MAGNET ALIGNMENT OF THE SPring-8 STORAGE RING

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Abstract

Wide area of the storage ring of SPring-8 is put on the hard rock, however the ground of other area was improved. The 21 monuments for the magnet alignment of the storage ring were surveyed before building construction. After tunnel construction the 88 monuments were surveyed again and these positions were determined. After setting girders and magnets, the girders were surveyed with a laser tracker by making network. After the smoothing the relative displacements were within ±0.04 mm. A laser and CCD camera system is used for a precise alignment of quadrupole and sextupole magnets on a girder and now this alignment has finished about half ring. The target shift from the 5m-straight line can be measured to an accuracy less than 10 μm. The misalignment of them are estimated to be less than the tolerance. For these alignment some convenient instruments have been made, for example a target stage with ball cage etc.

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. (Fig.1.) Alignment of multipoles consists of two steps. One is the alignment in a girder and the other is that between girders.

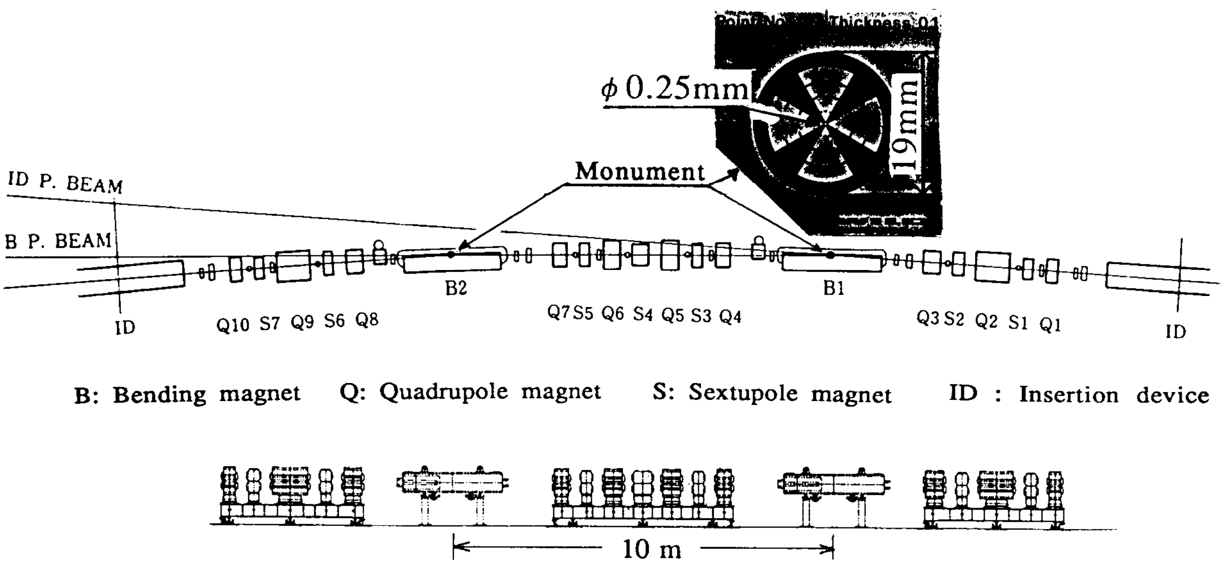

Fig. 1. Beam components of normal cell and monuments.

We had to decide where we mount the magnet on the girder. At first, we would align the magnets in a girder and divide, install the vacuum chamber and restore the upper-half magnets in an assembly room. After this we would carry into the tunnel and align between the girders. However in this method the schedule of magnet and that of vacuum correlate strongly. This correlation was serious, after all, magnets were determined to be installed by own schedule.

In the first plan it is not necessary to divide the magnet in the tunnel, however in the second plan the crane to divide magnet is required in the tunnel. Since crane is useful, we made crane

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rail after tunnel construction. If we have crane in the tunnel, we do not need to carry girder with magnets (maximum 10t). We can carry every component with a hand truck and mount on the girder by the crane. Thus the alignment between girders is prior to that of in a girder because the linearity on the girder may be broken when it is shifted.

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

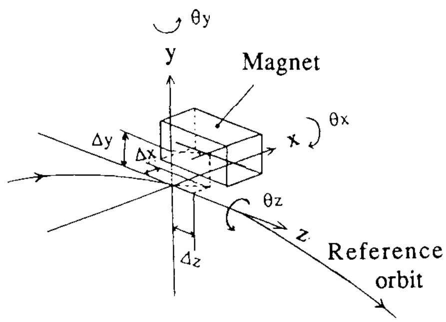
Table 1 Tolerances for magnet misalignment

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.

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 (tolerance 50 μm) and between girders (0.2mm).



Alignment schedule

An alignment schedule were planned as follows. The 2-3 Survey 3,6-l, 6-3 and 9 Precise alignment are described in another paper.[1,2] Other procedure are explained in this paper.

1. Foundation Improvement
2. Monuments Survey (on the Horizontal plane)
   2- 1. Survey 1 (1992.1) before tunnel construction
   2-2. Survey 2 (1993.10) before tunnel construction
   2-3. Survey 3 and marking for baseplate (1994.1 l-1995.3) after tunnel construction
3. Level Survey (floor level and reference level on the wall)
4. Girder and Magnet Setting
5. Rough alignment of both end magnets (already finished)
6. Alignment between girders (Horizontal plane)

   divided into 5 phases (lst-4cells, 2-8,3-8,4-12,5-16)

   6-l. Survey between girders

   6-2. Adjust

   Repeat survey(6- 1) and adjust(6-2) two times

   6-3. Survey
7. Level survey between girders
8. Alignment of Bending Magnet and light beamline marking
9. Precise alignment of Quadrupole and Sextupole magnets in a girder (1/2 finished)

10. Divide magnet and insert vacuum chamber

11. Restoration of upper-half magnet

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before commissioning survey and alignment will be done.

1. Foundation Improvement

Figure 2 shows the area where the ground was improved. The cross section is shown in Fig.3. The symbol C, D represent the hardness of the rock. After digging D and CL zone, broken stone, sand(10%) and cement(5%) were mixed and buried. After this improvement the test (boring, measurement of P-wave and S-wave velocities, measurement of density etc.) was done. The result showed that the artificial rock was very hard.

