CIRCUMFERENCE VARIATIONS OBSERVED AT KEKB

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1. INTRODUCTION

KEKB is a two-ring collider with a circumference of about 3016 m [1]. The two rings were built side-by-side in the TRISTAN tunnel. There are four experimental buildings called TSUKUBA, OHO, FUJI and NIKKO as shown in Fig. 1. The 8-GeV electron ring (HER) and 3.5GeV positron ring (LER) cross at one interaction point (IP) at TSUKUBA, where the BELLE detector [2] collects physics data. The KEKB construction was completed in November 1998 and the commissioning of the HER followed in December. The physics experiment started in June 1999 and the luminosity has been improving steadily since. The peak luminosity exceeded 80% of the design value of $10^{34}/cm^2/s$ in October 2002.

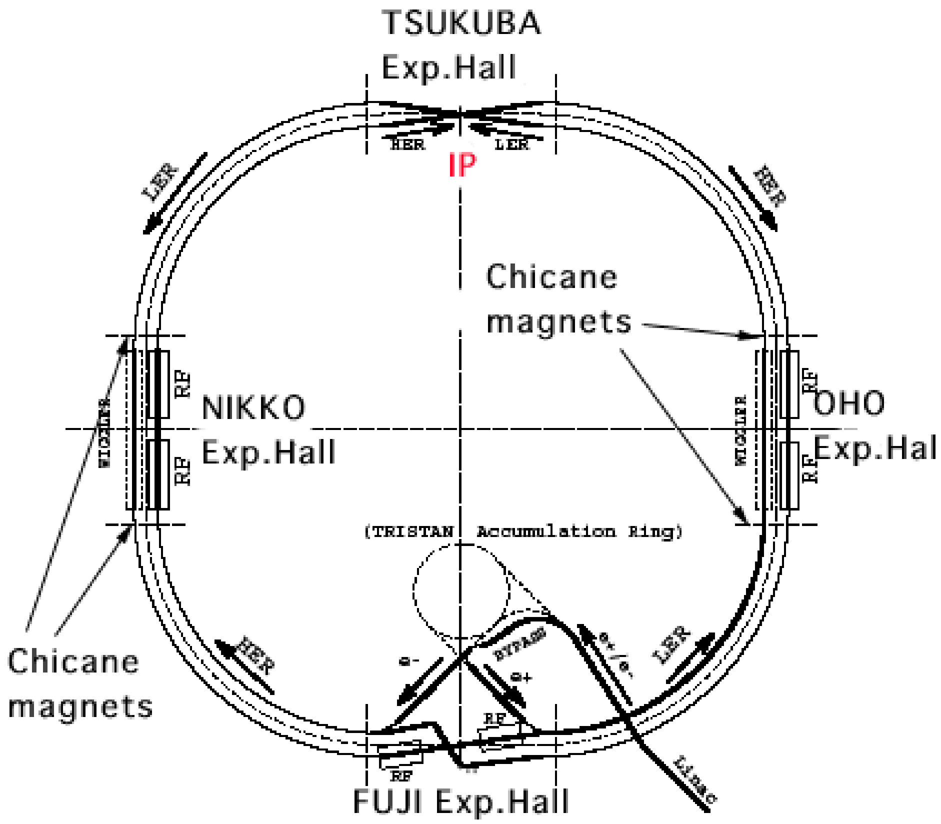

Fig. 1. KEKB tunnel. Two beams collide at the IP at Tsukuba Hall.

Various tuning tools have been developed in order to achieve higher luminosity and to keep the optics errors as small as possible. Adjusting the circumference is one of such tools. A change in circumference length leads to a horizontal orbit drift which causes serious optics errors. The circumference variations observed during the KEKB operation in 2002 are discussed in this paper.

2. TUNNEL SITE

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. The ground retains a large amount of water, which is pumped up at the rate of several hundred tons per day.

