POSITIONING THE SPRING-8 MAGNETS WITH THE LASER TRACKER

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1. INTRODUCTION

The SPring-8 storage ring has a circumference of 1436m with a Chasman-Green lattice of 48 cells. Each cell consists of three units of two bending magnets, ten quadrupoles and seven sextupoles. The storage ring of third-generation synchrotron radiation source is much sensitive to magnet misalignment, especially quadrupole misalignment. To reduce this sensitivity, the magnet alignment for the Spring-8 storage ring is divided into two stages: magnets are aligned within unit of about 5m with RMS error less than ±50μm, and the units are aligned along the storage ring with relative accuracy of ±0.2mm. The two-stage alignment method will reduce the amplitudes of the orbit distortions induced by the quadrupole misalignment [1].

The tasks face to us are: 1) For sake of Mihara-Kuriyama hill, It is impossible for us to set up a monument at the center of the storage ring, the central monument usually plays a very important role in controlling the absolute position of the beam elements. We have to find a solution that make the magnet alignment has not only a high relative precision but also a small displacement accumulation rate along the 1.4 km circumference. Two commonly used alignment networks of the quadrilateral and the triangulation are investigated. They are both have about 0.1mm or more relative error in controlling magnet positions, and the deviation accumulated along the ring is also enormous. 2) The storage ring installation is divided into five sections: in the first section four cell magnets are installed, second section eight cells, third section eight cells and so on. All the units are recommended to be put to the positions in one step before executing the overall survey and smoothing of the ring. This unclosed network is easily biased by systematic errors such as the two end datum points, atmospheric condition, calibration etc.

Alignment of Spring-8 storage ring magnets is composed of monument survey and magnet survey and alignment. 10 monuments are set outside the storage ring, 88 monuments are buried at the intersection points of the both side straight lines of the bending magnet. The monuments are used as the references for individual unit installation, also are used as the guideposts for magnet alignment and path smoothing. The magnets are surveyed and aligned with the laser tracker Smart 310, a 3-dimension measurement system. This system is for the first time employed in the measurement of storage ring networks.

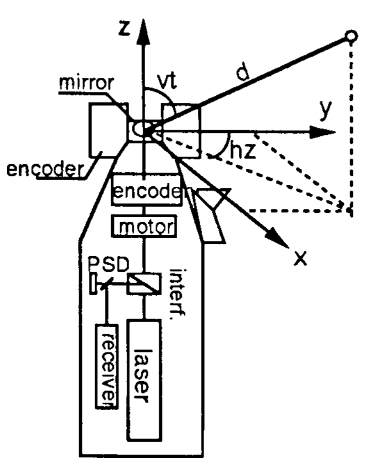
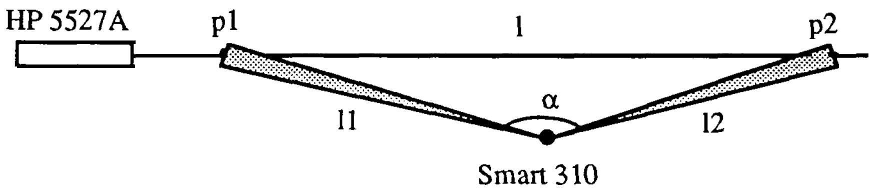


Fig.1 Principle of the laser tracker

The laser tracker SMART 310 is a dynamic measurement system which consists of a laser interferometer, a rotating mirror on two axes with two angle encoders and servo motors, a position diode etc.(Fig.1). Returning beam from retroreflector is partly divided to the position diode. Through a servo loop the offset on the diode corrects the angles of the mirror to keep the beam on the target. The tracker gives 3D spherical coordinates of a target in space with a distance resolution of 1.26μm, an angular resolution of 0.7".

Many factors may influence measurement accuracy of the laser tracker: the calibration, atmospheric conditions, and the way laser tracker been used, To realize the accuracy it can achieve, the laser tracker was checked under various condition such as different measurement angles and encoder positions, as well as two faces of its measuring head. Also it is compared with HP 5527A interferometer. Experiments show the laser tracker has a distance accuracy of 0.001+0.2ppmxL(mm) and an angular accuracy of about 10 μrad, which is four times the error of theodolite T3000. It is evident that using Smart for network survey, the precision is mainly restricted by the angular resolutions of the encoders. This accuracy will result at least 7mm traverse unclose for the storage ring orbit if the laser tracker is simply used for coordinate measurement.

