LASER AND CCD CAMERA SYSTEM FOR MAGNET ALIGNMENT ON GIRDER IN THE SPring-8 STORAGE RING

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Abstract

A new surveying system using a laser and a CCD camera with image processing has been developed to align magnets on a 5 m-long girder to an accuracy of 10 μm. A spacial filter with a pinhole and a collimator are used to make a parallel gaussian beam. In order to stabilize the laser axis, the heat capacity of the laser was made larger to reduce the influence of the fluctuation in the room temperature. The partitions, which are used to clean the inner side of the tunnel, are useful for stopping the air current. The glass in front of CCD device is covered with the non reflective coating to prevent from interference striped patterns. The accuracy of this surveying system is within 10 μm. This value satisfies the required accuracy. Now the SPring-8 alignment of the storage ring magnets is performed with this system.

1. Introduction

The SPring-8 (Super Photon ring-8 GeV) dedicated to achieve nano-meter radian emittance has been constructed by the SPring-8 project team joined by JAERI and RIKEN at Harima Garden City in Hyogo Prefecture. This storage ring is constituted of 48 cells and its circumference is 1436m. Each cell except for 4 cells is composed of three straight sections and two bending magnets. Each straight section consists of five or seven quadrupole and sextupole magnets on one 4 or 5m girder. At first, each girder is positioned to an accuracy of 0.1 mm along the ring [1,2]. Next, bending magnets are aligned within 0.5 mm according to the neighbor girders. Finally, each magnet on the girder is aligned in a straight line within ±0.05 mm. Therefore, a survey system whose resolution is about 10 μm was required to achieve this alignment accuracy.

In the survey using a telescope, it is difficult to obtain always the resolution of 10 μm at distance of 5 m. Thus we chose a laser. Generally, a four-divided photo diode, a two-dimensional PSD(Position Sensitive Device) and a CCD(Charge Coupled Device) camera are used as a detector of the laser beam. Laser light has many higher modes, those have larger divergent angles than gaussian TEM_{00}. Thus the straightness becomes worse unless separating gaussian mode from higher mode. A spacial filter with a pinhole is usually used to reduce the higher mode. When we used a laser source with collimator without pinhole and a four-divided photo diode as a detector, the straightness on the 4-m long stage was not good. Adding a pinhole to this system, the straightness became good. Thus a spacial filter with a pinhole is important. In our case, we have to move the alignment system to everywhere in the tunnel. Therefore, it is always necessary to monitor the profile of laser light because of using the small pinhole. After all, we chose a CCD camera. Actually, we sometimes adjust the position of ø 25μm pinhole after moving the laser to the next alignment position. It is easy to analyze quality of a laser beam and to improve it by using a CCD camera.

2. Survey System

A newly developed survey system consists of a laser source, a CCD camera and a Macintosh computer for processing image data. This system is shown in Fig. 1. All quadrupoles and sextupoles have fiducial points on upper part of yokes and their positions are measured in the magnetic field measurement using a rotating coil. The deviations from the

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reference line which connects the two reference points are obtained by putting a CCD camera on the four fiducial points and calculating.

Magnet alignment on a girder is being done using the same survey system as shown in the lower half of Fig. 1. Each magnet is adjusted taking account of the data of the fiducial points in magnetic measurement. The resolution is about 10 μm in this system and the magnets can be adjusted in the same resolution on a girder.

