Fine Alignment of the ATF Damping Ring

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1. INTRODUCTION

The accelerator test facility (ATF) was constructed in order to research and to develop necessary technology for future linear colliders. It consists of a 1.54-GeV injector linac, a damping ring, a beam transport line from the linac to the ring, and an extraction line for the beam diagnostics and several beam studies as shown in Figure 1. The ATF damping ring has a race-track shape, and mainly consists of 36 normal cells with a combined-function bending magnet and eight wiggler magnets to reduce the damping time. Normal cells form two arc sections with a radius of 13.8 m, and wiggler magnets are put in two straight sections with a length of 25.8 m. The circumference of the ATF damping ring is 138.6 m.

To achieve low emittance as well as high acceleration efficiency and strong final focusing is a critical issue to obtain high luminosity in future linear colliders. Future linear colliders require a very low vertical emittance, typically $\gamma\varepsilon_Y$ = 0.03 µm. A damping ring is the most feasible method for obtaining such a low emittance. Hence the ATF damping ring is designed for a vertical emittance of $\gamma\varepsilon_Y$ = 0.03 µm and a horizontal emittance of $\gamma\varepsilon_X$ = 3 µm. Magnets in the ATF damping ring must be aligned vertically within σ_Y = 60 µm and horizontally within σ_X = 90 µm to reach such a low emittance without bump tuning [1].

We assembled a set of magnets on 36 active support tables from July to September in 1996, and finished the initial alignment of the ATF damping ring in January 1997. A 3-D mobile tracking system, Leica SMART 310, was used for alignment and survey. Thus the ATF damping ring has been operated since January. The level of the ATF damping ring was measured with tilting levels in March. Furthermore, the outline of the ATF damping ring was surveyed with the SMART 310 in January, May, July, and September. In this paper, we report on results of the alignment and survey of the ATF damping ring.

2. SUPPORT TABLE

Two arc sections in the ATF damping ring are made up of 36 active support tables. One combined-function bending magnet, a pair of quadrupole magnets, and a pair of sextupole magnets are settled on a standard active support table as shown in Figure 2. Every magnet is fixed on a suitable positioning mount.

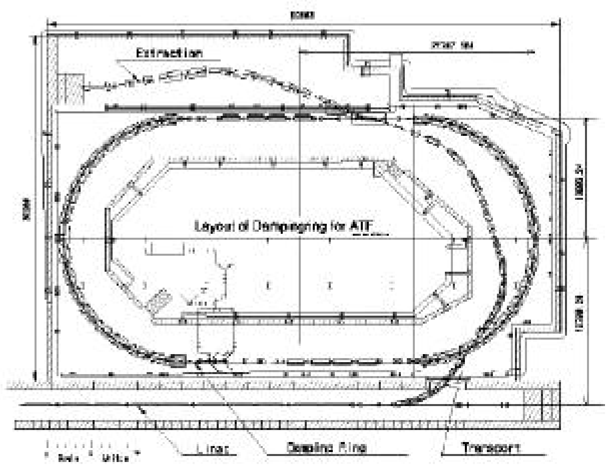

Figure 1. Layout of the ATF damping ring.

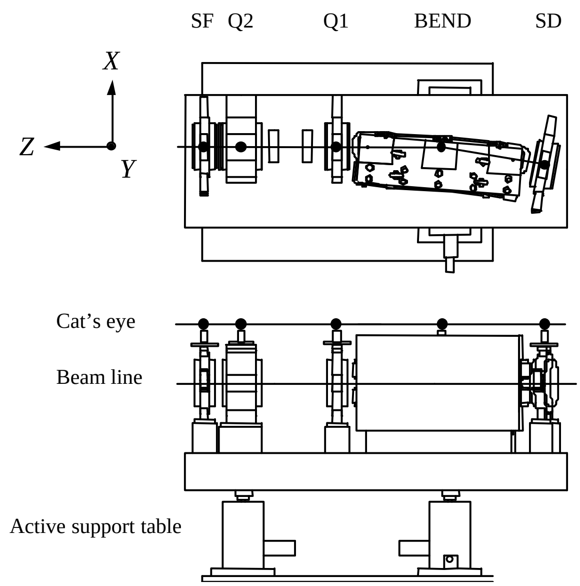

Figure 2. Standard active support table and a set of magnets on it.