Magnet alignment network for the Spring-8 storage ring is a distance-only trilateral network. The laser tracker has different accuracy for distance measurement when its position changes with 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(Fig.2):



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

Fig.2 Smart distance measurement between two points

where l is the length between two measuring points, α, l_1, l_2 are angle and lengths from laser tracker to these points, $m_\alpha, m_{l_1}, m_{l_2}$ are their measurement accuracy respectively. The laser tracker gives the most precise distance when it is placed at the extension line of two measuring points, where it can eliminate the calibration error of absolute distance and reflector eccentricity. The distance from the mirror to the target is also precise on the condition that the laser tracker is well calibrated. Because this distance is measured directly by the interferometer.

2. MONUMENT SURVEY

In January to February, 1993, 28 monuments around the storage ring were surveyed with an error of 0.5mm using mekometer ME5000 and theodolite T3000(Fig.3). In the some time the building construction began. After that, second time monument survey increased monument number in the tunnel. These monuments are lately used as monitors for the monument survey inside the tunnel after building construction.

After building construction all 88 monuments in the tunnel are surveyed with the Smart 310(Fig.4). Survey network includes 192 points and 480 distances. Because the tunnel is very narrow, if simply use the quadrilateral network, monument deviation is proved to be large: error ellipse of maximum deviation of 0.8mm in radial direction. For the following reasons the deviation increases: parts of the tunnel has completed while 3/4 parts are being constructed. Air temperature and refraction are quite different along the ring; After building construction the monument datums have about 0.8mm movements. Systematic error may increase deviation of survey to 1.5mm in radial direction. To reduce deviation the solutions are: 1) using T3000 measure 24 angles in every two cells, 2) from previous monument datum chose two fixed points which are believed to have least movements, 3) monument coordinates are adjusted by best-fitting to selected 16 monuments. These monuments are convinced to have little movement from three time surveys. Simulation study shows after taking above steps the monument survey will reduce the RMS error to 0.5mm, peak to peak error ±1.3mm in radial direction. Because using Smart 310 in survey causes only 0.3mm deviation in the beam direction, what we much concerned is the displacement in radial direction for the long and narrow tunnel. The survey results are compared with theodolite

T3000 angle measurement results. Difference between them is small. Peak to peak value of 0.7-0.8 is convinced(Fig.5).

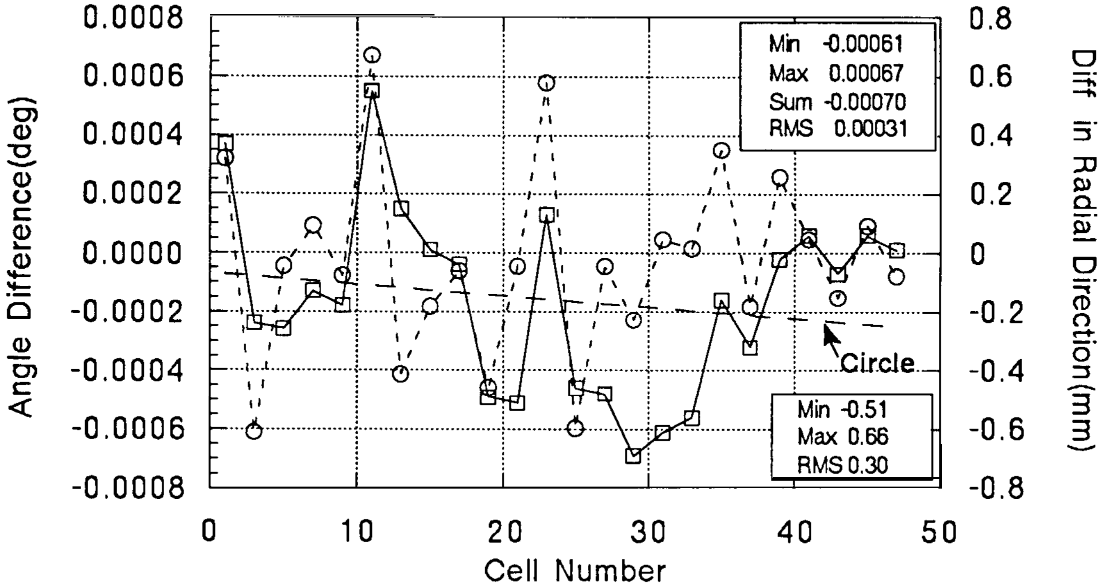


Fig.5 Monument Survey Results vs.Theodolite T3000 (per 2 cells)