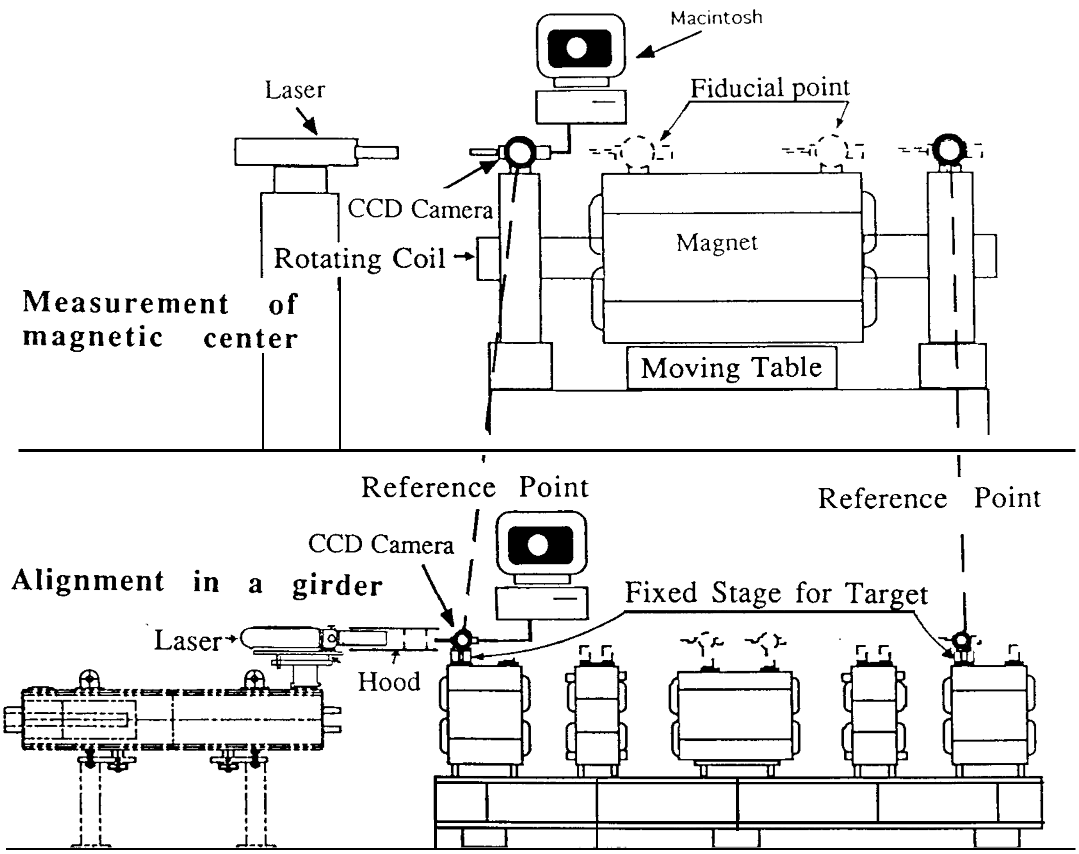

Fig. 1. Measurement of magnetic center and the alignment in a girder.

2-1 Laser Source

The laser source is composed of a laser tube, a spatial filter with a pinhole, and a collimator as shown in Fig.2. The unpolarized He-Ne laser is used for the laser tube whose wavelength, output power, a diameter ($1/e^2$) of the beam and expanding angle are 632.8 nm, 2 mW, 0.8 mm and 1.3 mrad, respectively. Use of three ND(neutra1 density) filters (absorption type) decreases beam strength by 8×10^{-4} to suit to the sensitivity of CCD device. The measured diameter of the laser beam was 3 mm and its change was within 3 % at distance of 2 to 6m from the laser source.

2-2 CCD Camera

The CCD camera manufactured by HAMAMATSU PHOTONICS K.K. is used for detecting a laser beam. The lens for imaging are removed and a laser beam is injected on the CCD image plane directly because we put the camera on the stage by hand. The camera is embedded in a spherical target so that the image plane is located at the center as shown in Fig. 3.

We can avoid the coupling horizontal direction and vertical one by using bubble tube and adjusting for the laser beam to path through near the center of the sphere. The CCD device had to be improved to detect the laser directly because the interference striped pattern was generated. Figure 4 shows the interference pattern and its intensity distribution when wide laser beam is incident.