2.1. Active support table for the arc section

The active support table comprises a 30-mm thick base plate, three movers, and a surface plate. Three movers are bolted onto the base plate. One of them has three stages: the bottom stage moves in the beam direction (in the *Z* direction), the middle one in the radial direction of the arc section (in the *X* direction), and the top one vertically (in the *Y* direction). The other two have only two stages, each: an *X* stage and a *Y* stage. Every stage moves along a linear rail guide. The roll, the pitch, and the yaw of the surface plate can be controlled by using these completely independent movers. The *Z* stage is manually driven, while the *X* and *Y* stages are moved by pulse motors. The range of each movement is ± 20 mm, and the accuracy is better than 2 μm.

2.2. Magnet positioning mount

A positioning mount for a quadrupole or sextupole magnet supports a magnet with three fine-pitch bolts of 0.5-mm pitch, and is fixed on a surface plate of an active support table by other three bolts with a spring as shown in Figure 3. The magnet on this mount is positioned by using six removable micro-meter heads, and then is fixed onto the mount by four bolts.

A combined-function bending magnet is settled on a positioning mount, supported by six turnbuckles with two rod-end bearings as shown in Figure 4. Three turnbuckles are used for the vertical adjustment. These vertical turnbuckles get long or short by 3 mm a turn. Other two turnbuckles are used for the adjustment in the radial direction, and one for the adjustment in the beam direction. These turnbuckles get long or short by 0.5 mm a turn.

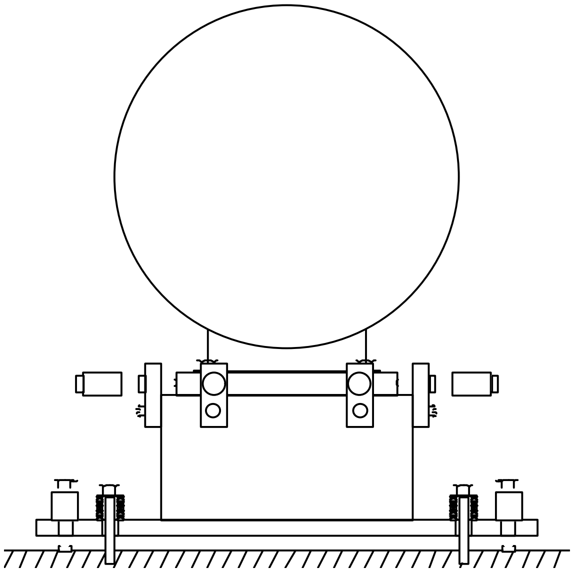

Figure 3. Positioning mount for a quadrupole or sextupole magnet.

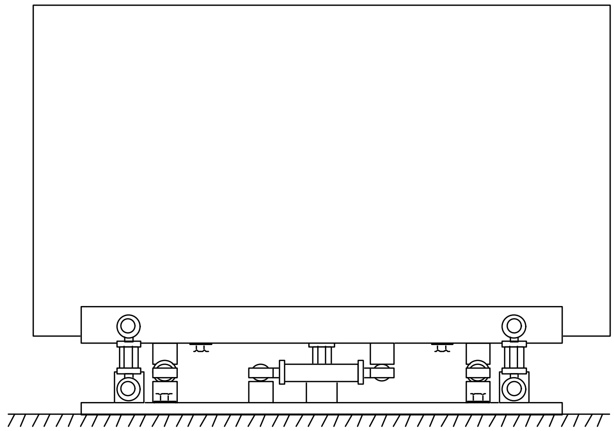

Figure 4. Positioning mount for a combined-function bending magnet.

3. ALIGNMENT OF THE ATF DAMPING RING

Magnets in the ATF damping ring were aligned with a 3-D mobile tracking system, Leica SMART 310, and conventional tools such as a theodolite, a Taylor-Hobson Micro-Alignment Telescope, a tilting level, and a bubble level. The SMART 310 is briefly explained below. Then we report on assembly of magnets on active support tables and alignment of the ATF damping ring.