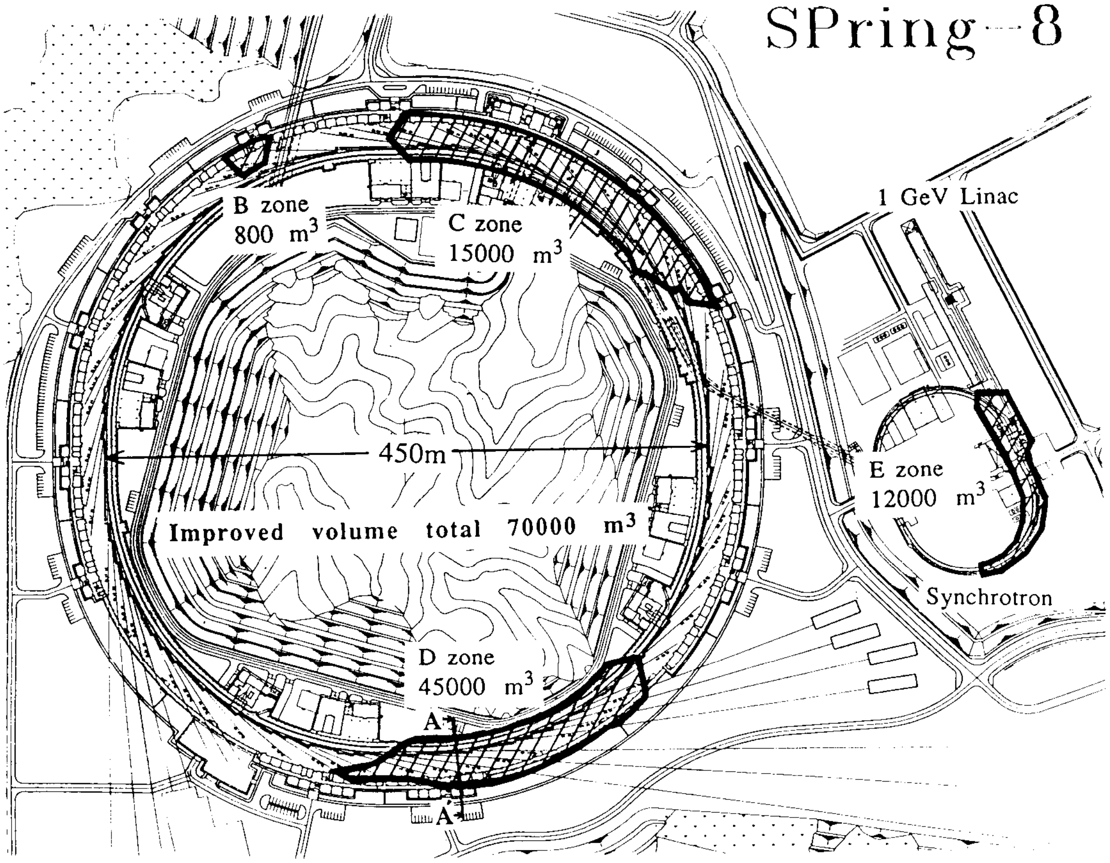


Fig.2 Area of foundation improvement.

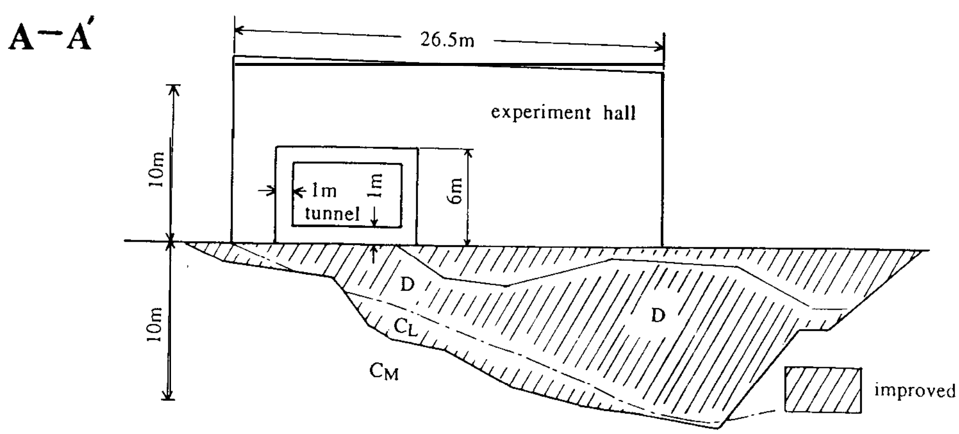


Fig.3. Cross section at the improvement.

2 Monuments Survey

Monuments were made to survey the whole ring before tunnel construction. We made concrete blocks shaped like tomb stone at 21 positions (every 60 m) along the ring as shown in Fig.4. We did not make the buffer layer for protection against the outside concrete. Monument is placed at the intersection point of the straight lines at both sides of the bending magnet as shown in Fig. 1. The surface level of the monument top is the same as floor level. A brass plate is buried on the top and a seal for the survey is stuck on this metal plate. After survey these monuments were also used for the reference points to make the body of the tunnel.

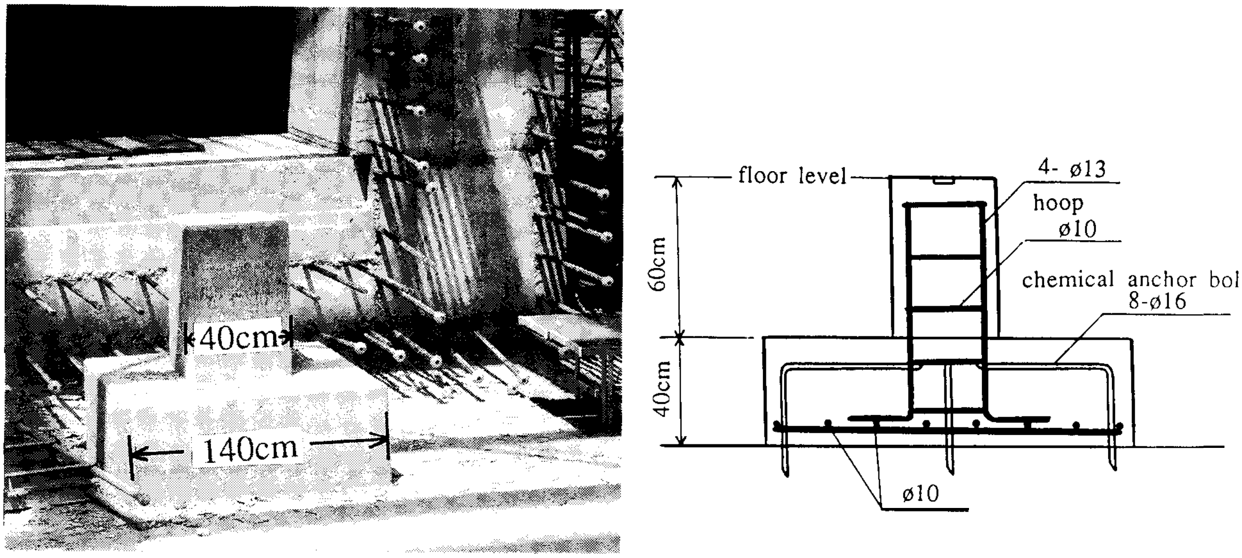


Fig.4. Photograph and the cross section of a monument.