3. SURVEY AND ALIGNMENT OF MAGNET UNITS

Alignment network for the storage ring magnet units is composed of 288 quadrupole fiducial points, 88 monuments and 96 auxiliary brackets on inner wall. Total distance observation is 1440 in the ring(Fig.6). Several aspects are particular in this magnet alignment network.

Quadrupoles and the laser tracker positions directly compose the knots of network. It make magnet positioning more directly, error translation of the reference points smaller. Among distance observations, over 50 percent distances are measured directly by the laser tracker interferometer, Accuracy of these distances is 4μm in 10 m range. The network precision depend on both the accuracy of laser tracker and the ratio of measurement length to the width of the net. Measurement lengths are optimized by simulation study of error accumulation. The study shows that measurement length shorter than 15 m, the ratio of measurement length to width of 5:1, has least error accumulation rate along the ring. Distance longer than one cell is no beneficial to control radial deviation of the magnets. Error ellipse analysis shows this network has a sufficient precision for controlling magnet displacement: Maximum magnet displacement of less than ±1mm is expected with respect to geodetic coordinate. The relative displacement between adjacent units is expected to be ±0.04mm(Fig.6).

Up to now over 60 percent of magnet units are surveyed and aligned. Survey is carried out three rounds: two rounds for adjustments, one round for check purpose. Cell 04 to cell 25 gives an example of magnet alignment process(Fig.7). In the first round, the magnets are adjusted to a smooth curve of polynomial fitting to the monuments. Monuments are the guideposts to control absolute positions. Magnets in the second round are adjusted to a local weighted curve which fits to magnets only. After two round of adjustment, the relative displacement between units achieves a precision ofi 0.04mm of RMS value.

Four 50-meter long straight sections provide good spots to examine the accuracy of magnet positioning by using Taylor-hobson telescope to examine the straightness. This result shows magnet deviations are less than 0.1mm within 40 meters. Fig.8 gives the straightness of short straight sections. In short straight sections four magnets in 14 meters are measured by the telescope. The result well convinces the relative precision of magnet alignment is better than ±0.04mm.

Precise calibration is essential to the measurement of the Smart 310. Smart's absolute distance error includes 'home point' distance error, interferometer error, and reflector eccentricity. To calibrate it precisely, a 20-meter calibration stand is made and set up in the tunnel. Calibration method can be referred to Fig.2. On the stand HP 5527A interferometer is used to provide a standard length. the HP reflector and the Smart reflector are in the same moving stage. Precise leveler ensures the two laser reflector moving the same distance(Fig.9). To eliminate angle measurement error the Smart is set up most nearly to the stand. Smart measures the two point distances l_1, l_2 and angle α, Distance correction value is deduced by the cosine law, referring the HP interferometer length. Through this process both the 'home point' distance error and reflector eccentricity error are corrected. Distance measurement accuracy of 3μm is obtained in 10 meters.

4. CONCLUSION

Third-generation synchrotron radiation source is very sensitive to magnet misalignment. To reduce this sensitivity magnet alignment for the SPring-8 storage ring adopts two-stage alignment method, and the relative displacement is more concerned. Although the Smart 310 has a large angle measurement error which is not match for its distance accuracy, it is also can be successfully used in network survey for positioning magnets as long as take its strong point and avoid its shortcoming. The magnet alignment results are gratifying and reliable. We can adjust the magnet to wherever we want to a lo range of 0.04mm.

