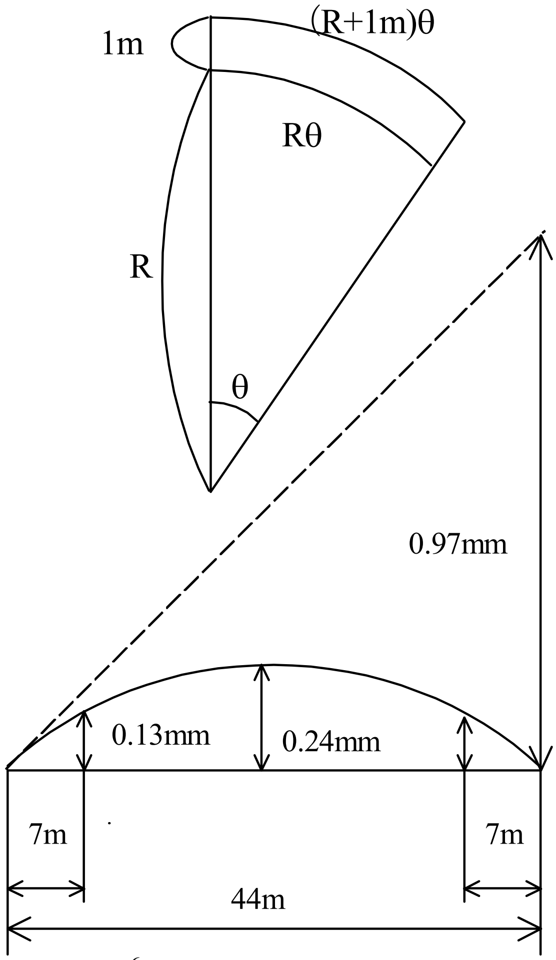
Fig.16.Mechanical center of the six quadrupole magnets QL1~QL6.



the upper half and lower one or outside half and inside one.The difference between the results using laser CCD camera system and telescope plus optical tool was small after first alignment (6 years ago). However the difference became large this time as shown in vertical graph of Fig.16. These magnets had been suffered magnetic force for several years. After that these magnets were divided and restored. Thus the reference plane made of 15mm-thick stainless plate might be deformed by the division and restoration.

4. REFRACTION DUE TO TEMPERATURE GRADIENT

4.1 Curvature



R=10^6 m (Gradient :1degree/m)

The change of the refractive index is about 1×10^{-6} per temperature one degree. Assuming the gradient of the temperature per 1m is ΔT, the light path lengths at the upper and lower points are different but these two phase advances are same. Thus the following equation is given as,

$$(R+1m)\theta - R\theta = R\theta \cdot \Delta T \cdot 10^{-6}$$

where R and θ are the curvature and the angle change of light direction, respectively. Then, the curvature is written as

$$R=10^{6}m/\Delta T\ .$$

Right figure shows the curve of the light in case of the 44m straight section and the gradient is 1degree/m. The light passes along the circle, so that the points on the circle seems on the straight line. The vertical apparent position at the 7m is shifted 0.13mm from the straight line. If the CCD camera is at 44m point, the difference between curved and non-curved lights becomes 0.97mm.

The gradient of air pressure is 0.12hPa/m at around the earth surface. This value corresponds $R=3\times10^{7}$m. Thus the influence due to the air pressure is negligible in our case.

4.2.Experimental Setup

Laser light proceeds in the two type pipes. One pipe is made of paper and the other copper. Two laser and CCD camera systems were used as shown in Fig.17. This plastic greenhouse is built in the experimental hall. The air temperature in this hall is controlled within ±1degree. The temperature change in this greenhouse is less than that of the hall. The change is normally less than 1 degree. The distance from laser to CCD camera is 47m.