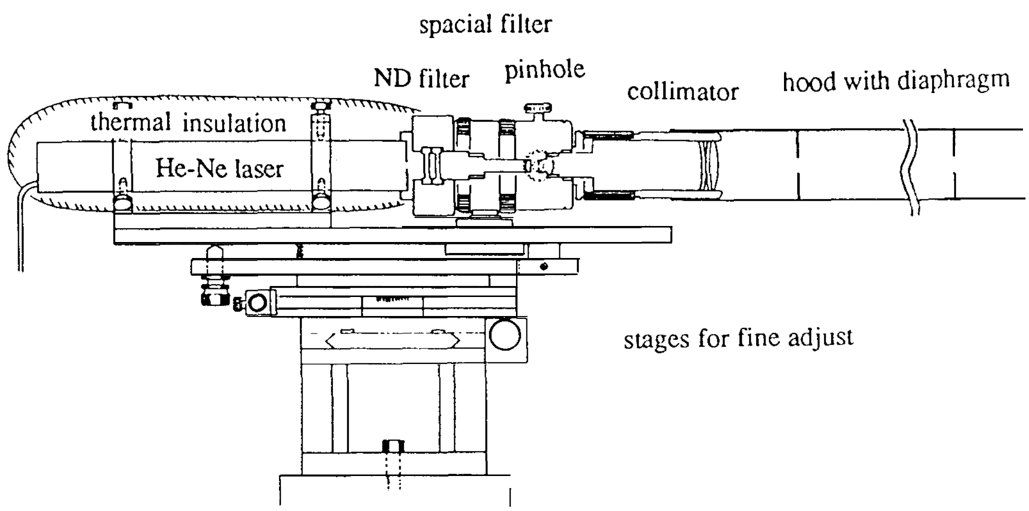

Fig.2. Laser source.

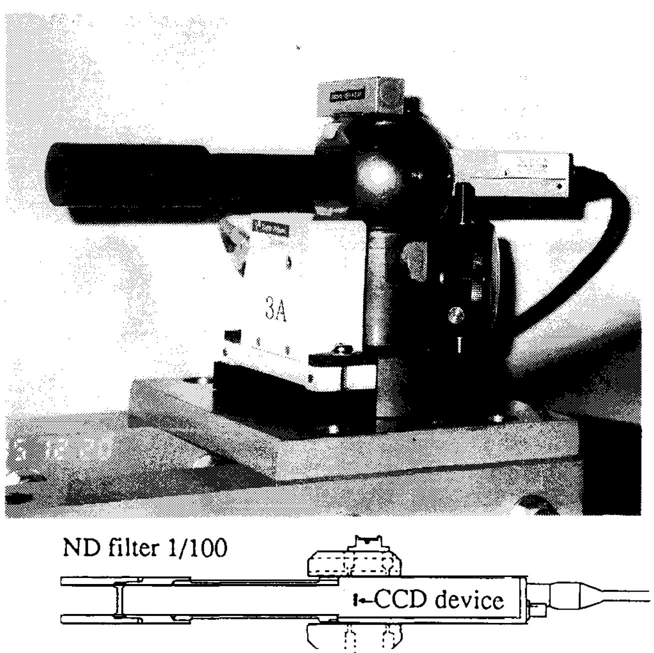

Fig.3. CCD camera and its photograph.

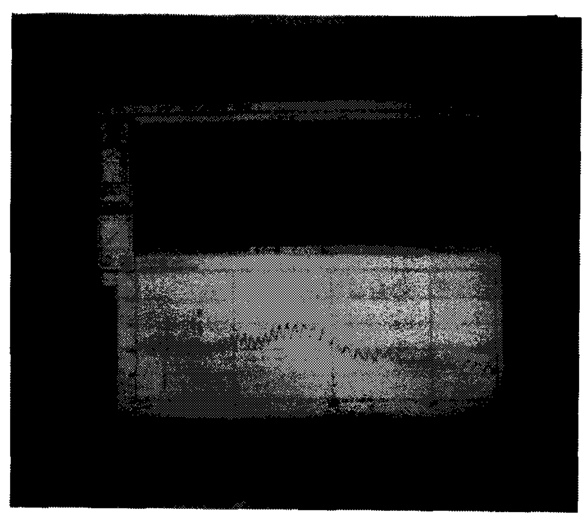

Fig.4. Interference pattern and its distribution.