2-1 Monuments Survey 1 (1992.1)

The geodetic points(SR2-SR10) outside the ring(Fig.5) are buried on the same rock on which the ring is put except SR1. These geodetic points and monuments(C01-C47) were surveyed with a distance meter ME5000 and two theodolites T3000 by many members of accelerator group. The plummet NL was used to set the survey instrument precisely. Survey instruments were set on the stand fixed on the monument (Fig.6). Since the building construction had already started, there were many obstruction (earth laid on the ground etc.) intercepting the line of sight. Figure 7 shows the survey network. The error ellipses of these results were smaller than the circle of radius 1 mm.(Fig.8.)

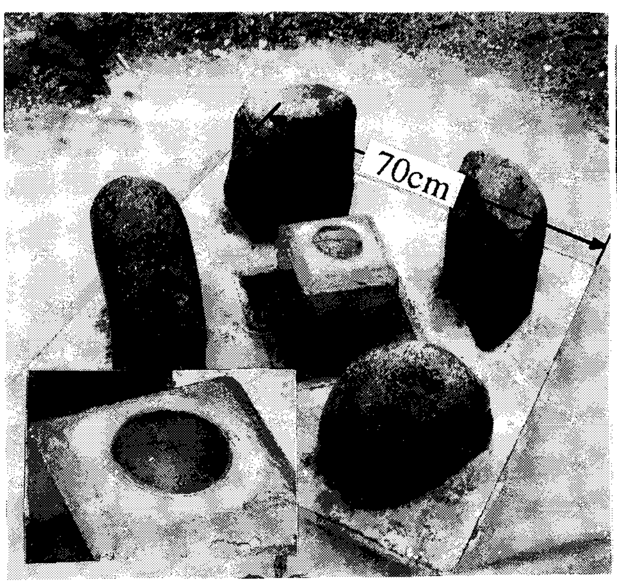


Fig.5. Geodetic point of Japanese style.

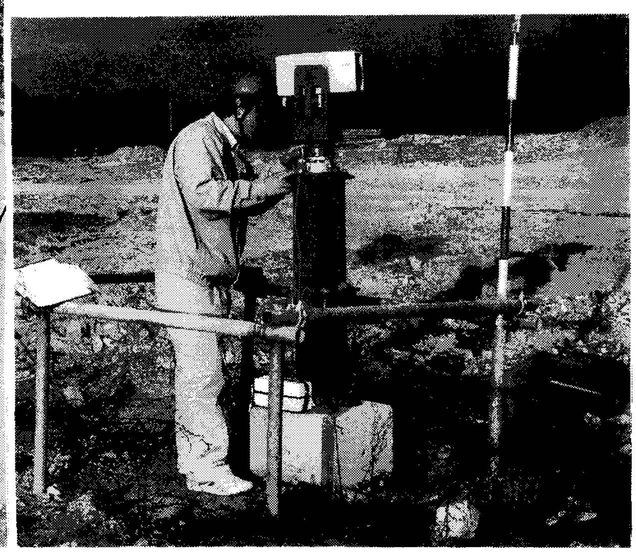


Fig.6. Survey stand fixed on the monument.

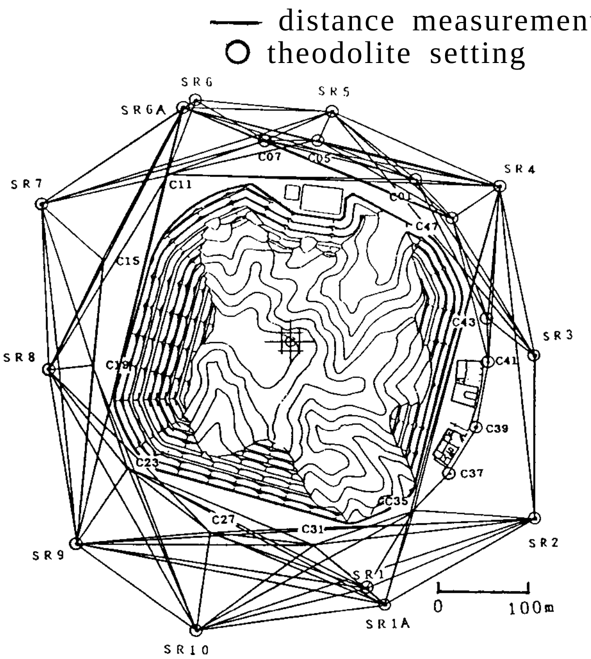


Fig.7. Survey 1 network.

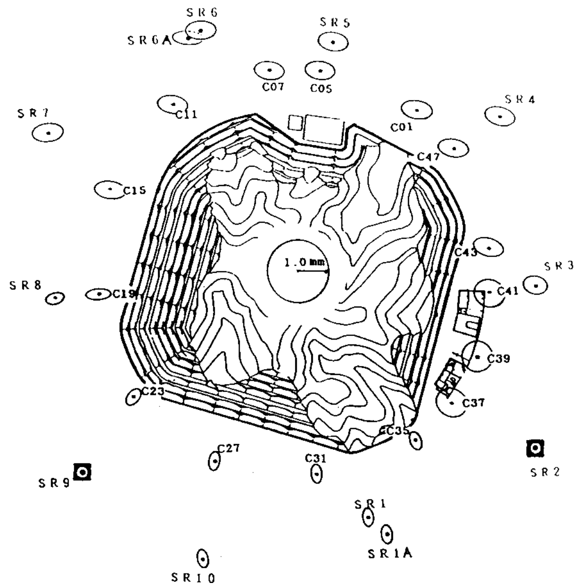


Fig.8. Error ellipses (known points=SR2,SR9).

2-2 Monuments Survey 2 (1993.10)

After the monument survey 1, according to the result we made small hole with a center punch on the monuments, and we surveyed the punched positions with outside geodetic points again. This time we used 7 corner cube targets for ME5000 to reduce the times of change target. This number was efficient. We surveyed also the monuments which were not surveyed in survey 1.