3. MEASUREMENT AND CORRECTION METHODS

The circumference deviation from a reference orbit is obtained by measuring the closed orbit distortion (COD). An orbital feedback system called CCC (Continuous COD Correction) [3] adjusts the circumference length every 10-20 seconds. The circumference adjustment feature using the chicane magnets in the LER was first employed in the CCC in June 2001 and has been used continuously since. The circumference of the two rings can also be adjusted by changing the beam revolution frequency. The frequency adjustment is not performed as frequently as the chicane adjustment.

3.1 Measurement methods

The momentum deviation ΔP from the reference momentum P_0 is obtained by the following equation, where η_i is the design horizontal dispersion and x_i is the measured horizontal beam orbit at the *i-th* beam position monitor.

$$\Delta P/P_0=\Sigma_i x_i \eta_i \,/\Sigma_i \eta_i^2$$

The momentum deviation $\Delta P/P_0$ is translated into the circumference deviation ΔC by the momentum compaction factor α, which is 3.4×10^{-4} for the current optics. C_0 represents the design circumference in the following equation.

$$\Delta C=\alpha \cdot \Delta P/P_0 \cdot C_0$$

The circumference deviation ΔC is measured independently for the LER and the HER.

3.2 Correction methods

There are four sets of chicane magnets, located on both sides of the NIKKO and OHO straight sections in the LER. Each set consists of four bending magnets. By changing the magnetic field strength of the chicane magnets, the beam path length can be adjusted while the resulting dispersion and orbit bumps remain localized within the chicanes. The chicane magnets were originally used to compensate for the circumference difference between the LER and the HER. They have also been used to keep the LER circumference constant since June 2001.

4. CIRCUMFERENCE VARIATIONS

A long-term drift has been observed in the circumference length variations. Semi-diurnal tidal effects from the sun and the moon have also been observed. An expansion of about 200 μm was seen when Typhoon 21 hit the area. These variations are described in this section.

4.1 Circumference Drift

The circumference drifted about 2.5 mm from March 1 to June 30, 2002, as is shown in Fig. 2. Atmospheric pressure, well depth at a location near the tunnel, roof temperature of the building between the OHO and FUJI experimental buildings and the outside air temperature are plotted for the same period.

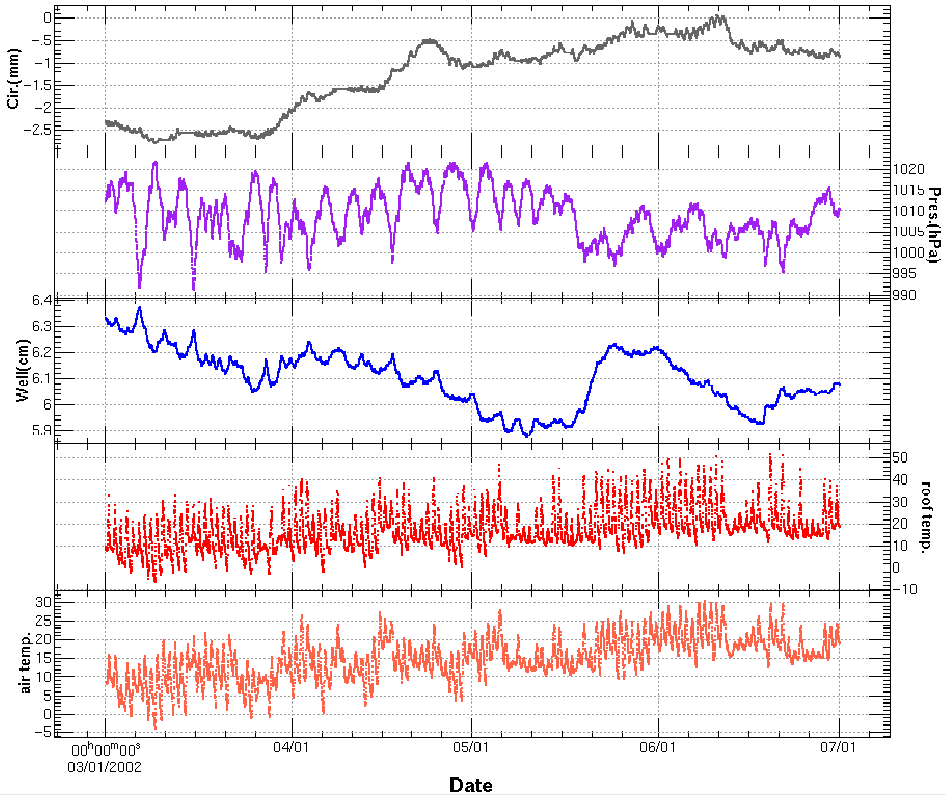

Fig. 2. LER Circumference drift.