3.1 SMART 310 [2,3]

The SMART 310 is a 3-D mobile tracking system. It includes a heterodyne-type laser interferometer, a rotating mirror with two angle encoders, and a position detector. Servo-motors in the tracking head turn the rotating mirror to direct the laser beam onto a target retro-reflector. The retro-reflector returns the beam to the rotating mirror along a line parallel to the path which the beam takes when it leaves the tracking head. Part of the returning beam is directed to the position detector. The position detector controls servo-motors to keep the beam on the target. The SMART 310 measures a distance to the target retro-reflector with the laser interferometer, and polar and azimuthal angles of the rotating mirror with two angle encoders. The distance resolution is 1.26 μm, and the angular resolution is 0.7 arc second (3.4 μrad) according to the specification. The accuracy of a coordinate is 10 ppm for a static target.

3.2. Assembly of magnets on active support table

We assembled magnets on 36 active support tables from July to September in 1996. Every magnet except for the combined-function bending magnet has a fiducial plane on its top. There are three fiducial holes to set a target holder on the fiducial plane. These fiducial holes are arranged in the radial direction, and are used to adjust a yaw of the magnet. The bending magnet has three fiducial plane with a fiducial hole on its top. Three fiducial holes of the bending magnet makes a bending angle of 10 . A target can be set on a magnet at the same level as other types of magnet by using a suitable target holder for each type of magnet. We use two types of target: one is a spherical Taylor-Hobson target for a Taylor-Hobson Micro-Alignment telescope and a tilting level, the other is a retro-reflector (Cat's eye) for the SMART 310. Because these targets have a spherical shape of 75 mm in diameter, they can keep the center position on a target holder. A target set on a target holder is treated as a fiducial point of the magnet. We repeatedly set target holders and a target ten times, and measured fiducial points of magnets on an active support table to estimate the setting error of the target. The setting error was better than 20 µm.

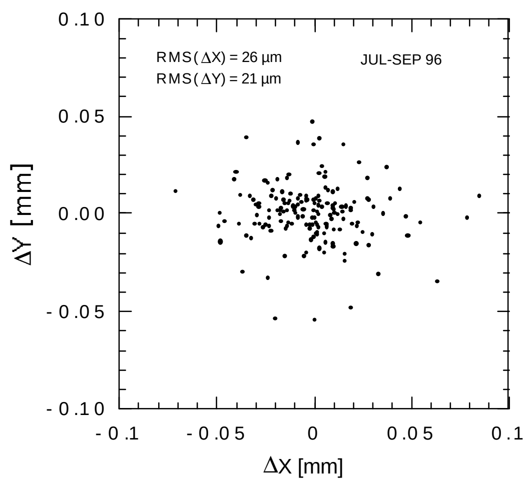

Figure 5. Positioning deviations in the radial and vertical directions after assembly of magnets.

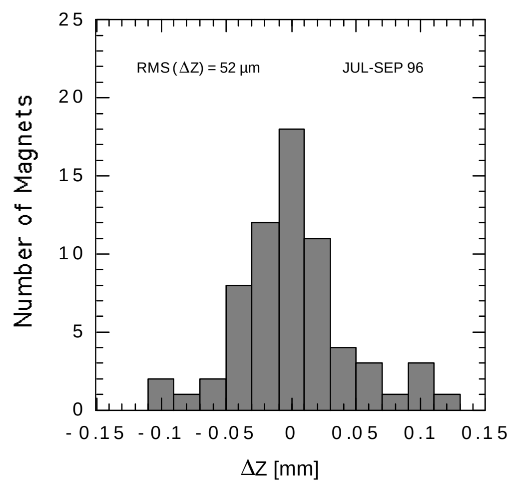

Figure 6. Positioning deviation in the beam direction after assembly of magnets.

There are two stages to assemble a set of magnets on the active support table: The first is rough alignment to install a vacuum chamber, the second is fine alignment with the SMART 310. The procedure of assembling magnets on a table is described as follows:

(1) There are fiducial holes at three corners on a table. A target is set with a target holder at these corners by turns, and the level of the table is adjusted with a tilting level.

(2) A roll and a pitch of each magnet on the table are adjusted with a bubble level put on the fiducial plane.

(3) The height of each magnet is adjusted with a tilting level.

(4) Magnets are roughly aligned with a theodolite or a Taylor-Hobson Micro-Alignment Telescope, a 600-mm vernier caliper, and a straight edge, and then a vacuum chamber is installed.

(5) The level of the table is adjusted again. The roll, pitch, and height of each magnet on the table are also readjusted. Finally, magnets are positioned horizontally with the SMART 310.

