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Magnet Alignment System of the SPring-8 Storage Ring using Laser

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Abstract

The SPring-8 storage ring is under construction. The girders on which several magnets are put are surveyed with a laser tracker by making network. After the smoothing the relative displacements are within ±0.04 mm. A laser and a CCD camer system is used for a precise alignment of quadrupole and sextupole magnets on a girder. The target shift from the 5m-straight line can be measured to be less than 10 μm. The misalignment of them are estimated to be less than the torelance.

Introduction

The storage ring has a 1436m circumference which surrounds the hill called Mihara-Kuriyama, and has 48 cells. Each cell has 17 quadrupole and sextupole magnets put on three girders, and two bending magnets.

Whole ring was surveyed before building construction two times. After tunnel construction, all monuments were surveyed again. According to these survey results, the 88 monuments positions were decided. After the girders are set up, both the end magnets on the girder are surveyed by the laser tracker SMART310, and then girders are smoothed.

Five or seven magnets on the girder are aligned precisely using a laser and CCD camera system and tiltmeters. The hole center on the magnet fiducial plane are shifted from the line right above the magnetic axis, and the shifted values have been acquired at the magnet measurment process. Spherical targets which diameter is 75 mm are used at several steps, that is survey, level measurement, pre-alignment and precise alignment.

Tolerances for magnet misalignment

The tolerances for the magnets of this storage ring are listed in Table 1. In order to reduce the sensitivity to the misalignment of quadrupoles adopted alignment method is to divide the alignment into two stages, that is in a girder (torelance 50 μm) and between girders (0.2mm).

Table 1 Torerances for magnet misalignment

Magnet	rms displacement error*1) Δx	Δy (mm)	Δz	rms rotation error*2) θx	θy (mrad)	θz
Dipole	0.5	0.5	0.5	1.0	1.0	0.1
Quadrupole						
•magnet	0.05	0.05				
•girder	0.2	0.2				
•total	0.21	0.21	0.5	1.0	1.0	0.2
Sextupole						
•magnet	0.05	0.05				
•girder	0.2	0.2				
•total	0.21	0.21	0.5	1.0	1.0	0.5

*1)Δx, Δy, and Δz denote the horizontal, vertical, and longitudinal displacement errors, respectively.
*2)θx, θy, and θz denote the rotation errors around the horizontal, vertical, and longitudinal axes, respectively.

Monuments Survey 1

Before building construction, 21 concrete blocks shaped like tombstones were made along the ring every 60 m, and monument plates were buried on the top. Monument is placed at the intersection point of the straight lines at both sides of the bending magnet. These monuments and geodetic points outside the ring were surveyed two times with a distance meter ME5000 and a theodolite T3000. The error ellipses of these results were smaller than the circle of radius 1 mm.

Monuments Survey 2

The laser tracker is for the first time employed in the measurement of storage ring networks.

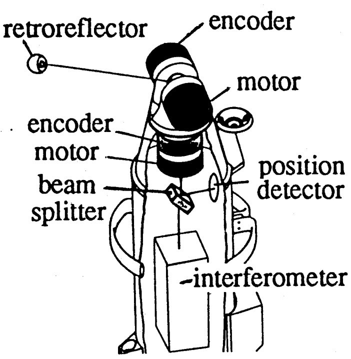

Fig.1 Principle of the laser tracker

The SMART is a dynamic measurement system, that is laser can chase the target wherever we move. This system consists of a laser interferometer, a rotating mirror on two axes with two angle encoders and servo motors, a position diode etc. The tracker gives 3D spherical coordinates of a target in space with a distance resolution of 1 μm, an angular resolution of about 1 arc sec..

Experiments show the laser tracker has a distance accuracy of 0.001+0.2ppm×L(mm) and an angular accuracy of 10 μrad. This accuracy will result at least 7.3 mm traverse disclosure for the storage ring orbit if SMART is simply used for coordinate measurement.

Alignment network for SPring-8 storage ring is designed as a distance-only trilateral network. Several aspects are optimized. The laser tracker has different accuracy for distance measurement when its position changes in respect to measuring targets. To reduce the influence of angular error, the laser tracker's positions within network are chosen by checking the distance accuracy it results:

$$M_l=\sqrt{\left(\frac{l_1-l_2\cos\alpha}{l}\right)^2 m_{l_1}{}^2+\left(\frac{l_2-l_1\cos\alpha}{l}\right)^2 m_{l_2}{}^2+\frac{1}{\rho^2}\left(\frac{l_1 l_2\sin\alpha}{l}\right)^2 m_\alpha{}^2}$$

where l is the length between two measuring points, α, l_1, l_2 are angle and lengths from laser tracker to these points, m_α, m_{h1}, m_{h2} are their measurement accuracy respectively. To calibrate measuring distance, a 20m-long stand is being made to compare SMART with HP 5527A interferometer.

When putting the target on the monument, a tripod is used. The laser light when measuring the target is in the plane which height is 1700mm. The height of the stage on the wall is also 1700mm. The body of SMART sensor unit is modifyed so that we can adjust the height and shift horizontally. This is because the survey can be carried out without using the rotary encoder for vertical angle.