In order to remove the short term (daily) effects from the plots in Fig. 2, the daily minimum and maximum circumference lengths are plotted against the daily lowest and highest outside air temperatures in Fig. 3. Figure 4 shows the correlation between the circumference and the temperature (seasonal effect). The circumference expands as the outside temperature becomes higher though the correlation plots have rather wide spreads. The wide spreads might indicate some time lag between the two variables. The mechanism for the outside temperature to have some correlation with the circumference is not understood. However, while the KEKB tunnel is located 12 m below the ground surface, it is connected to the outside via the four experimental buildings.

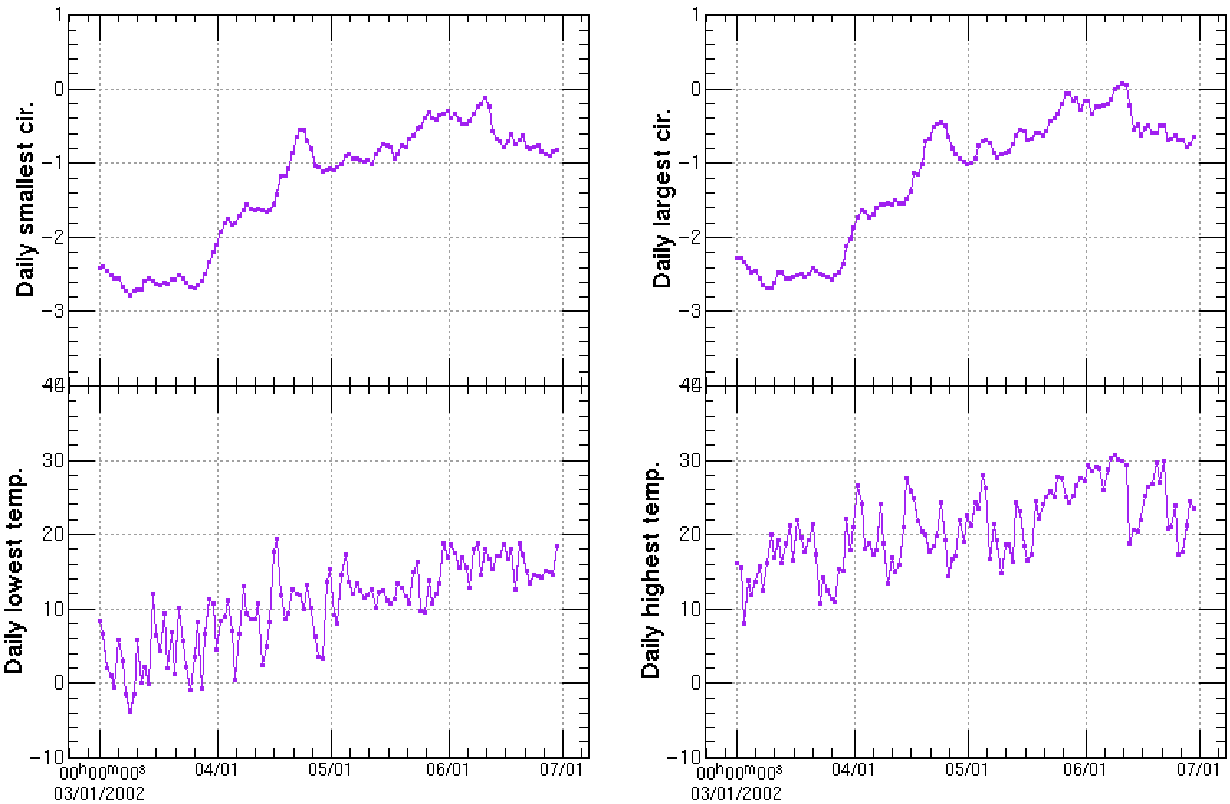

Fig. 3. Daily minimum and maximum Δcircumference lengths in millimeters (top) and daily lowest and highest outside air temperatures (bottom) from March 1 to June 30, 2002.