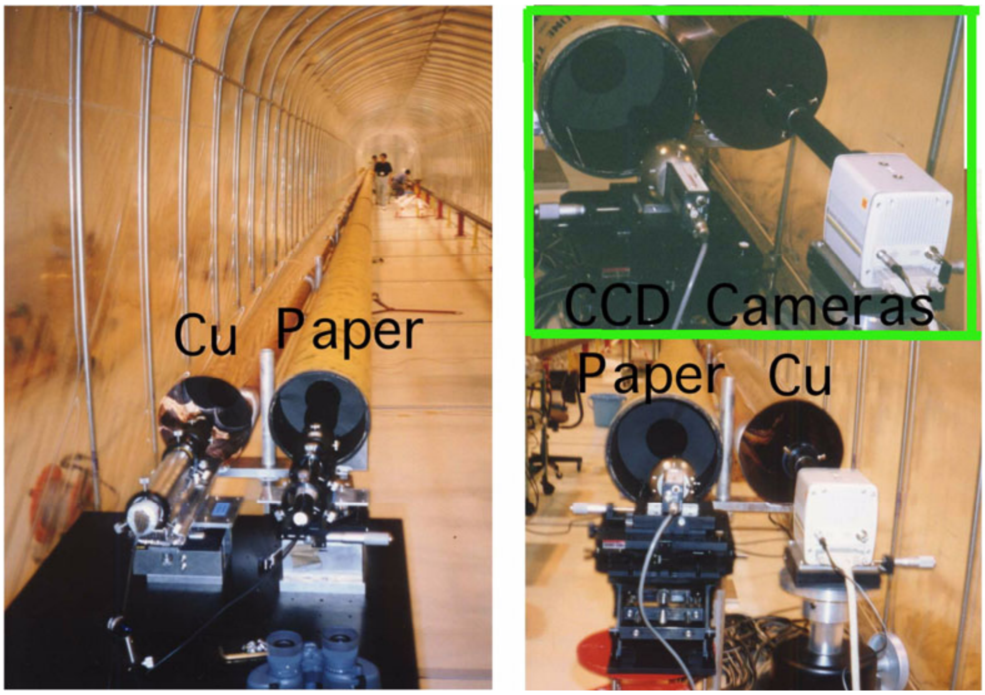


Fig.17. Two laser and CCD camera systems in the plastic greenhouse.

4.3 Comparison of paper and copper pipes

The horizontal and vertical positions of the laser beams during almost one day are plotted in Fig.18 with three set-up conditions. Though the two type pipes are in the Fig.17 at the same time, there is slight difference between these two systems as shown in the left side of Fig.18. The abscissas of upper and lower graphs represent same time. The ordinates of six graphs are all 0.5mm. Thus the lower graphs are only the monitor of the condition in that time. We can compare upper three graphs, i.e. without pipe, copper pipe and paper one. The difference seems very small between without pipe and copper pipe. On the contrary, the difference between the without pipe and paper pipe is very large. However the change patterns of paper pipe are similar to the others as shown in red plot which is reduced to 1/4.