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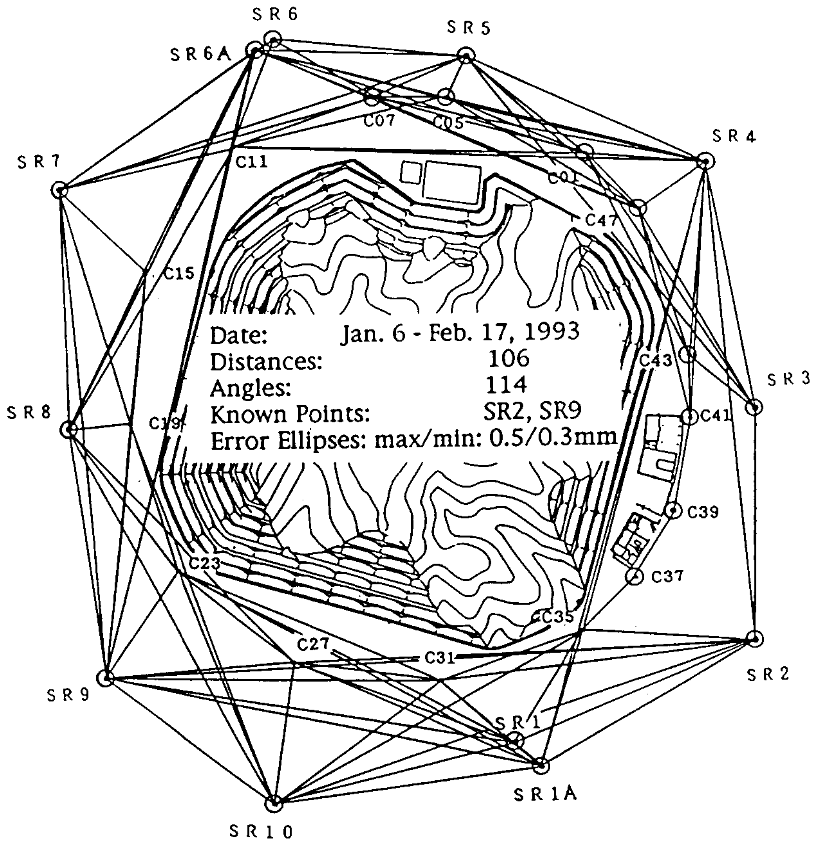