At first, we tested the CCD device covered by the optical fiber (diameter 3 μm) plate in bundle to hide striped pattern. However, this camera was sensitive to the incident light angle. Finally the CCD device with low reflectance coating on the covered glass was adopted. A ND filter (1/100) covered with this coating is used for reducing the other light than laser. We do not use the interference filter which passes through only 633nm wavelength light because it generates many interference patterns.

2-3 Image Processing

Image of the laser beam is acquired by a VFG(Video Frame Grabber) board (HAMAMATSU PHOTONICS IQ-V55) in a Macintosh which consists of an analog to digital converter and a frame memory. We modified the program (Image Quest VFG Third Party Developer's Kit) written in C language. Images are obtained at rate of 25 Hz and accumulated up to 126 times (5sec) into the frame memory directly. After accumulation two 1-dimensional distributions are obtained by projecting the 2-dimensional distribution in both horizontal and vertical directions. Figure 5 shows the laser image and the vertically projected distribution. The abscissa and ordinate indicate the CCD cell number and light strength, respectively. After smoothing the distribution the center of gravity is calculated from the area higher than the 30% level of the peak. After image accumulation, these calculated positions and the values to be shifted are displayed with the beam image about 3 seconds later.

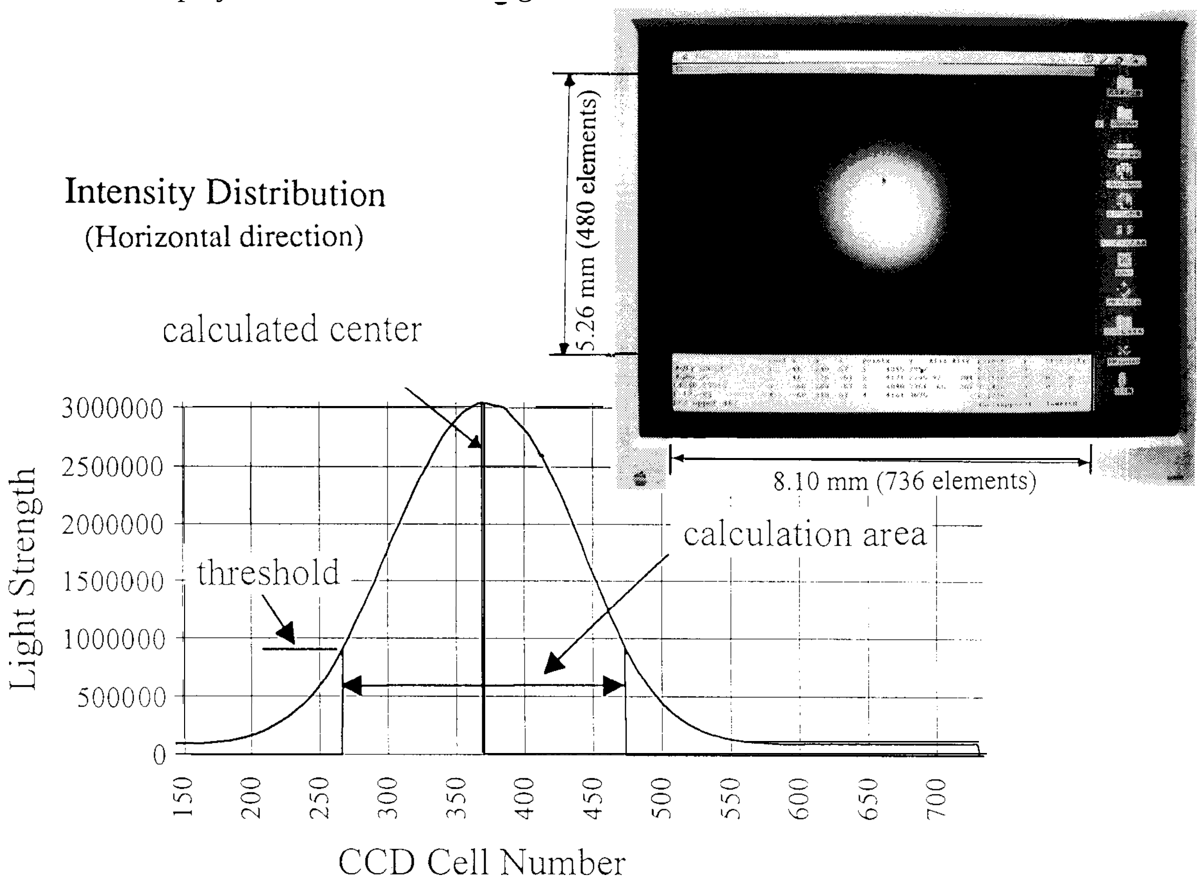

Fig.5. Image of the laser beam and its intensity distribution (horizontal direction).

3. System Performances

3-1 Pointing Stability of the laser beam

The displacement of the laser beam position is strongly correlated with the change of the laser tube temperature. Thus the laser tube was improved by packing in the cold reserving materials to increase the heat capacity and to reduce the amplitude of the temperature change. Since the temperature change in the tunnel is very small, the stability is good as shown in Fig.6. The beam was measured every 1 minute. The drift at the laser-camera distance of 5.5m was about 10 µm for 8 hours. However, when we measured the magnetic axis, the room temperature changed rapidly because of the air-conditioner. Therefore we covered the laser source and the support with a large vinyl sheet.

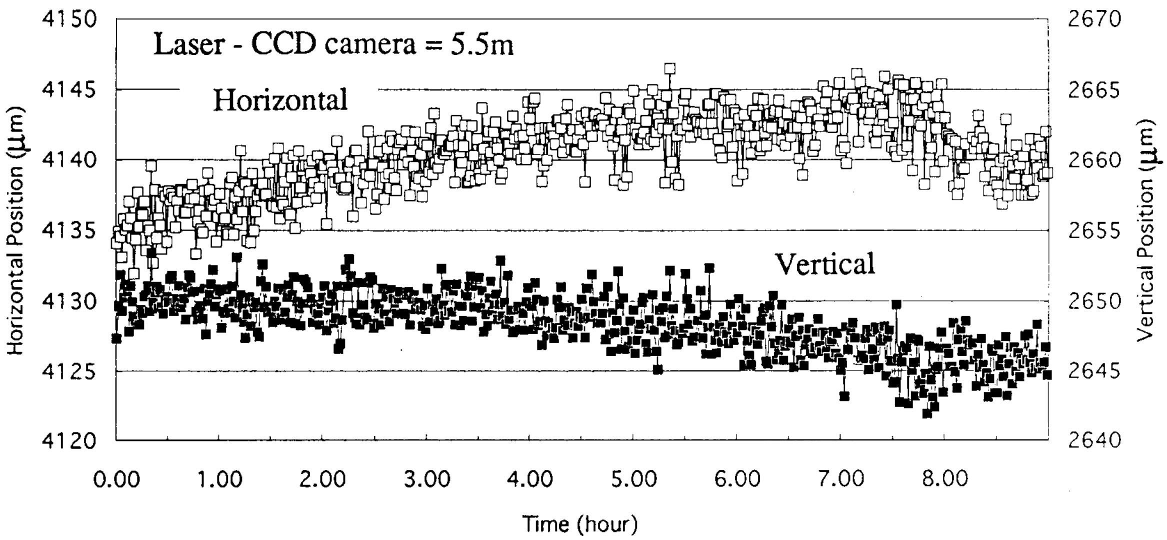

Fig.6. Laser pointing stability in the tunnel for 8 hours.