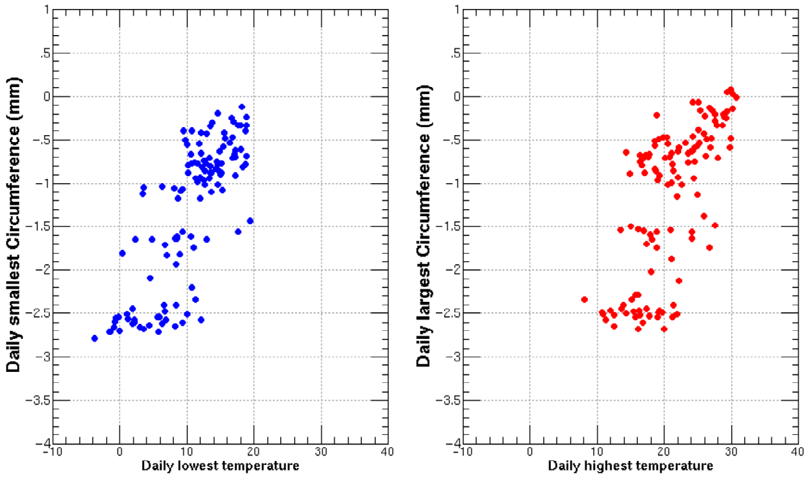

Fig. 4. Daily minimum and maximum Δcircumference length vs daily lowest and highest outside air temperature.

4.2 Tidal Effects

A spectrum analysis of the circumference data was performed and is shown in Fig. 5. There are two clear peaks around the frequency 2/day. The frequency of the larger peak is 1.932/day, which agrees with the lunar semi-diurnal tide as shown in Table 1 [4]. Its amplitude is measured to be about 15 μm. (Tidal effects have been reported at Spring-8 as well, with approximately the same amplitude [5].) The lower peak corresponds to the solar semi-diurnal tide and its amplitude is about 10 μm. The ratio of lunar semi-diurnal tide to solar semi-diurnal tide is 1.5, which is smaller than that expected from the ratio of the lunar and solar tidal potentials. ($M_m/M_s \cdot (R_s/R_m)^3 \sim 2.2$, where M_m, M_s, R_m and R_s represent the mass of the moon, the mass of the sun, the distance between the earth and the moon and the distance between and the earth and the sun, respectively [4].) This is probably due to the leakage of the higher harmonic component of the large peak at 1/day. The peak at 1/day is several times larger than the expected contributions from the diurnal tides. Temperature is suspected to be the cause for this enhancement but no quantitative analysis has been done.