After tunnel construction, all 88 monuments including 21 points were surveyed with SMART. Since this survey network was narrow and the circumstances were not good, it was difficult to decide the monuments coordinates using only SMART. Thus the data of the angles between the 24 monuments were added. The difference between survey1 and survey 2 was small.

Magnets Setting

The quadrupole and sextuole magnets are set.

Alignment of both end magnets on the girder

There is a fixed target stage on both end magnet. This stage is used for the alignment between girders and for a reference stage of the precise one in a girder.

Both the end magnets are aligned using survey2 results. This alignment is necessary before girder alignment. The magnets except both end are also aligned roughly to make shorter the time used for precise alignment in a girder.

Alignment between girders

1. Survey

The network precision depends on both the accuracy of laser tracker and the structure of network, and also the ratio of measurement length to the width of net. Measurement lengths are optimized by simulation study of error accumulation. The results show that the measurement length shorter than 15 m (1/2 cell) has least error accumulation rate along the ring.

The alignment network is composed of 288 quadrupole fiducial points and 96 auxiliary brackets on inner wall. Over 50 percent distances are measured directly by laser tracker interferometer. Precision for magnet positioning is estimated on the assumption that the distance measurement errors have a Gaussian distribution. Error ellipse analysis shows that maximum position displacement of magnets in respect to geodetic coordinate less than ±1 mm, relative displacement between adjacent girders of ±0.05 mm are expected. Simulations results are well coincide with precision estimation.

First survey and smoothing is 4 cells, second 8 cells, third 8 cells,..and so on. Also the monuments are surveyed for references in these survey. The shift values from the smoothed fitting curve are calculated.

2. Smoothing

The girders are adjusted according to these values. The girder is monitored with eight digimatic ingicators.

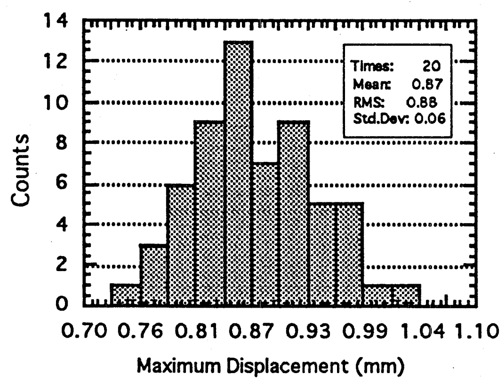

Fig.2. Maximum magnet displacement of twenty time simulations.

3. Survey

After repeating this 1-2 cycle two times, survey is made. If this result is good, girder alignment is finished.

Primary magnet installation results show that the relative displacement between girders of ±0.04 mm has been achived.

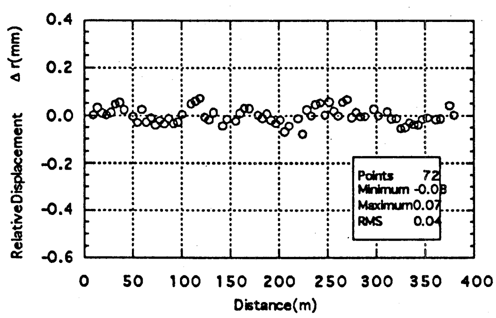

Fig. 3. Relative displacement between girders.

Level survey

The level reference on the wall is for pre-alignment of the magnet. It is important to smooth not the wall references but the magnet stage. This level survey is done after the girder position on the horizontal plane is fixed and is locked. Wild N3 is used. Now NA2 with a diode laser instead of N3 is tested. A PSD(Position Sensitive Devise) is used as the detector. However, this method is too sensitive to the NA2-PSD distance.

Alignment of bending magnet

Bending magnet is aligned with SMART after the

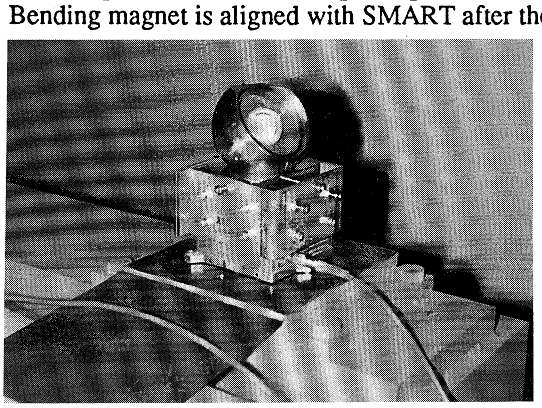

Fig.4. Tiltmeter and SMART target on it.