3-2 Fluctuation in Laser Beam

The effect of air current was observed in the tunnel. We partitioned off the tunnel with vinyl sheets to reduce the air current. Figure 7 shows one of the experimental results at distance 5m. Open squares and triangles indicate the fluctuation of the laser position before making partitions and closed ones after doing that. The fluctuations were largely suppressed and became 2 μm in both directions. Now, since there are partitions every 60 or 90 m for the cleaning, the air current is stopped. Moreover during alignment on a girder we stop the air-conditioner around the area, and the velocity of air usually decreases to about 0.02m/sec. It is important to enclose the light beam as long as possible.

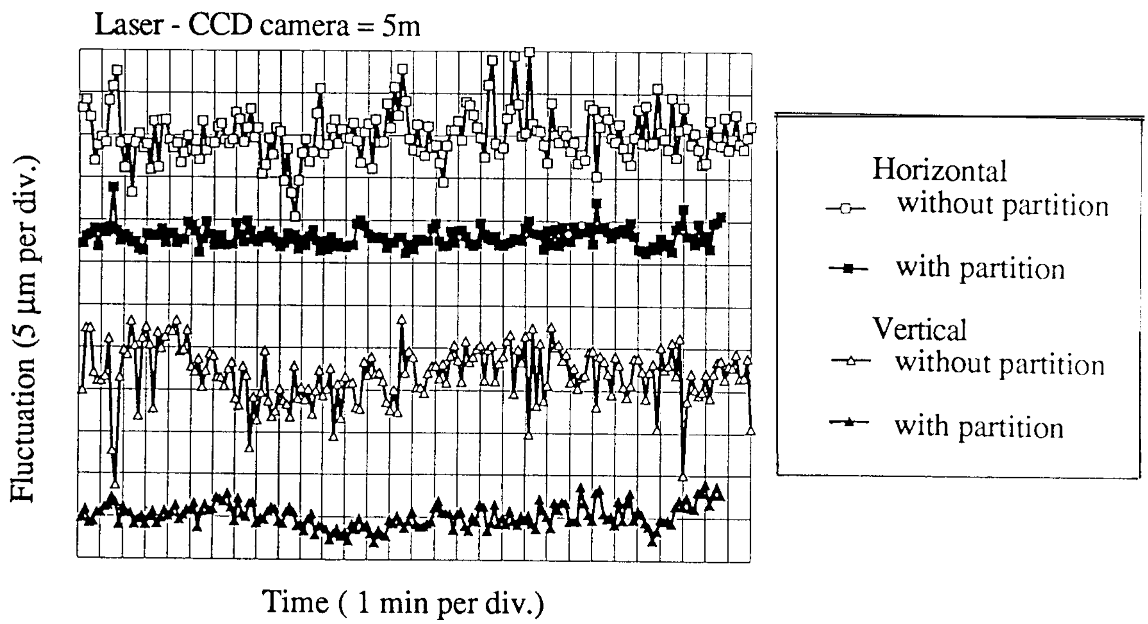

Fig.7. Laser beam fluctuation due to air current and the effect of partition.

3-3 Errors in Detection and Calculation

We estimated the errors in detection of laser beam and calculation. The error in detection is thought to be due to ununiformity of the CCD elements in size and sensitivity. The CCD camera was placed on the stage with the micrometer which minimum division 2μm and moved in horizontally. The distance between the laser and the CCD camera was about 60 cm. The shift of this stage was checked by a laser interferometer (HP5527A). Figure 8 shows one of the experimental results. The ordinate is the difference between the values of micrometer and calculated position of the laser beam center on CCD. When we translate from channel number to the position, the value of 10.9 μm as a CCD periodic cell size was used. (In the catalog the size is described as 11.0 μm.) Measurements were done in several shift pitches to avoid the drift of the laser axis. The shifted area and pitches were 3 mm, 2 - 1000 μm, respectively. This result shows that the accuracy is within ±4μm in the ±1mm area and within ±1.5 μm in the ±0.1mm area. Rotating the camera by 90°, the same accuracy was observed also in the vertical direction.