Fig.3 Monument survey before building construction

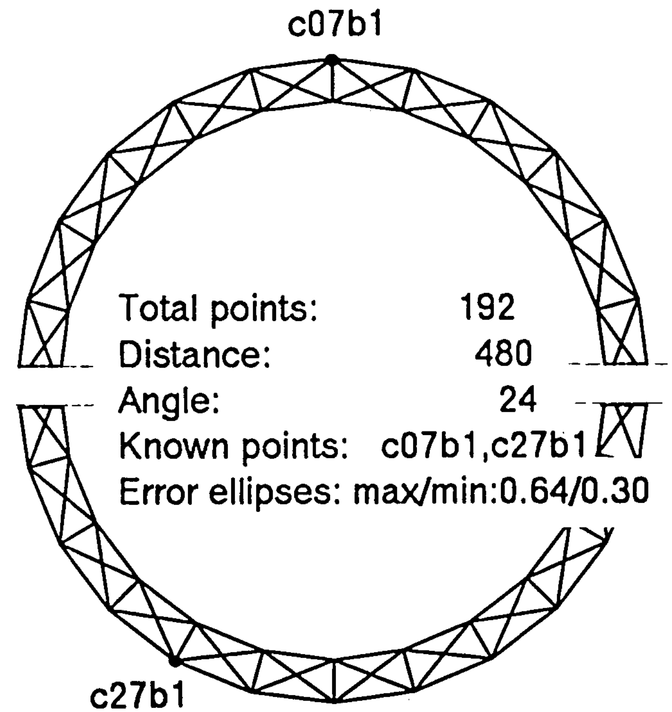


Fig.4 Monument survey after building construction

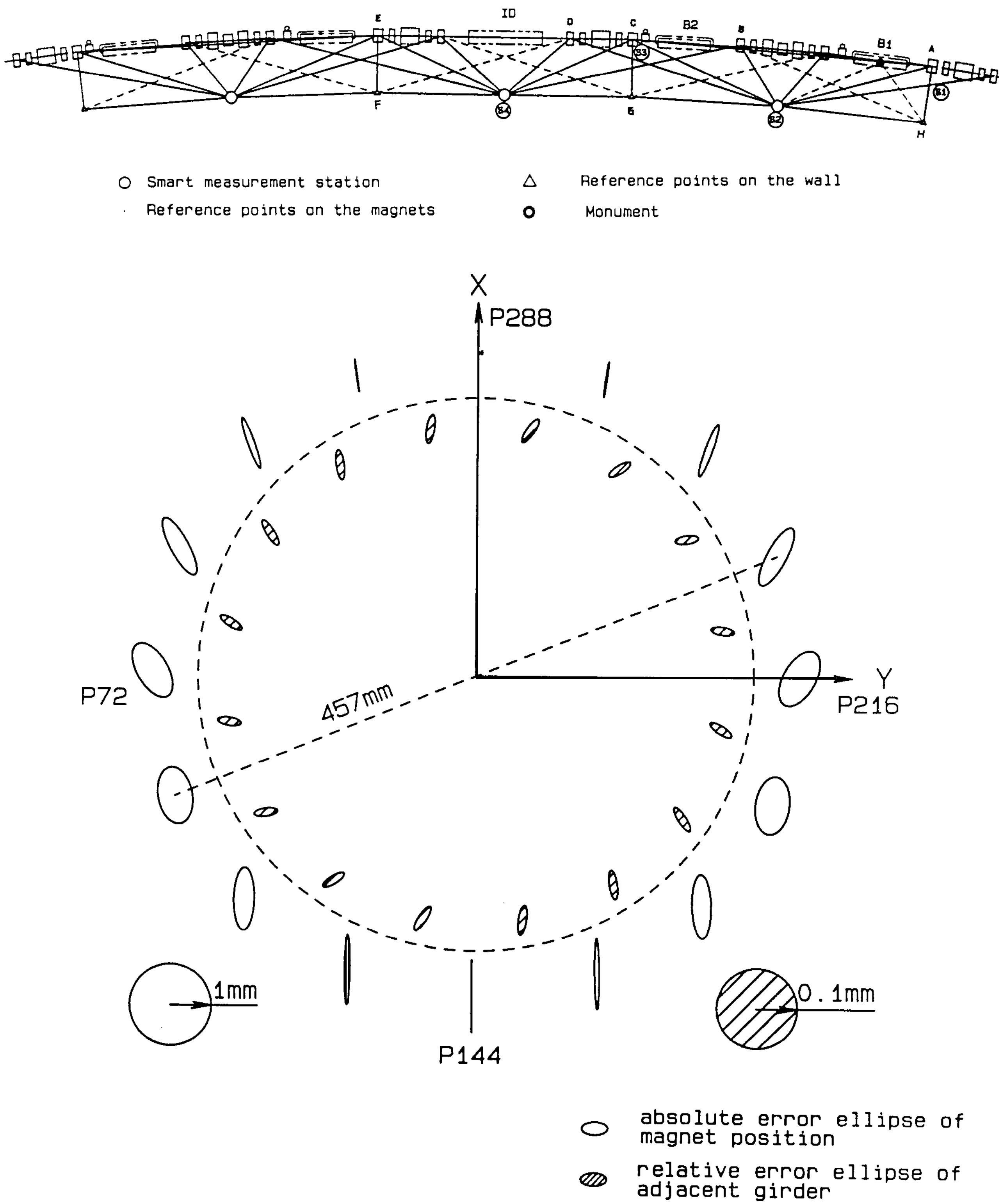


Fig.6 Alignment network and error ellipse analysis for positioning magnets of the SPring-8 storage ring