After assembly of a set of magnets on each active support table, fiducial points of magnets were measured with the SMART 310. The SMART data were compared with the CAD design data by fitting the CAD design data to the SMART data. Results of assembly of magnets on each table are shown in Figures 5 and 6. Figure 5 shows position deviations of magnets from the design in the radial (*X*) and vertical (*Y*) directions. The positioning errors (in RMS) are 26 μm and 21 μm in the *X* and *Y* directions, respectively. Figure 6 shows position deviations of magnets in the beam (*Z*) direction, and the positioning error in the *Z* direction is 52 μm.

3.3. Alignment of the ATF damping ring

Every active support table on which a set of magnets had been assembled was moved to its position marked on the floor. We used air pallets to move tables with less vibration. After moving, a roll and a pitch of every table were adjusted with a bubble level, and the height was adjusted to that of the beam transport line with tilting levels.

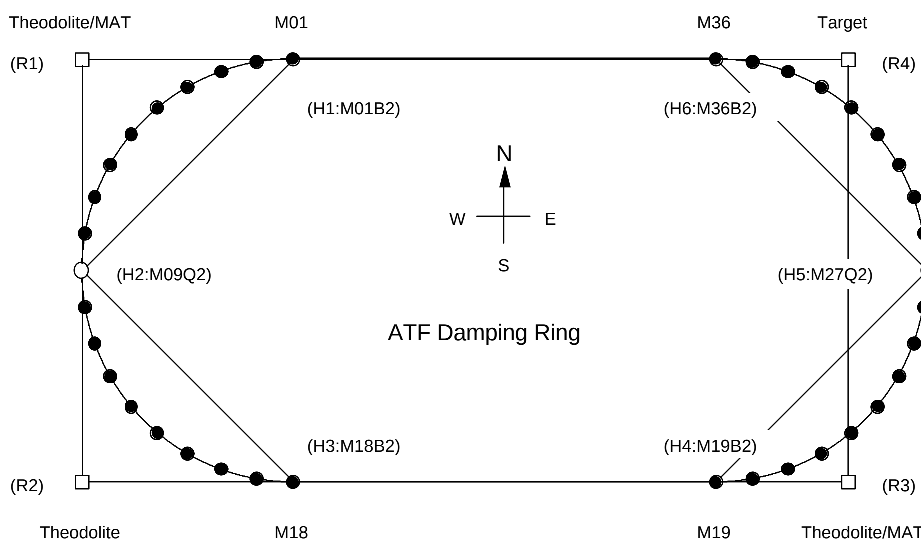

Figure 7. Alignment method of the ATF damping ring.

Reference marks on the floor of the ATF damping ring were marked by using theodolites and a steel measuring tape. There are four important reference marks, and they forms a rectangle (R1-R2-R3-R4) as shown in Figure 7. We transferred reference marks on the floor to fiducial points of magnets, and aligned the damping ring as follows:

(1) We put tripods, and settled a target or a theodolite at the reference marks of the rectangle. Theodolites were attached a target holder to set a target on their tops. Corner angles of the rectangle were measured with both a theodolite and the SMART 310, and distances were measured with the SMART 310.

(2) After investigating a distortion of the rectangle, six active support tables, M01, M09, M18, M19, M27, and M36, were positioned with the SMART 310 so that bending magnets and quadrupole magnets on these tables form a hexagon (H1-H2-H3-H4-H5-H6).
(3) The other tables in two arc sections were positioned with the SMART 310 by referring the hexagon.
(4) Quadrupole magnets in two straight sections were arranged into straight lines with Micro-Alignment Telescopes, and positioned with the SMART 310.

We finished the initial alignment of the ATF damping ring in January 1997, and positions of bending magnets were measured with the SMART 310. A typical distance between two hinge points (B2) of neighboring bending magnets is 2422.545 mm in the design. Figure 8 shows a difference of the distance measured with the SMART 310 from the design distance. The distance error is 144 µm in RMS. Figure 9 shows a deviation of a bending angle made by three hinge points of neighboring bending magnets from the design angle of 10 . The angular error is 0.0036 in RMS, and it is equivalent to a positioning error of 150 µm in the radial direction.