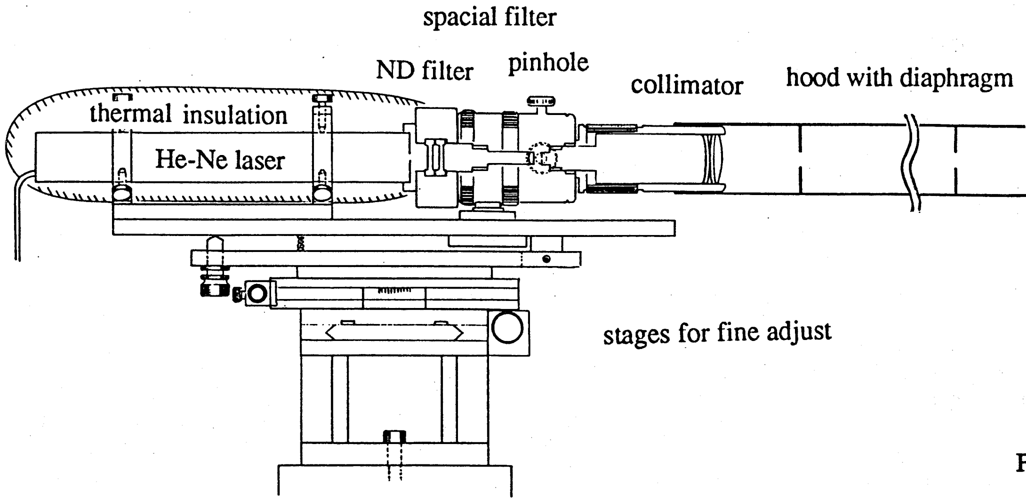

Fig.5. Laser with spacial filter and collimator.

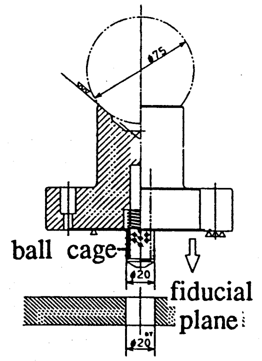

Fig.7. Stage on which the taget is put.

girder alignment. Target for SMART is put on the tiltmeter as shownin Fig. 4. and its coordinates are displayed in real time on the CRT.

Alignment of quadrupole and sextupole magnets in a girder

-- Laser and CCD camera System --

A laser source is put on the fiducial plane of the aligned bending magnet because the adjust of laser is easy. This He-Ne laser shown in Fig.5. has a spacial filter and a collimator to make parallel light beam of gaussian shape. The diameter of a pinhole is 25 μm. The diameter of the light beam is about 3mm and its change is within 2% from 1m to 5 m. A CCD camera is used for a detector shown in Fig.6. The CCD camera can always see the distribution of light beam which is sensitive to the mechnical stress because of small pinhole.

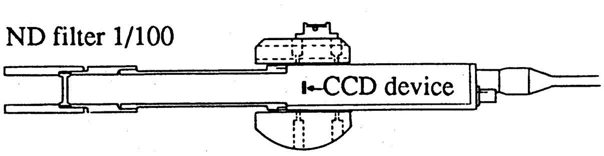

Fig.6. CCD camera with spherical housing.

It is difficult to receive the laser light directly on the CCD device because of the interference striped pattern. Thus the coating to suppress the reflection is used. However the interference pattern remains a little. The CCD device on which an optical fiber plate was tested. This camera showed no interference pattern, but it was too sensitive to the incident angle of the light.

The signal of the image comes into a video frame grabber board in the Macintosh computer. The center coordinates are extracted from this two dimensional distribution. Thouth the size of a CCD cell is 11 μm x 11 μm, the accuracy of this system is about ±2 μm in the ±0.5 mm region at 60 cm distance. The total counts of summed up distribution is of the order of 10^8.

The straightness of this laser and CCD system was checked with 4m-long stage. The small deformation of the stage was observed by a tilt sensor. The straightness is estimsted to be within 10 μm during 4m. If there is no pinhole in the filter, the straightness became bad.

It is important to place the camera in the housing so that the center coordinates do not change even if the spherical housing rolls a little.

The hood is quite important to stop the air flow. The magnets on the girder are usually aligned where the wind velocity is around 0.02m/s.

The change in temperature is very small in the tunnel. Thus the direction of laser beam is rather stable. The drift of laser beam observed at the distance 6m is usually within 10 μm during a few hours.

One or two planes are made on the magnet for the fiducial ones, and has a hole into which the stage is inserted. The diameter of this hole is 20 mm and its fluctuation among the fiducial planes was over 20 μm. Thus the ball cage is used as shown in Fig.7. It is easy to take the stage in and out the hole.

The reference line used for alignment is 0.5 m upper than the electron beam axis, thus the roll of the magnet is very important. It is difficult to measure the tilt precisely with a tiltmeter if the span between the contact points is short. A means to get good repeatability is necessary.

Since the tolerance between the girder is lager than that of magnets on one girder, firstly, both the end magnets are aligned. The fixed target stage is adjusted only the height, because this position is already aligned.

While the magnet is being adjusted, not only CCD camera but also 8 digimatic ingicators are used to monitor the magnet shift. The shifted values are displayed on the CRT also. Operators adjust the magnet looking at the ingicators. These ingicators are useful for moving to an accuracy of several μm.

The adjust of each magnet continues until the displacement at the position of CCD camera becomes within 10 μm on the CRT monitor.

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