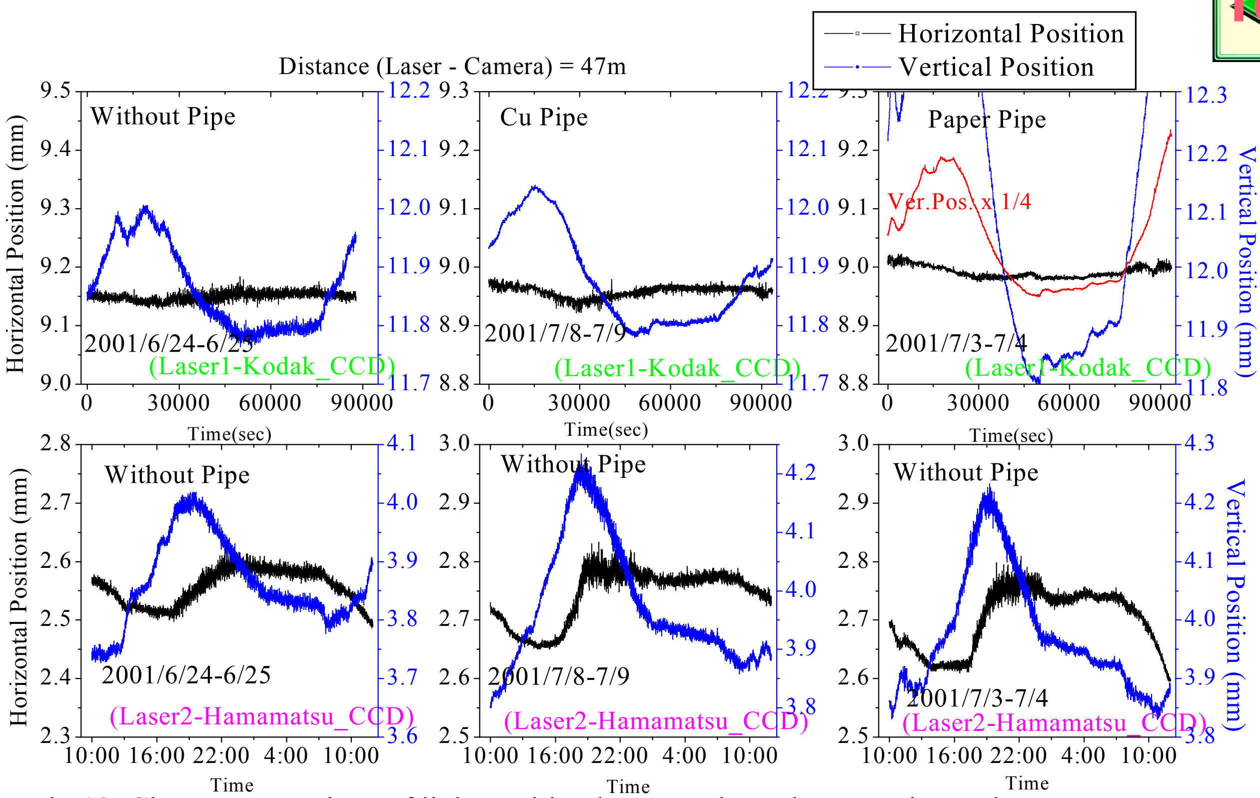


Fig.18. Change comparison of light position between through paper pipe and copper one.

4.4 Pipe Rotation

The laser light went up at the rotation of paper pipe as shown in Fig.19.

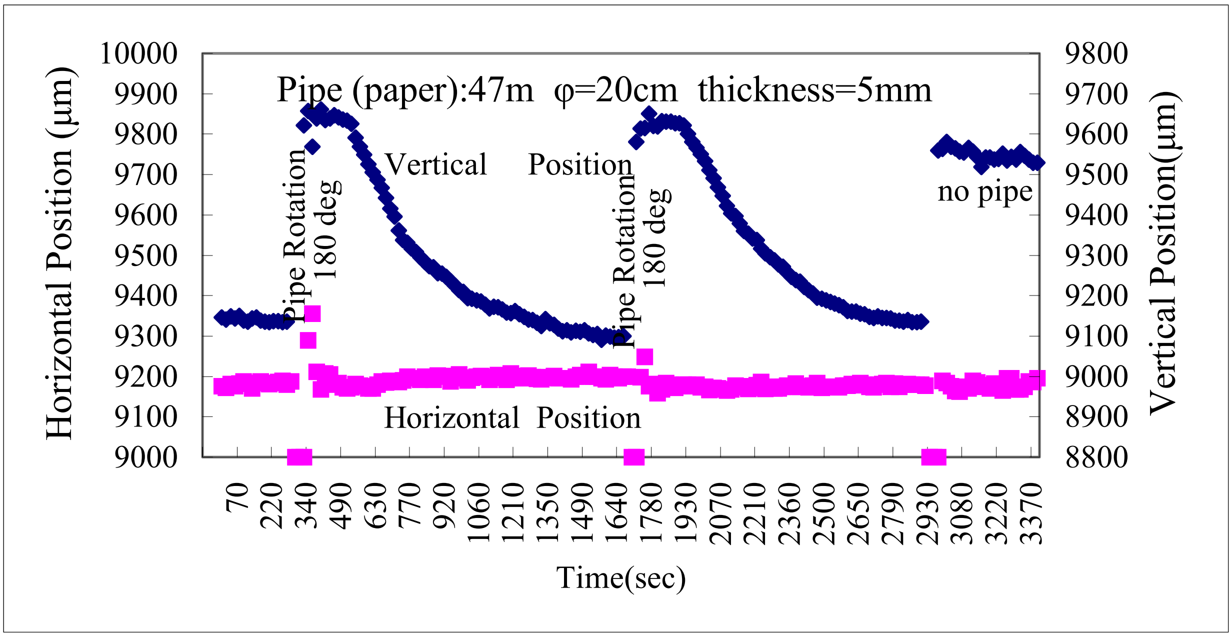


Fig.19. Change of the light position at CCD camera due to the rotation of paper pipe.