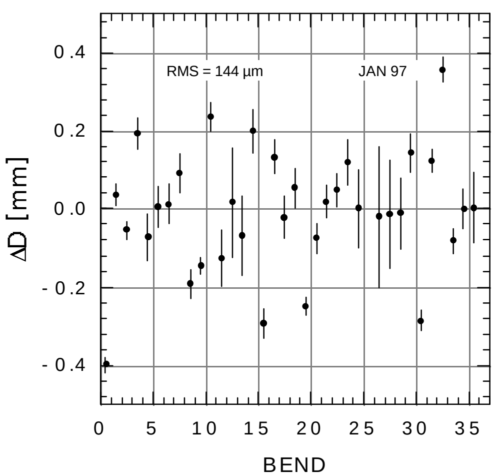

Figure 8. Distance between two bending magnets.

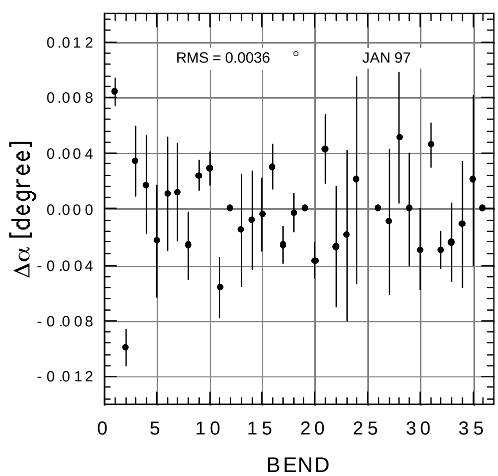

Figure 9. Bending angle made by three bending magnets.

Table 1. Positioning error of magnets on each active support table.

	Tolerance	Before moving	After moving
s_{DX} [µm]	90	26	37
s_{DY} [µm]	60	21	19
s_{DZ} [µm]	—	52	100

Positioning errors of magnets on each active support table are shown in Table 1. In this table, the positioning errors measured in May (after moving) are compared with those measured after assembly of magnets onto each table (before moving). The radial and vertical positioning errors are less than the tolerances. However, magnets on tables moved in the horizontal direction, especially in the beam direction, whereas they did not moved in the vertical direction. Therefore, the magnet positioning mount seems to be sensitive to vibration in the beam direction.

4. SURVEY OF THE ATF DAMPING RING

The level of the ATF damping ring was measured with tilting levels in March 1997, and a distortion of the level was found out. Furthermore, the outline of the damping ring was surveyed with the SMART 310 in January, May, July, and September. These surveys show a change in the circumference. We report on results of the survey of the ATF damping ring.

4.1. Level survey

The level of the whole damping ring was surveyed with tilting levels settled at 19 points by turns in March 1997. Figure 10 shows a height of bending magnets in two arc sections (circles) and a height of quadrupole magnets in the beam transport line (diamonds) and two straight sections (triangles), where offsets between 19 surveys are determined by fitting with a constraint that a sum of them is zero. Error bars indicate a standard deviation of mean value.

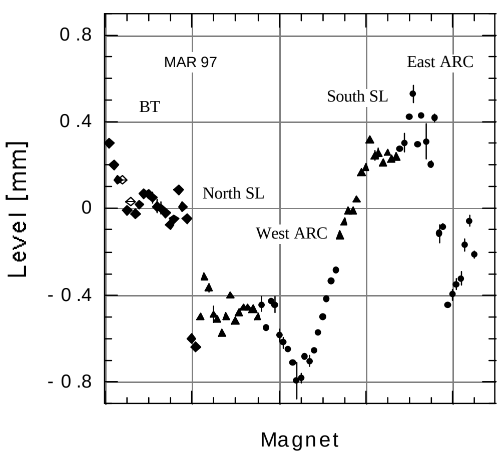

Figure 10. Level of the ATF damping ring in March.

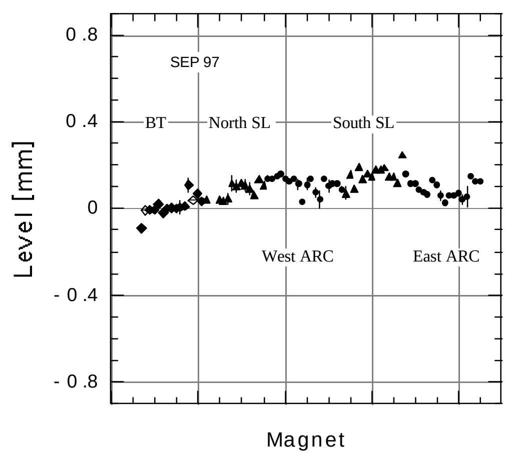

Figure 11. Level of the ATF damping ring after correction.