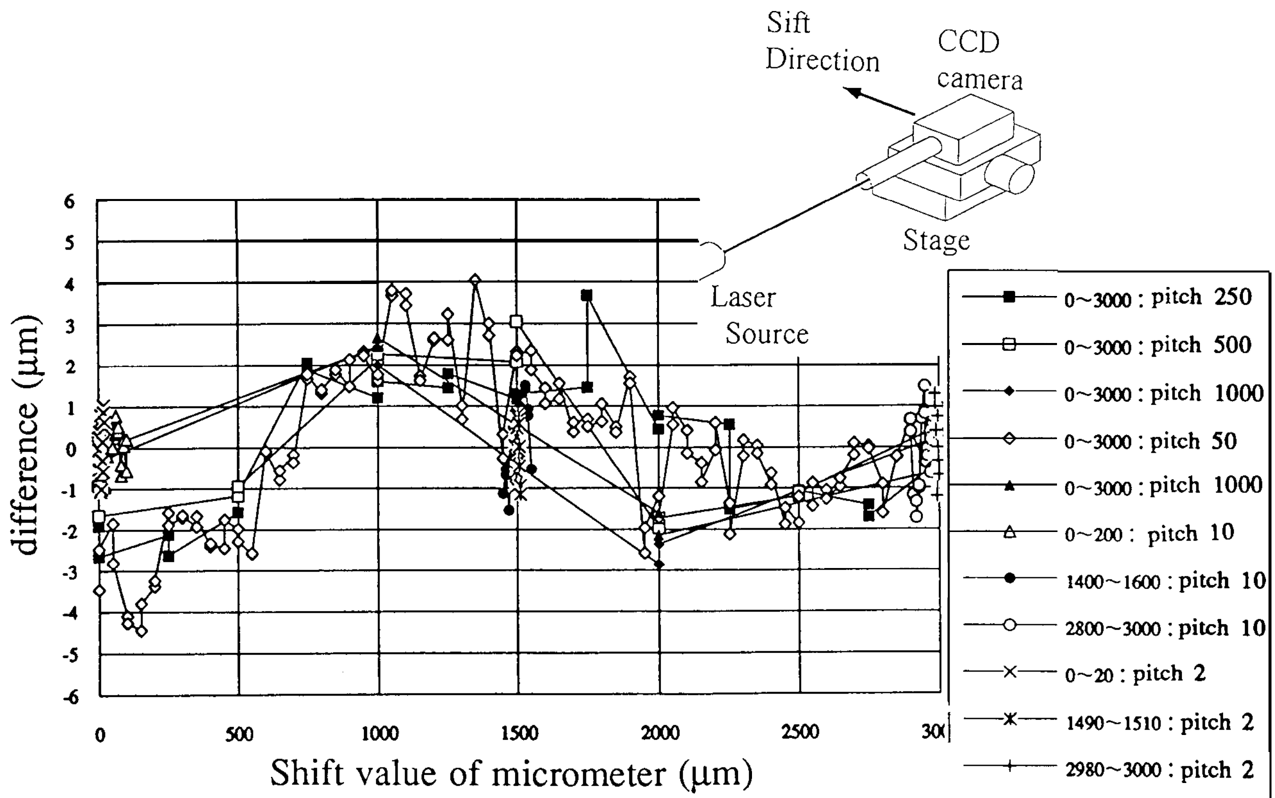

Fig.8. Accuracy of CCD camera.