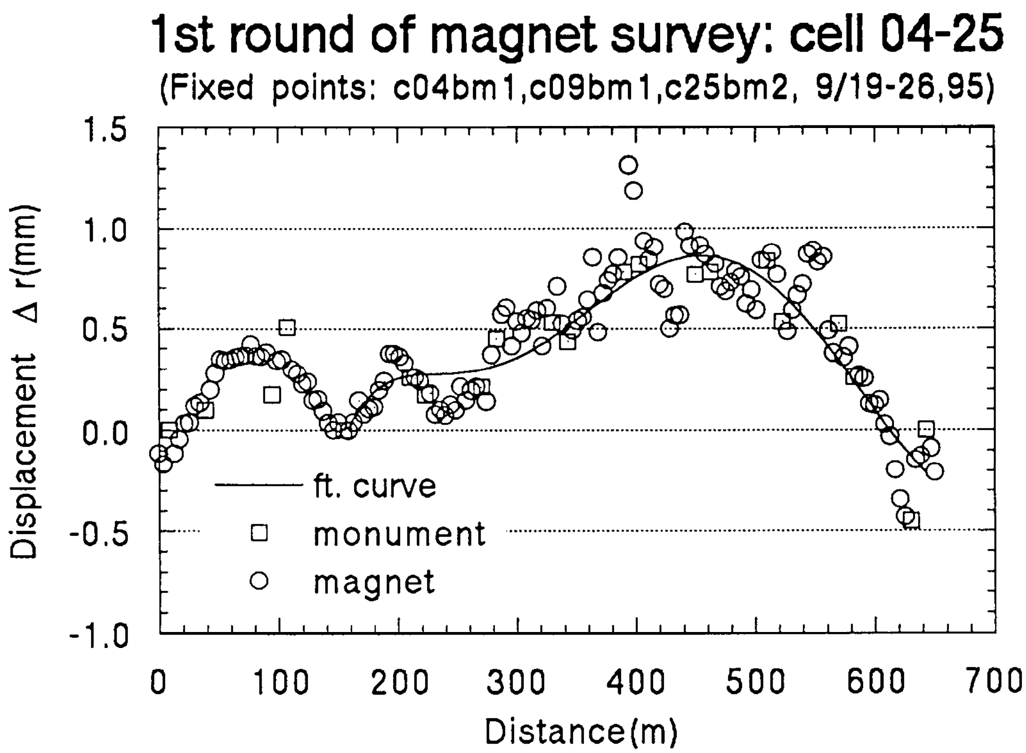

1st round of magnet survey: cell 04-25
(Fixed points: c04bm1,c09bm1,c25bm2, 9/19-26,95)
Displacement Δ r(mm)
1.5
1.0
0.5
0.0
-0.5
-1.0
0
100
200
300
400
500
600
700
Distance(m)
ft. curve
monument
magnet

Fig.7a

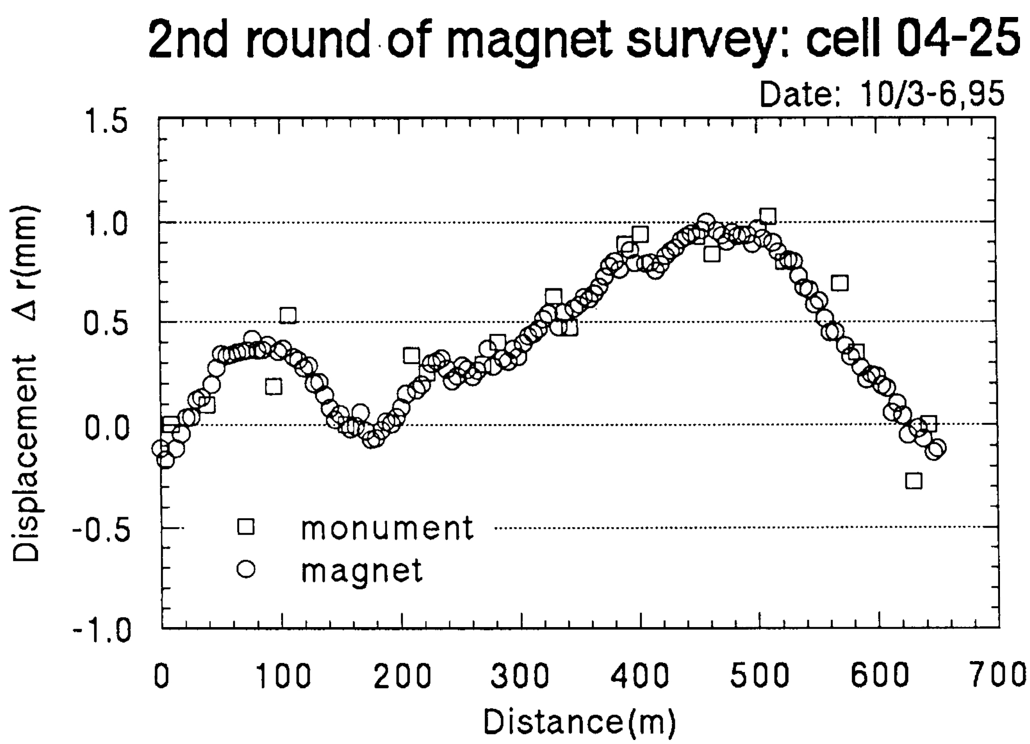

2nd round of magnet survey: cell 04-25
Date: 10/3-6,95
Displacement Δ r(mm)
1.5
1.0
0.5
0.0
-0.5
-1.0
0
100
200
300
400
500
600
700
Distance(m)
monument
magnet