Because a huge distortion of the level was found out as shown in Figure 10, we corrected this distortion in August. First, the height of six active support tables forming the reference hexagon was adjusted to that of the beam transport line, then other tables and quadrupole magnets in two straight sections were adjusted. The height of magnets was adjusted within a range of about 200 µm as shown in Figure 11. We moved up most of active support tables in the West arc section, whereas we moved down most tables in the East arc section as shown in Figure 12. The level correction was opposite to the measurement in March. The level of the ATF damping ring seems to have been changing because of tunneling around the ATF during this summer.

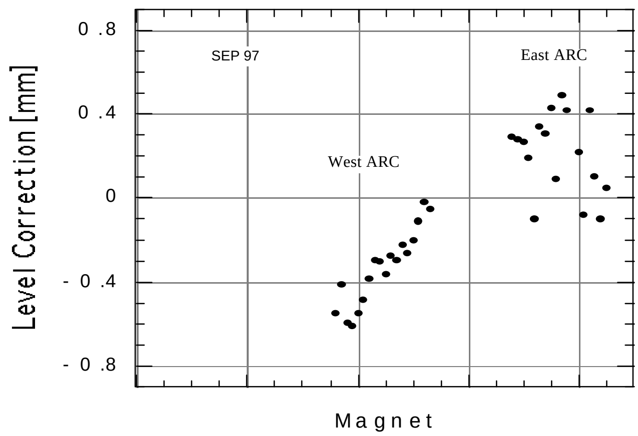

Figure 12. Level correction.

4.2. Circumference survey

The outline of the ATF damping ring was surveyed with the SMART 310 in January, May, July, and September. We investigated a distance between two neighboring bending magnets. The mean difference of the distance measured with the SMART 310 from the design, ΔD, and the standard deviation, $\sigma_{\Delta D}$, are shown in Table 2. The difference of the circumference from the design, ΔC, is also estimated by summing up ΔD. In addition, the mean difference of the bending angle made by three neighboring bending magnets from the design angle of 10°, $\Delta\alpha$, and the standard deviation, $\sigma_{\Delta\alpha}$, are shown. The bending angle did not change during eight months from January to September, whereas the circumference expanded by 6 mm from January to July, and shrank by 3 mm during the following two months. We actually operated the damping ring with a slightly lower RF frequency (Δf = –10 kHz) in July. This change of RF frequency was consistent with the circumference expansion. If this change of circumference simply comes from the thermal expansion of the floor, the temperature of the floor must have increased by 5 K. We have started to measure floor and room temperatures at several places in the damping ring.

Table 2. Deviations of the distance between two bending magnets, the circumference of the damping ring, and the bending angle made by three bending magnets from the design.

	JAN	MAY	JUL	SEP
ΔD [µm]	1 ± 25	63 ± 30	118 ± 37	48 ± 33
$\sigma_{\Delta D}$ [µm]	144	173	197	190
ΔC [mm]	–0.33 ± 0.40	2.71 ± 0.28	5.77 ± 0.50	2.76 ± 0.55
$\Delta\alpha$ [$\times 10^{-3}$]	–0.1 ± 0.6	–0.2 ± 0.5	0.0±0.6	0.8±0.7
$\sigma_{\Delta\alpha}$ [$\times 10^{-3}$]	3.6	3.1	3.4	3.7

5. SUMMARY

Reference marks on the floor of the ATF damping ring were transferred to the six fiducial points of magnets by using a 3-D mobile tracking system, Leica SMART 310. The other magnets were aligned by referring to these six fiducial points of magnets. Thus a set of magnets on every active support table are aligned vertically with s_{DY} = 19 µm and horizontally with s_{DX} = 37 µm, whereas the positioning error between two active support tables is about 150 µm.

We have two problems in regard to the alignment of the ATF damping ring. First, the floor level seems to be changing within a range of ±1 mm during a half year. Second, the circumference of the damping ring is also changing by 6 mm during a half year. We have started to investigate these causes.

References

[1] F. Hinode, et al., “ATF Design and Study Report”, KEK Internal 95-4 (1995).

[2] Leica, “SMART 310 How to use” (U2-248-0EN III.95).

[3] Leica, “SMART 310 Hardware Guide” (U2-259-0EN III.95).