3-4 Total Performance

Finally, to investigate the total performance of the survey system, we put a CCD camera on the stage having good straightness and measured the position of a laser beam changing the distance from the laser source as shown in Fig.9. Since the stage on which camera and 5 tiltmeters are put is not hard and the 2 rails are not parallel, maximum twist of this plate was 20 μrad. The curves of tiltmeters are extracted from only y direction tilt and are not taken account of the twist of two rails and that of the plate. However, the differences of both measurements are so small.

The newly developed survey system using a laser and a CCD camera enabled to survey with the accuracy of 10 μm in the 5m range. And this system can be used for the magnet alignment on girder within the tolerance of 50 μm. Now, SPring-8 magnets alignment is being performed in good accuracy with this system.

It is important to stable the temperature and stop the air-conditioner when using the laser.

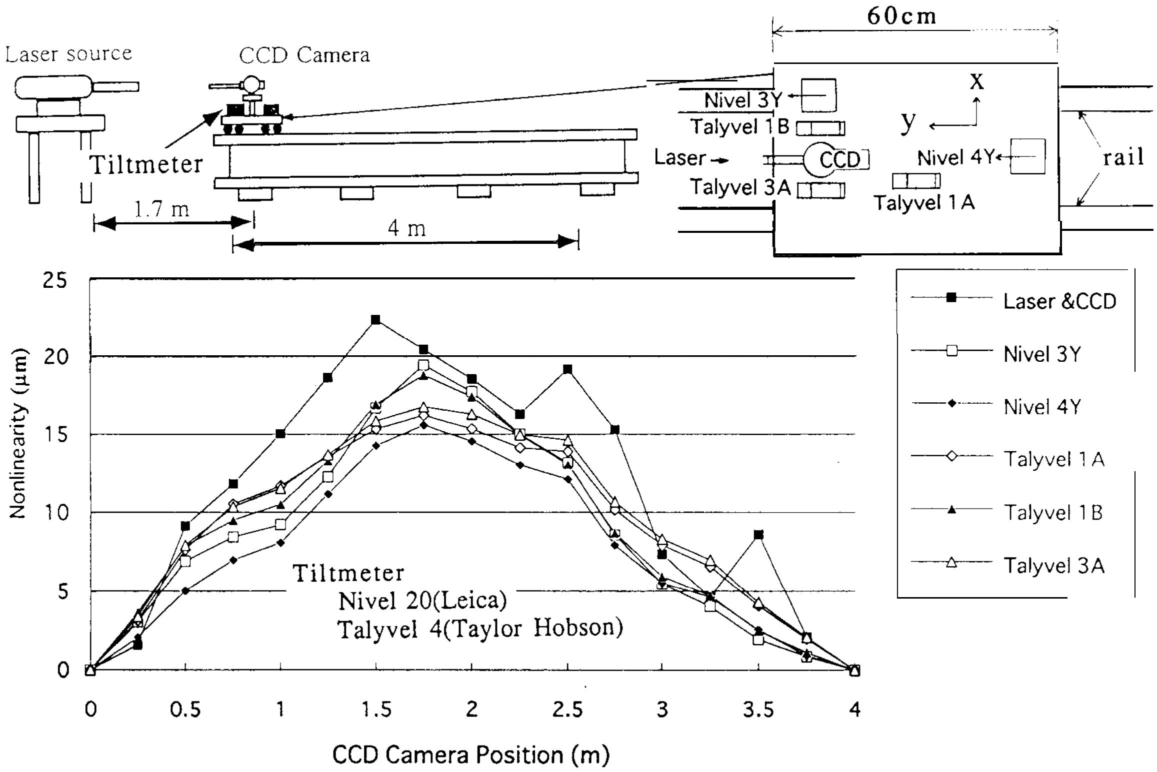

Fig.9. Linearity test of the laser and CCD camera system.

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References

[1] S. Matsui et al., in this proceedings.
[2] C. Zhang et al., in this proceedings.