Fig.7b

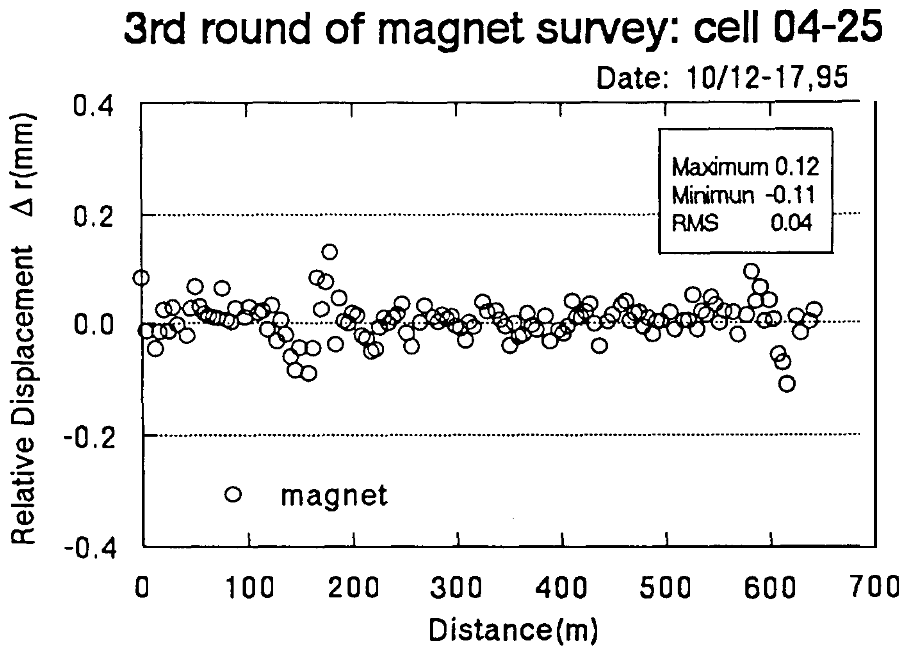
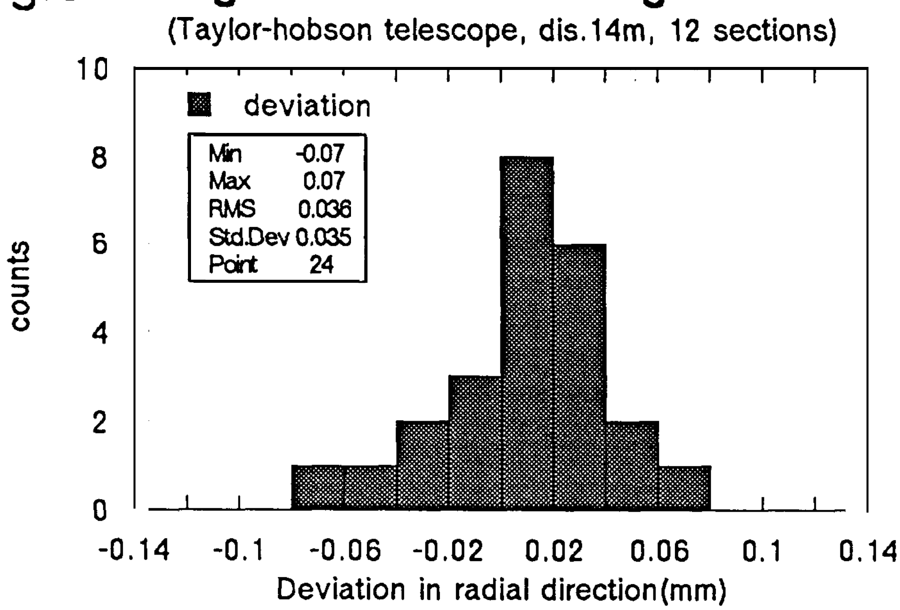


