TUNNEL AND MAGNET SURVEY OF KEKB AFTER TEN YEARS OF OPERATION

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Abstract

KEKB is a double-ring collider with a circumference of 3016 m [1]. The two rings were built side-by-side in the TRISTAN tunnel, 12 m below ground. KEKB has been operating successfully for more than 10 years, since 1999, and its peak luminosity continues to improve. During the summer shutdown of 2008, the magnet tilts were measured for the first time since installation and it was found that some magnets were rotated over time. The tunnel level marker was also surveyed. The south region of the tunnel continues to sink. The survey results are reported in this paper.

INTRODUCTION

The KEKB tunnel is composed of four straight sections called Tsukuba, Oho, Fuji and Nikko from and four arc sections called the North, East, South and West arc sections as shown in Fig.1. The arc sections of the tunnel are founded on a gravelly diluvial layer 12 m below the ground level (GL). The basement floors of the four experimental buildings are located ~16 m below GL. Because this depth consists of a diluvial clay stratum, the experimental buildings are built on pile foundations. The piles extend to a gravelly layer about 40 m below GL. The four straight sections between the arc sections and the experimental buildings are built on pile foundations as well. There are expansion joints every 50-60 m in the arc and straight sections.

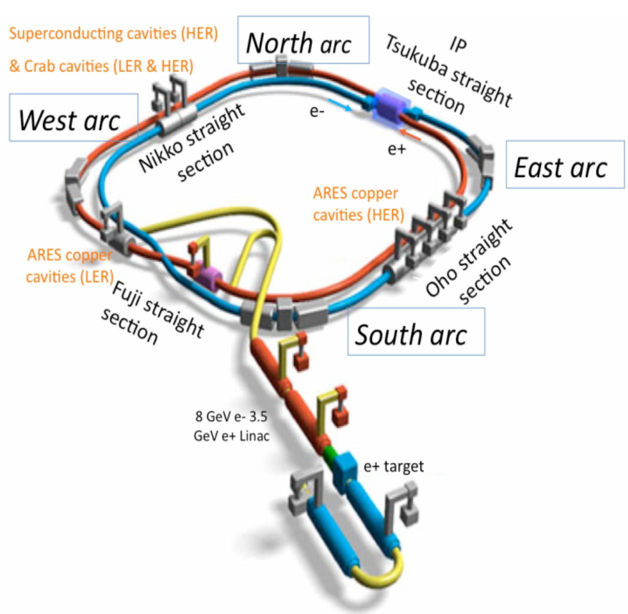

Figure 1: KEKB tunnel. The 8 GeV electron beam circulates clock-wise and the 3.5 GeV positron couterclock-wise.

TUNNEL LEVEL SURVEY

Before the construction of the KEKB ring, the level of the TRISTAN quadrupole magnets was marked on the tunnel wall as a reference level. The survey in 1997 showed that the South arc section was lower than the interaction point (IP) in the Tsukuba straight section by ~18 mm [2]. This was once corrected at the beginning of the KEKB construction in 1997. The tunnel markers have been surveyed once a year during the summer shutdown since the beginning of the KEKB operation and it is shown that the South arc section continues to sink. Fig.2 shows the survey results for the six year period of 2003-2008. The marker levels are plotted against the distance *s* (m), the counter-clock wise distance from the IP. The level change is smaller at Nikko and Fuji experimental buildings, which indicates that the 40 m pile foundation has been effective to stabilize the tunnel motion. The largest sinking over 10 years is measured to be ~23 mm, which is observed at the location where s ~ 1800 m. There are a couple of potential explanations as to why the South arc section continues to sink, one is the underwater pumping by the wells near by, and the other is the concentration of the buildings over the South tunnel. There has not been any clear explanation determined yet.

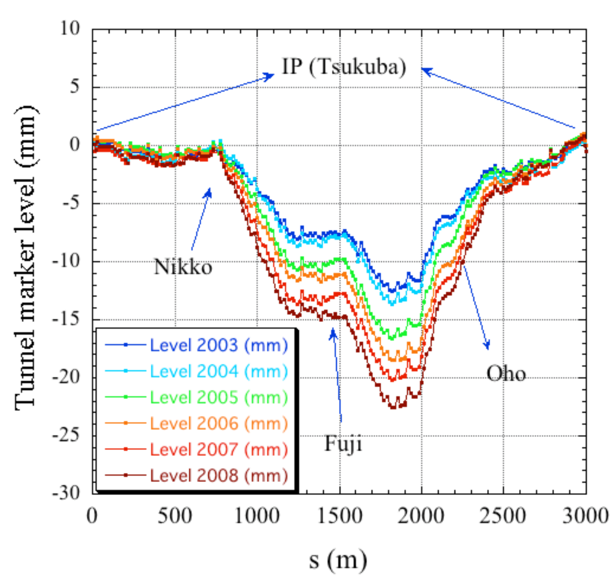

Figure 2: Marker positions measured along the tunnel.