2-3 Monuments Survey 3 (1994.11~1995.3)

The laser tracker is a dynamic measurement system,[1] that is laser can chase the target wherever we move. The distance between the surveyed monuments was 60 m, thus if setting the tracker at the middle point, we could stick the seals on the other three monuments only by the tracker. After this we surveyed these monuments with the laser tracker by making network shown in Fig.9. The reference level for the magnet setting is 1700mm, we made target stages at this height on the wall shown in Fig.10. Thus the laser light when measuring the target is in the plane which height is 1700mm. The body of tracker sensor unit is modified so that we can adjust the height and shift horizontally. This is because we want to survey without using the rotary encoder for vertical angle. On the monuments we used the modified tripod with XYZ stages (Fig. 11).

Before the tunnel was completed, we had to make baseplates for the magnet girder. Thus we made marks for baseplate with a laser tracker according to this survey results. Baseplate is shown in Fig.12. As the next tunnel area was constructed, also we proceeded to survey next area. It took about 4 months for the whole ring survey. All 88 monuments including 21 points were surveyed.

Since this survey network was narrow and the circumstances were not good, it was difficult to decide the monuments coordinates using only tracker. Thus the data of the angles between the 24 monuments were added. The difference between survey 1,2 and survey 3 was small.

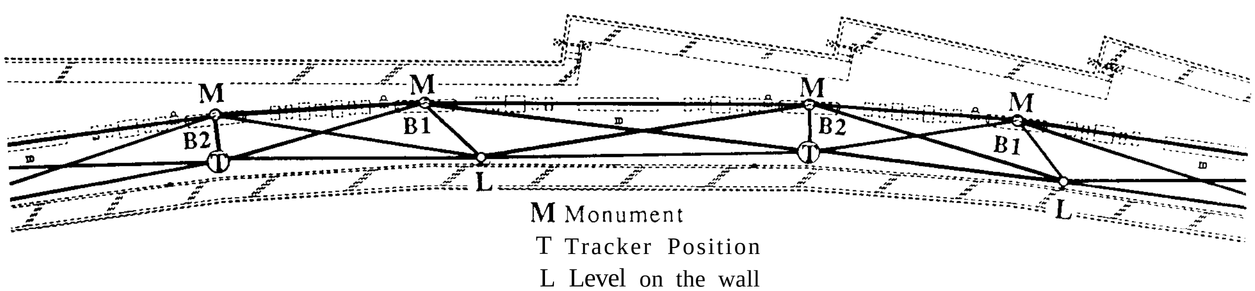


Fig.9. Network for the monuments survey.

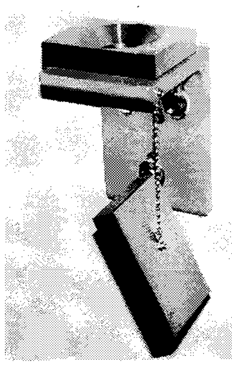


Fig.10. Level stage on the wall

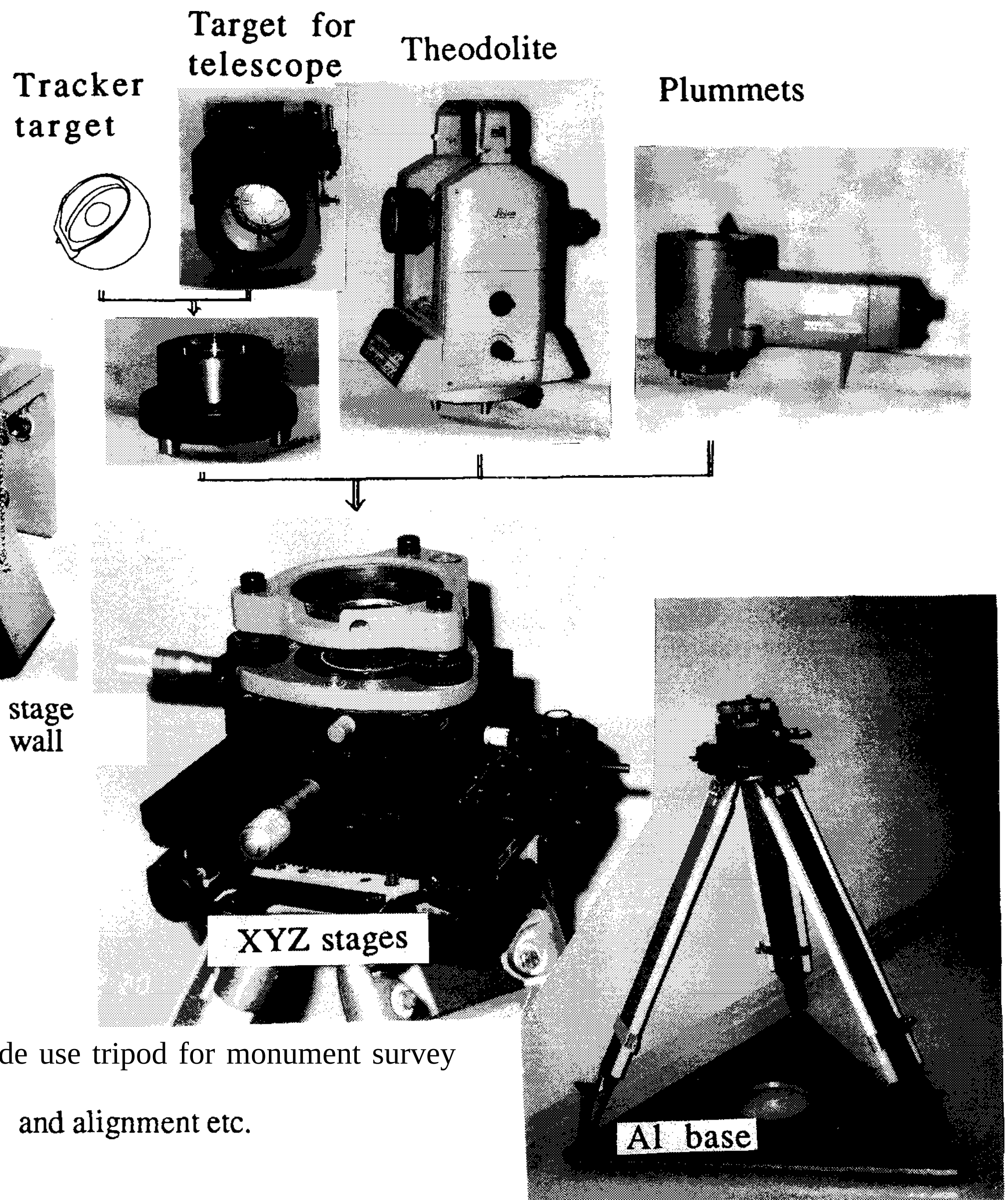


Fig.11 Wide use tripod for monument survey

and alignment etc.