Fig.7c

Fig.7 Results of magnet unit alignment

Fig.8 Straightness of short straight sections



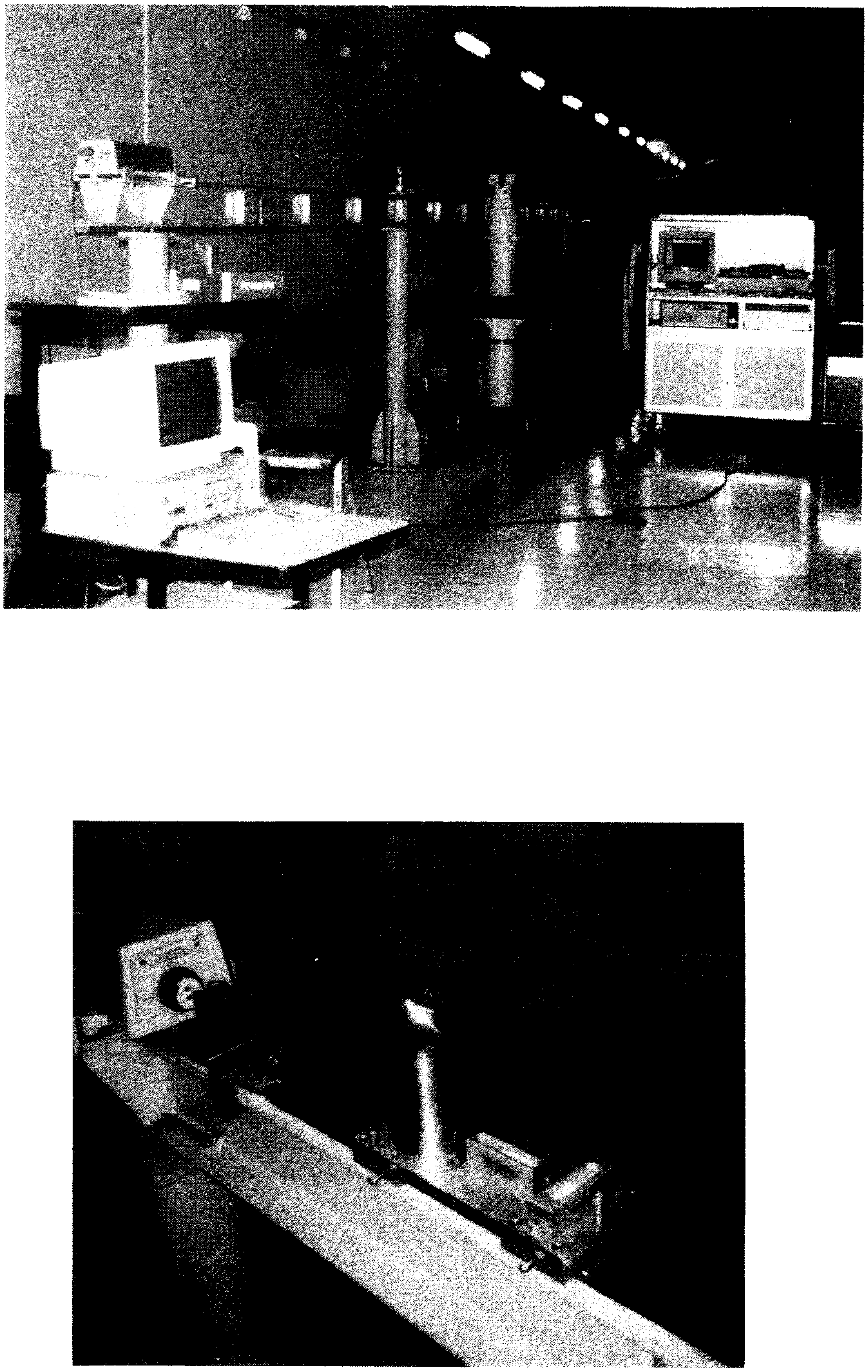


Fig.9 20m calibration stand