MAGNET TILT MEASUREMENT

The magnet tilt angles θ around the beam axis and ϕ around the horizontal axis perpendicular to the beam were measured during the winter and summer shutdown periods of 2008 for the first time in 10 years after the

KEKB construction. The tilt measurement was done for dipole, quadrupole and sextupole magnets in both HER and LER. Two reference bases shown in Fig. 3 were used for the measurement. The KEKB magnets were originally aligned using a Carl Zeiss level for a higher accuracy. A digital level with a minimum reading of 10 μrad was used for the survey this time, mainly to save time and man power.

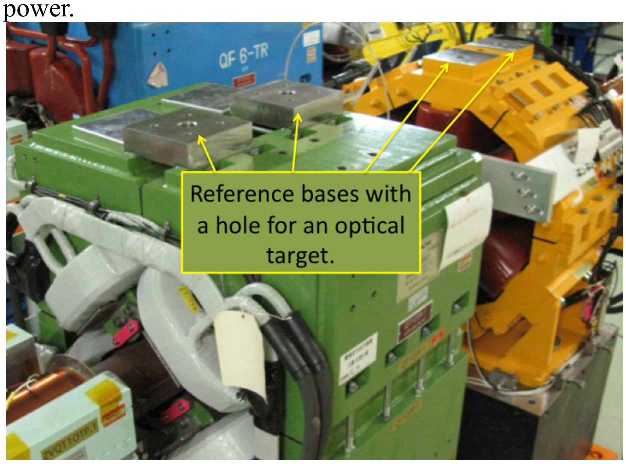

Figure 3: Magnet reference bases for alignment. There are two reference bases per magnet for defining the magnet axis along the beam line.

Fig.4 shows the magnet tilt angle θ plotted as a function of s for the HER and LER quadrupole magnets. The sign of the rotation angle is defined to be positive when the magnet is tilted toward the center of the KEKB ring. It is seen that the magnets are tilted large at s ~1300 m. The cause of this is explained in the following section. The magnets were intentionally tilted by 80 μrad in order to compensate for the earth curvature at the initial alignment and this offset is subtracted in all the plots in this paper. The small number of events in the tail of the histogram in Fig.5 correspond to the magnets at s ~1300 m. The tilt angle θ measured for the sextupole and dipole magnets are plotted as a function of s in Fig. 6 and Fig. 7, respectively, where a large error is also found at s ~1300 m. Even though the HER and LER magnets are placed on a common concrete floor, the sign of the magnet tilt is opposite in this region. The HER magnets, which are located at the inner side of the tunnel at s ~ 1300 m, are tilted toward the ring center (θ positive) while the LER magnets are tilted oppositely.

Table 1: Magnet tilt θ in mrad. Q,Sx,B and σ represent quadrupole, Sextupole, Dipole magnets and standard deviation, respectively.

Magnet type	*Average*	σ	σ *(tolerance)*
Q(HER)	0.00	0.09	0.2
Q(LER)	0.02	0.11	0.2
Sx(HER)	-0.01	0.10	0.2
Sx(LER)	0.02	0.12	0.2
B(HER)	0.01	0.07	0.1
B(LER)	-0.02	0.09	0.1

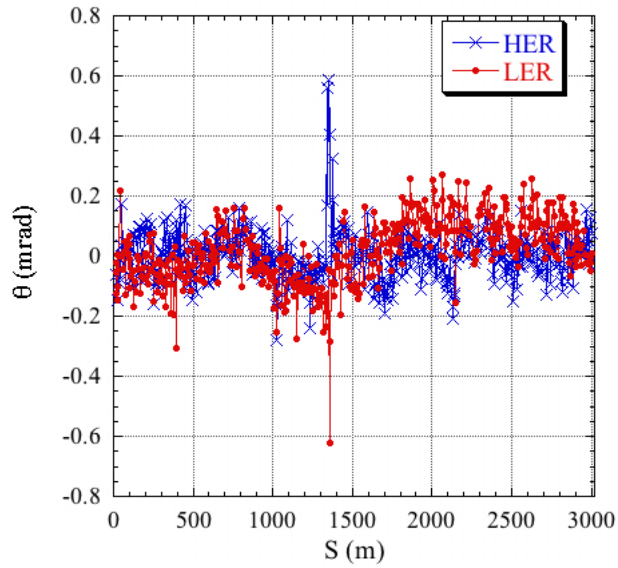

Figure 4: Quadrupole magnet tilt θ. The average of two reference bases is plotted for each HER/LER magnet against s.