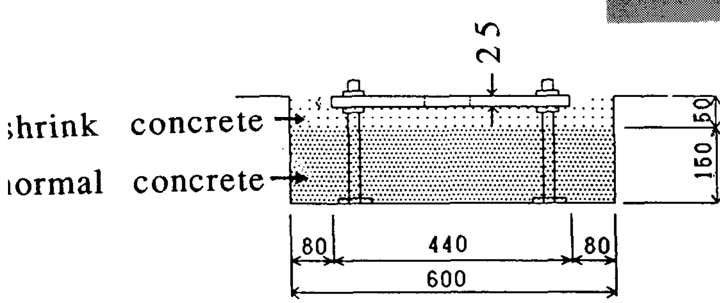


Fig. 12. Cross section of base plate.

3. Level Survey (floor level and reference level on the wall)

In order to define the floor level (291.2m above sea level) the floor level in the tunnel around the beam line was measured by a laser level. The range of the floor level was within ±20mm except one small area. Thus the adjustable range of the girder was decided to be ±25mm. We defined the middle level of the floor as floor level. The beam level is 1200mm. We adjusted target stages on the wall shown in Fig.10 at the height of 1700mm.

4. Girder and Magnets Setting

Girder is carried into the tunnel and put on the pedestals. Magnets are put on the girder by the crane which can move below the ceiling of the tunnel.

Prototype girder was not hard to twist. Thus we adopt a box-type girder. This girder has 6 pedestals to tolerate the strong force applied from outside, for example, the vacuum force (in our case 700~800kg weight). Low friction material is used at the slip plane between the pedestal-girder and girder-the plate on which magnet is put. (Fig. 13) The coefficient of friction is less than 0.1. Since the friction is low, the girder do not bend when we adjust on the horizontal plane, and it is easy to adjust the magnet.

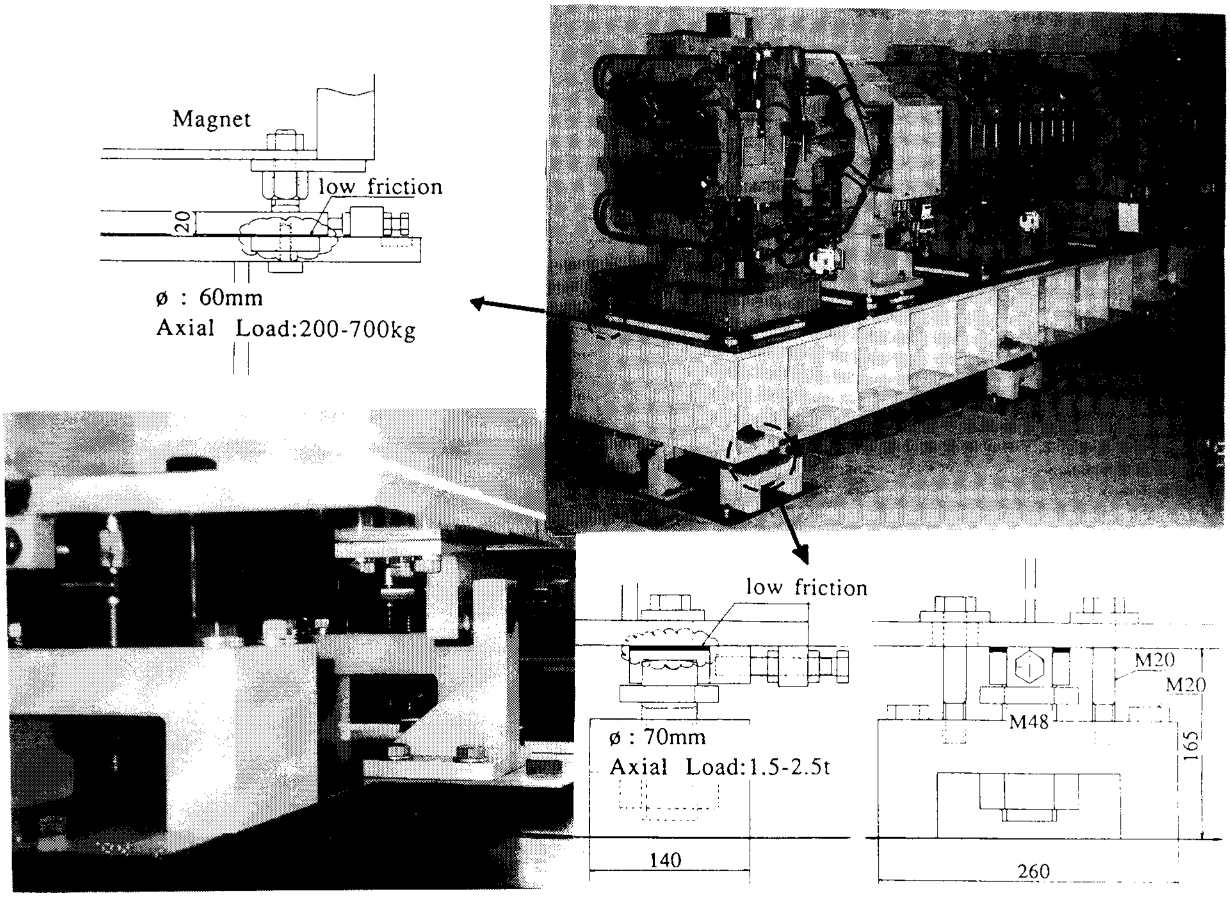


Fig.13. Girder and magnets on it. The slip planes are made from low friction material.