The temperatures in the pipe were measured by two thermocouples as shown in Fig.20. This indicates that the temperature gradient is reversed by the pipe rotation. The change is larger in the paper pipe than in the copper one.

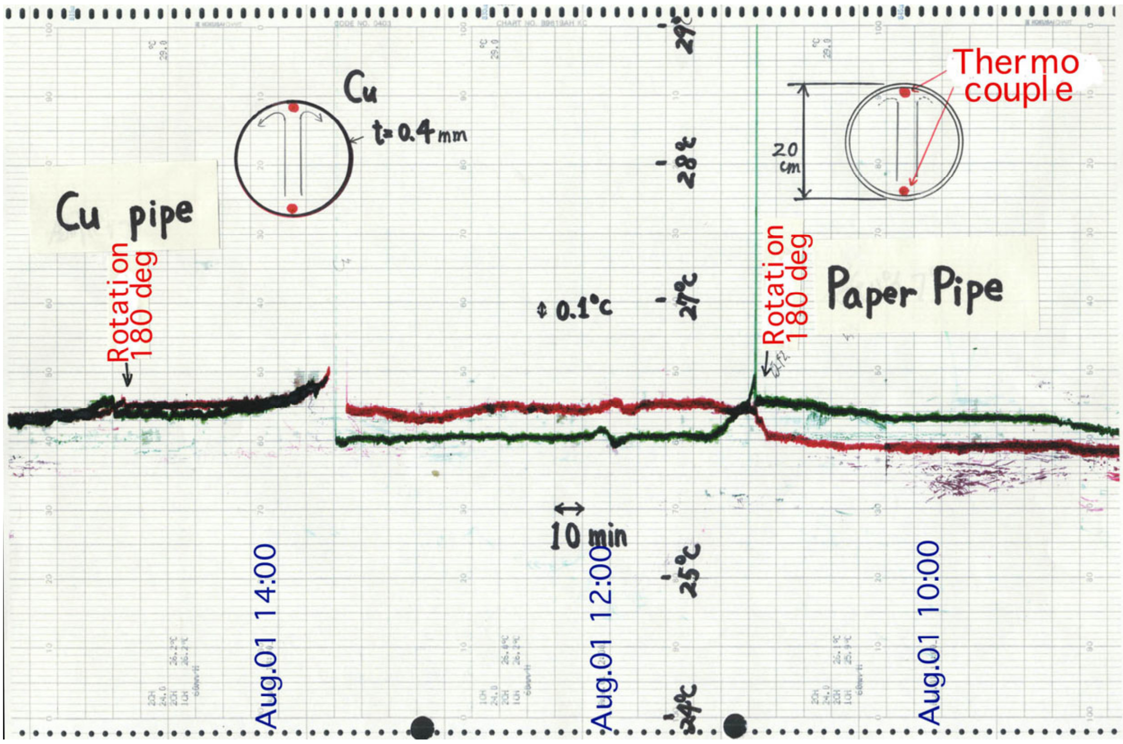


Fig.20. Temperature change at the 180-degree rotation in the pipe.

The change direction depends on the temperature gradient in the pipe at that time.

5. CONCLUDING REMARKS

The interference pattern of laser light on the CCD device is suppressed by removing the cover glass in front of the device.

The reference plane of the quadrupole magnets after division and restoration becomes unreliable for six years.

The measurement tool for mechanical center of the multipole magnet is useful for checking the alignment. Few magnets of which reference planes were unreliable were aligned by using this tool. This also can measure the twist between the poles.

It is quite important for the suppression of light fluctuation to choose pipe material. Temperature gradient refracts the light more in the pipe. Copper pipe is better than the paper one.

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