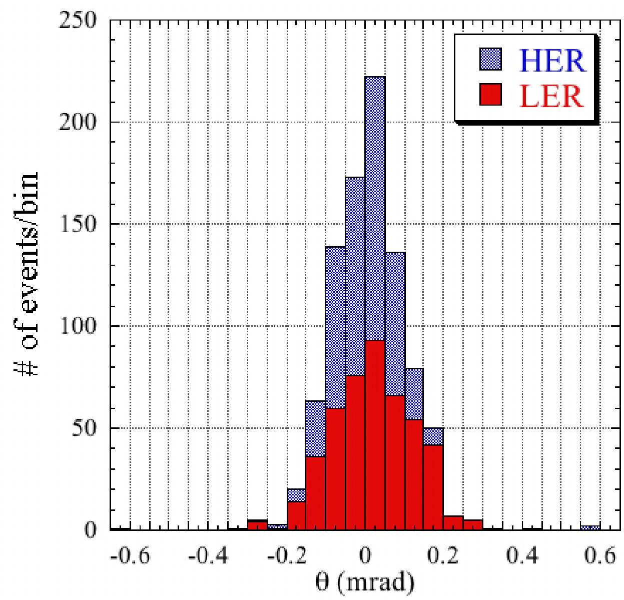

Figure 5: Histogram of magnet tilt θ for HER and LER quadrupole magnets.

The average and standard deviation of θ are summarised in Table 1 with the tolerances given in the KEKB Design Report [1] for each type of the magnets. The magnet alignment has become worse over ten years of operation, though it still satisfies the tolerance given in the KEKB Design Report. It seems that the LER magnets suffered more degradation in alignment than the HER magnets, independent of the magnet type. The reason for this is not understood at this point. The LER magnets are smaller and therefore lighter than the HER magnets, by a factor of 2 or more, for the quadrupole magnets, for example. This might be causing the LER magnets to move or slip more easily than the HER magnets.

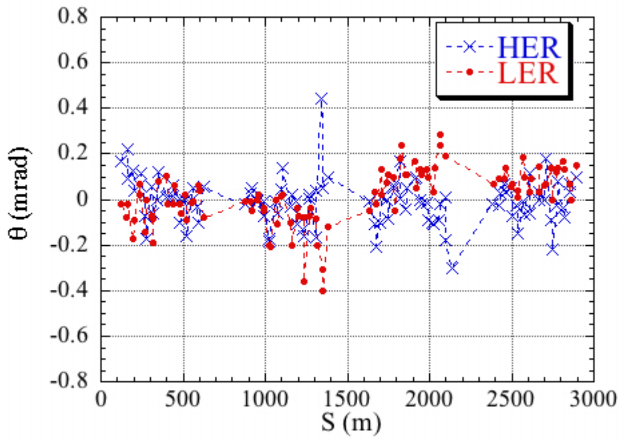

Figure 6: Sextupole magnet tilt θ vs. s.

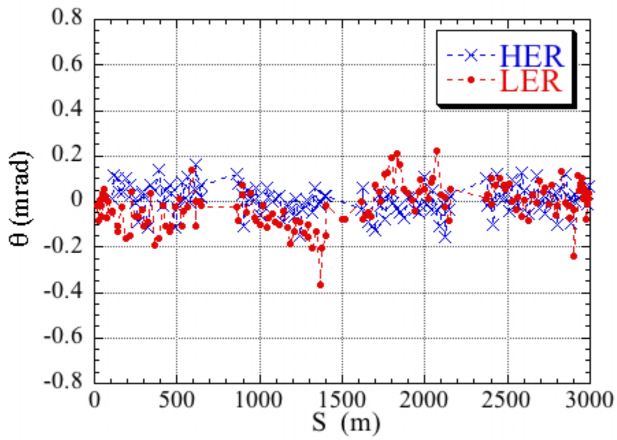

Figure 7: Dipole magnet tilt θ vs. s.

CAUSE OF THE LARGE MAGNET TILT

The tunnel floor was examined in the west arc section in order to find a possible cause of the large magnet tilt at s ~ 1300 m. Many cracks were found on the concrete floor, some in between the HER and LER magnets which extends for more than a few tens of meters. These cracks between the HER and LER magnets are probably the cause of the opposite signed tilts of the HER and LER magnets. The cracks were most likely created by the tunnel deformation caused by the PF-AR construction [3] near that particular area of the KEKB tunnel in 2001.

Fig.8 shows the PF-AR construction site and one of the cracks found in the KEKB tunnel at $s \sim 1300$ m.

Figure 8: The PF-AR construction and one of the cracks found in the KEKB tunnel.

SUMMARY

The tunnel level survey results show that the south arc section of the KEKB tunnel continues to sink with an average speed of 2 mm/year.

The magnet tilt was measured for the first time in the 10 years of KEKB operation using a digital level for all the quadrupole, sextupole and dipole magnets in both HER and LER. It was found that the magnets in a certain part of the KEKB tunnel in the west arc section were tilted much more than the original alignment locally. The HER and LER magnets, which are placed side-by-side, were tilted oppositely. Large cracks found on the tunnel floor between the HER and LER magnets in that area of the tunnel indicate that the tunnel was deformed in the past, probably during the PF-AR construction in 2001. The magnets in this section were realigned during the summer shutdown.

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REFERENCES

[1] KEKB Design Report, KEK Report 95-7, August 1995.

[2] R. Sugahara et al, “Status of KEKB”, International Workshop on Accelerator Alignment, SPring-8, 11-14 November 2002; http://www.slac.stanford.edu/econf/C0211115/

[3] Design Report on Advanced Ring for Pulse X-rays (PF-AR), KEK Report 97-2, May 1997.