5. Rough alignment of both end magnets & also inner ones

Figure 14 shows the arrangement of rough alignment of girder and both end magnets. There is a fixed target stage on both end magnet. This stage shown in Fig.15 is used for the alignment between girders and for a reference stage of the precise one in a girder. This stage is fixed after fine adjust at the 500.00mm right above the magnetic axis when the axis is measured. One magnet has two fiducial planes. This is fixed only on the upper-stream fiducial plane attached on the both end magnet of the girder. The reason is as follows: 1) when we survey between the girders, the target position must not move strictly ; 2) this position is used frequently ; 3) the hole center on the fiducial plane is shifted less than 0.1mm from right above the magnetic axis. When putting the spherical target on the other plane, we use detachable stage (manufactured by HIRAI CO.,LTD) as shown in Fig. 16. Since the diameter dispersion of the hole on the fiducial plane is larger than ±10μm, we can not use one-diameter rod. However the ball cage can have good repeatability even if the dispersion of the hole diameter exceeds ±20μm. Moreover it is easy to put in and out.

Both the end magnets are aligned using the results of survey 3. 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.

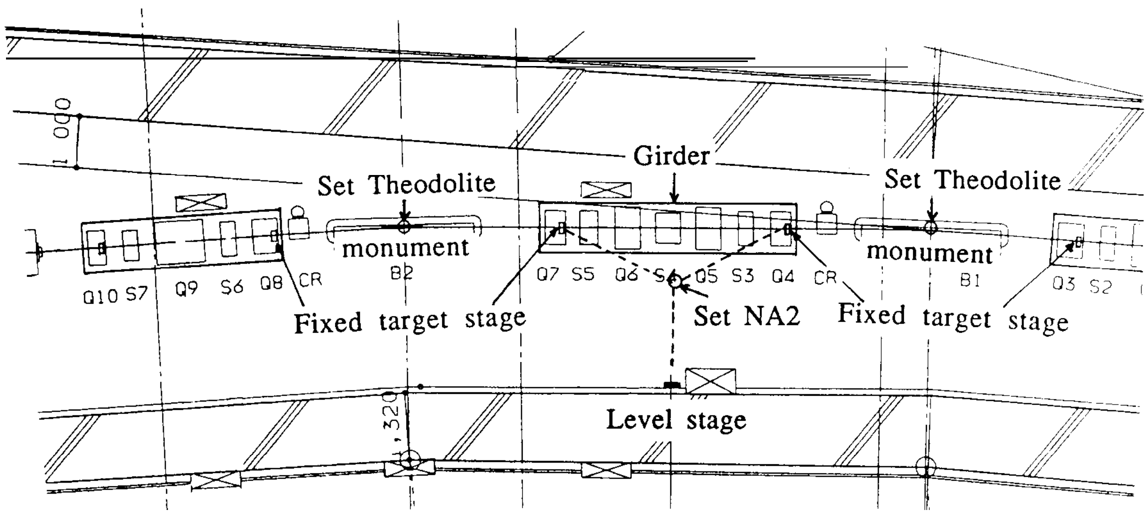
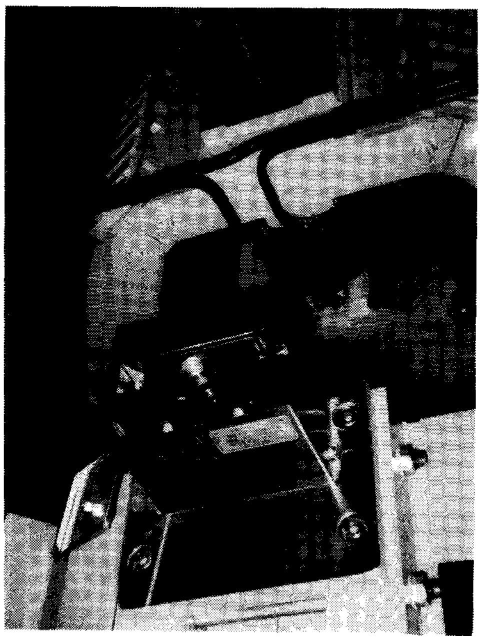


Fig.14. Arrangement of rough alignment of girder, both end and inner magnets.



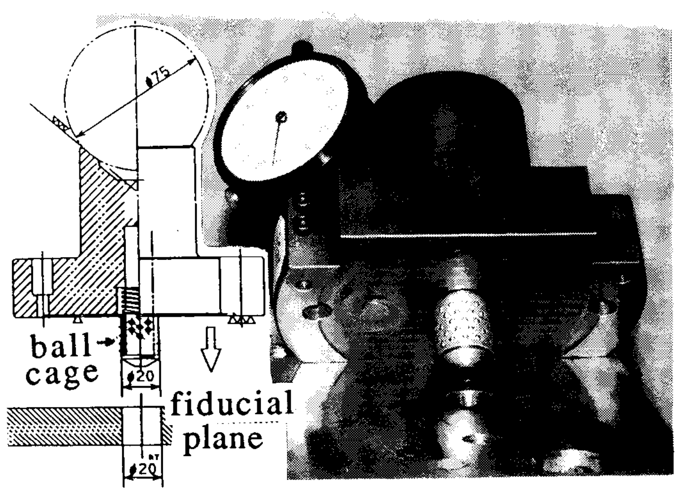


Fig. 15. Fixed stage on upper-stream fiducial plane. Fig. 16. Detachable stage using ball cage.

6. Alignment between girders (Horizontal plane)

6-1. Survey

Girders and some monuments are surveyed with only the laser tracker by making network. First survey was 4 cells and connection area. The smoothing area was 4 cell. Second was 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. This process is reported in detail by C.Zhang in this proceeding.

6-2. Adjust

According to survey results the girders are adjusted while being monitored with 8 digimatic indicators.

6-3. Survey

After repeating this 1-2 cycle two times, the third survey is carried out. At second adjust, the girders are locked. If this survey results is good, girder alignment is finished.

Girder smoothing results show that the relative displacement between girders of ±0.04 mm has been achieved.

7. Level survey

The level reference on the wall is used for pre-alignment of the magnet. However it is important to smooth not the wall references but the magnet level. This level survey is done after the girder positions on the horizontal plane are fixed and locked. Wild N3 is used. Figure 17 shows the simple network.

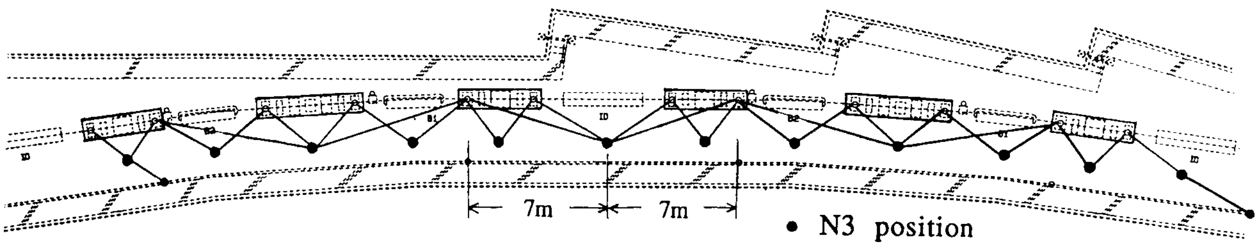


Fig.17. network for the level survey.

8. Alignment of bending magnet

Bending magnet is aligned with laser tracker as shown in Fig.18. The coordinate can be made by putting the target on the fixed stages and the stage on the wall. After making a coordinate system we align the bending magnet by putting the target on the tiltmeter (Leica Nivel 20) put on the fiducial plane. Target coordinates are displayed in real-time on the CRT.

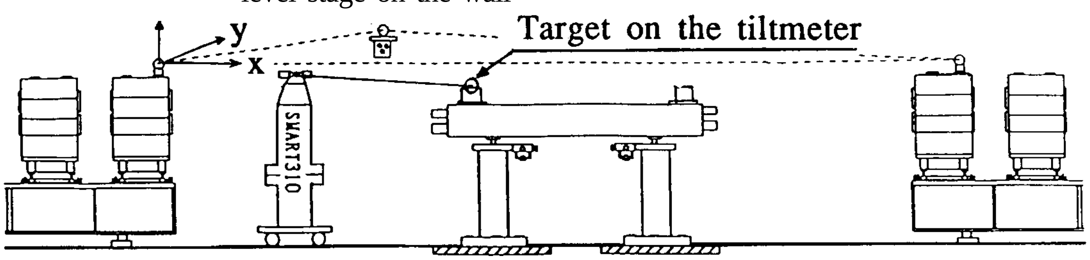


Fig.18. Make a coordinate system for the alignment of bending magnet.

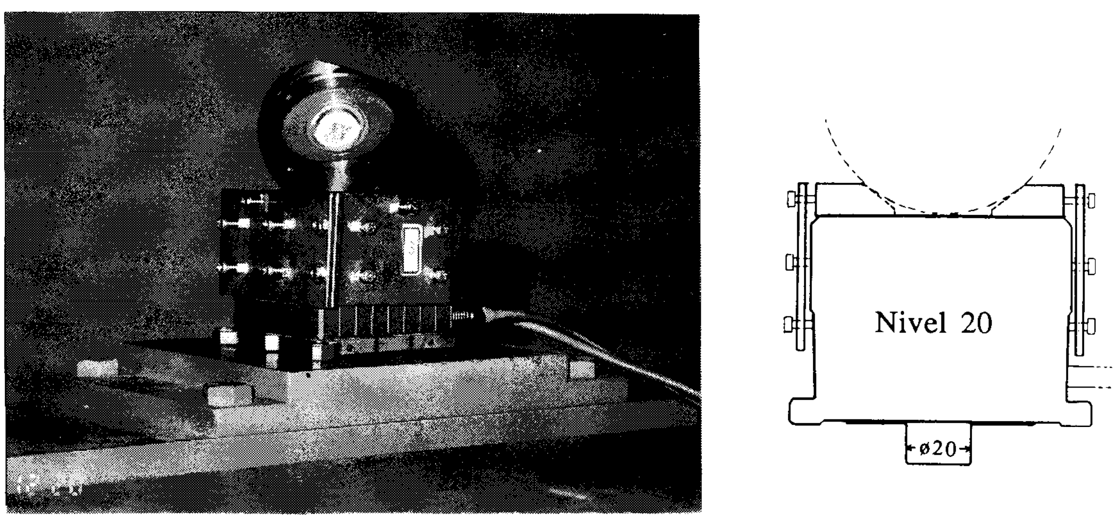


Fig.19. Modified tiltmeter on the fiducial plane and tracker target on it.

At the same time the marks of light beam line are made on the floor by the tracker.

9. Alignment of quadrupole and sextupole magnets in a girder

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 makes parallel light beam of gaussian shape. The straightness of this laser and CCD system was checked with 4m-long stage. The straightness is estimated to be within 10 μm during 4m.[2)]

The magnets on the girder are usually aligned where the wind velocity is around 0.02m/s, this condition is attained by stopping the air-conditioner.

Since the tilts of two fiducial planes are different, we assume that the lower-stream fiducial plane is parallel to the median plane of the magnet. The tilt is very sensitive to the small dust and scratch on the fiducial plane. Thus the tilt is measured with two tiltmeters (Taylor Hobson Talyvel 4) by reversing them. If the two averages are different largely we have to measure again. The reference line used for alignment is 0.5 m upper than the electron beam axis, thus the tilt (θ_z) 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. Moreover the fiducial plane is not flat, thus we decide the tiltmeter position strictly beside the detachable stage.

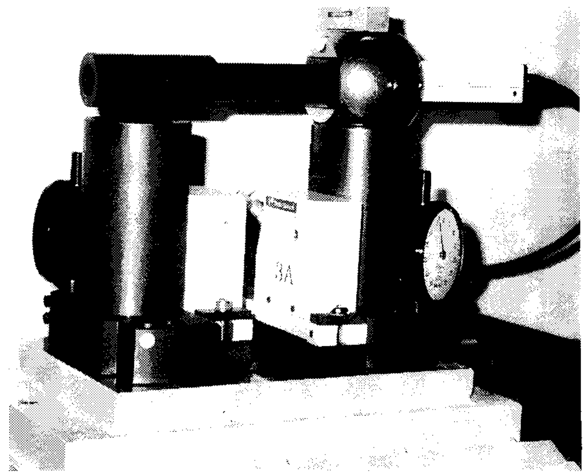


Fig. 18. Two tiltmeters and CCD camera on the fiducial plane.

Magnet is fixed to the intermediate plate by 4 bolts and the plate is fixed to the girder by another 4 bolts as shown in Fig. 13. Thus we can separate the adjust of height and tilt from that of horizontal shift.

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 according to the level survey, because this position on the horizontal plane is already aligned. Actually the alignment is done as follows:1) measure the tilt and the two positions by putting the CCD camera on the two detachable stages, 2) adjust the height and tilt (θ_x and θ_z), 3) fix the magnet to the intermediate plate by locking 4 bolts with upper and lower nuts, 4)measure the positions with CCD camera, 5) unlock the intermediate plate, 6) measure again, 7) shift the plate, 8) lock the plate.

While the magnet is being adjusted, not only CCD camera but also 8 digimatic indicators are used to monitor the magnet shift. The shifted values are displayed on the CRT also. Operators adjust the magnet looking at the indicators.

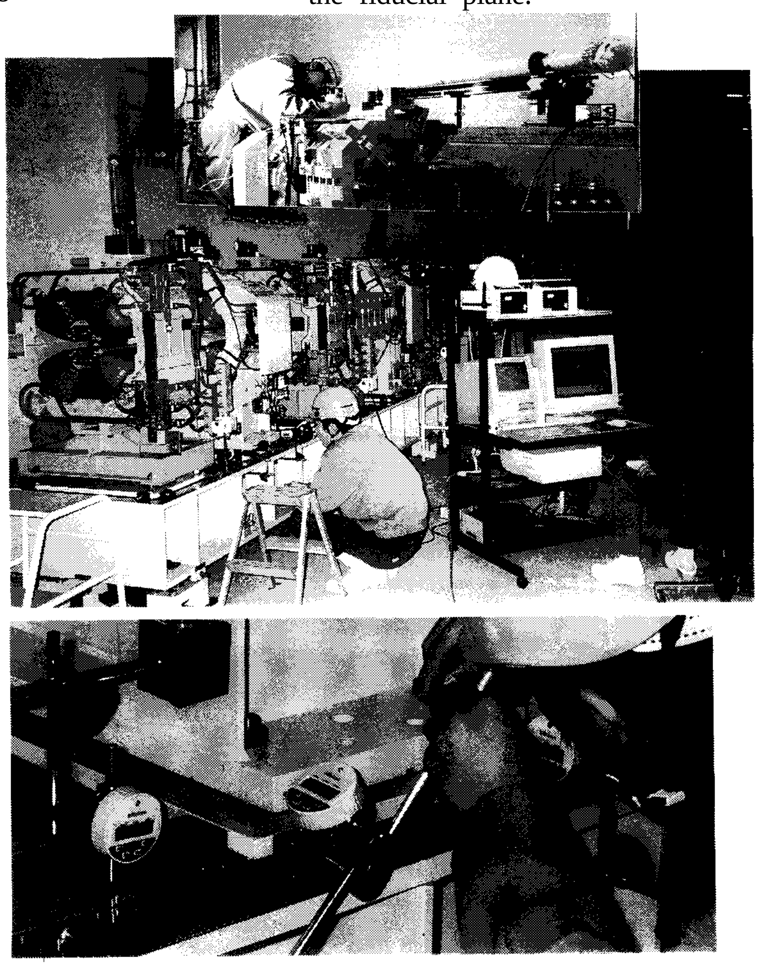


Fig.18. Photographs of precise alignment in a girder.

These indicators are useful for moving to an accuracy of several μm. When we lock the magnet, it does not move because we tie both upper and lower nuts looking the indicator.

The adjust of each magnet continues until the displacement at the position of CCD camera becomes within 10 μm on the CRT monitor. Tolerable tilt is less than 10 μrad.(Fig.19). The residual values after adjust are within 10μm as shown in Fig.20. It is easy to adjust the magnet within 10 μm because the friction is low and we use digimatic indicators. Now the time required for one magnet alignment is typically half hour.

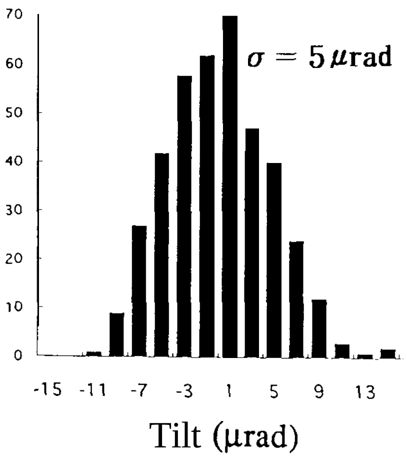


Fig.19. Tilt histogram.
(lower-stream fiducial plane)

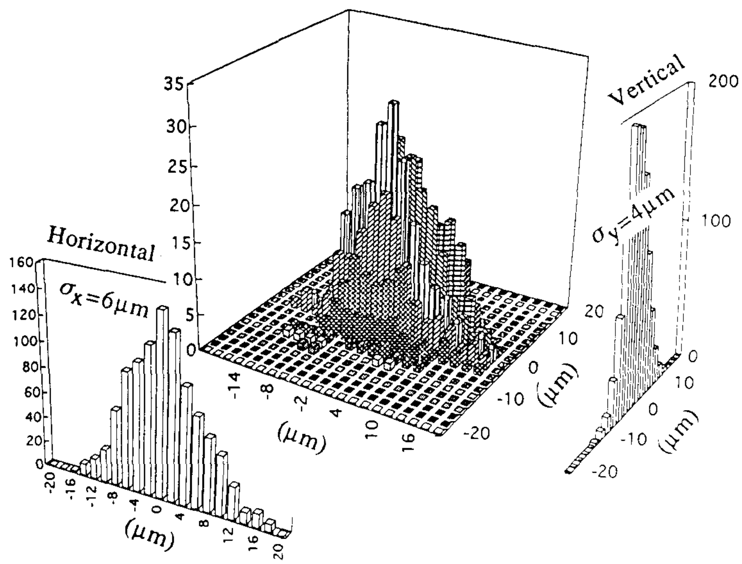


Fig.20. Histogram of unadjusted residual values.

10. Divide magnet and insert vacuum chamber

Multipole magnets are divided after precise alignment by the crane and the upper half magnet are put on the side of the path in the tunnel, Vacuum chamber is installed.

11. Restoration of upper-half magnet

The upper-half magnet is put on the lower half one by the crane. The key is very important to restore the magnet correctly.

Summary

In our case the magnet are aligned two times. Telescope is used at first step, laser is used at second. However the loss time was less than the estimated before.
Laser tracker is useful for real-time alignment and marking.
It is especially important that the span of tiltmeter is long and its position is always same.
Before magnet fiducial design we have to decide what tiltmeter and target are used.
We used detachable stage and spherical CCD camera. As these steps are two, the error increases.
Though there are some problems, we think these alignment system has no serious problem.
The movement of the target stage on the wall is small and difficult to understand.
After this it seems that the level change becomes important.

Acknowledgments

We would like to thank Dr. K. Endo, Dr. R. Sugahara, and the personnel of KEK survey alignment group for their useful advice. We are much indebted to Dr.N.Kumagai, Mr.I.Takeshita for their suggestions and also acknowledge to collaborators of Hitachi Plant Engineering & Construction Co., Ltd. for their various help.

References

[1] C.Zhang et al., in this proceeding
[2] Y.Chida et al., in this proceeding