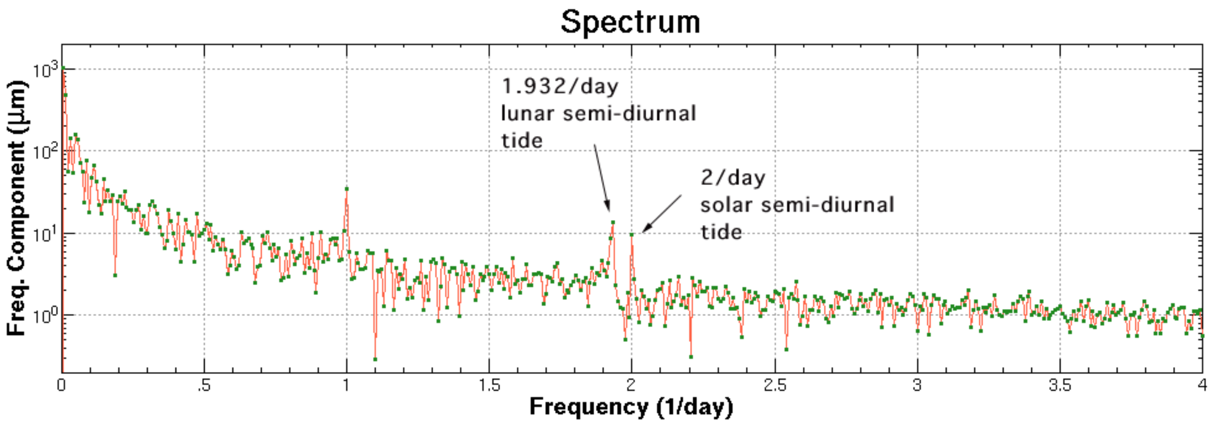

Fig. 5. Spectrum analysis of the circumference.

Table 1

Tidal potential parameters at equilibrium by Mund and MacDonald (1960) [4]. O1, K1, M2 and S2 represent principal lunar diurnal, luni-solar diurnal, principal lunar semi-diurnal and principal solar semi-diurnal components, respectively. θ represents the angle from the north pole(90 degrees – latitude).

period	symbol	period(hours)	frequency(1/day)	amplitude	latitude correction to amplitude
1/day	O1	25.82	0.9295	0.377	sinθcosθ
	P1	24.07	0.9971	0.176	
	K1	23.93	1.0029	0.531	
1/2day	N2	12.66	1.8957	0.174	1/2 sinθsinθ
	M2	12.42	1.9324	0.908	
	S2	12	2	0.423	
	K2	11.97	2.005	0.115	

4.3 Effects of Typhoon 21

The circumference expanded about 200 μm over a several hour period when Typhoon 21 hit the area on October 1st as shown in Fig. 6. It should be pointed out that the pressure drop was rather rapid, compared to the usual movement of low pressure systems. The other environmental variables are also plotted in Fig. 6. The well depth changed rapidly when the atmospheric pressure dropped. It could be argued that the circumference expanded because of the uprising of the underground water level. Figure 7 shows the well depth variation over a longer term. The water level went up by about 0.5 cm after the Typhoon and stayed high until the end of October. If well depth is the main source for the circumference expansion, we should see a similar trend in the circumference plot. The longer trend graph of the well depth and the circumference indicate no strong correlation between each other, however. Atmospheric pressure seems to have caused the temporary circumference expansion.

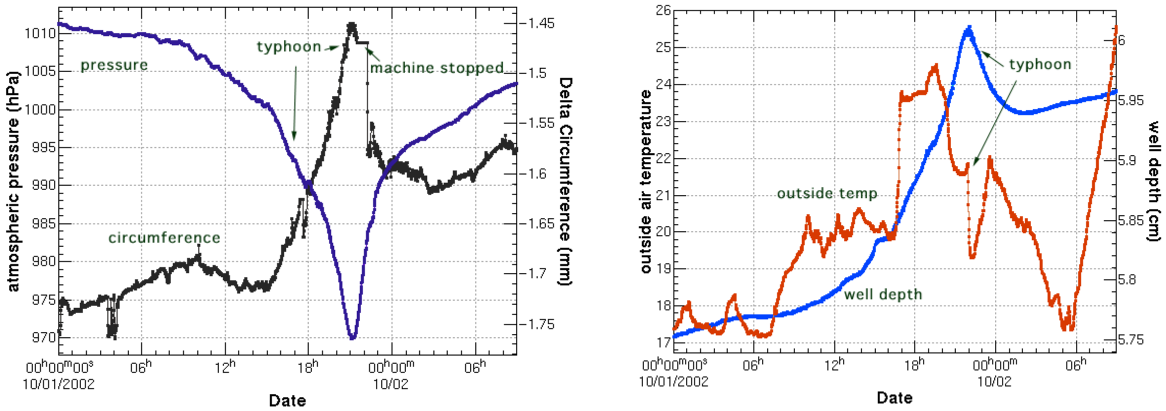

Fig. 6. Atmospheric pressure and Δcircumference (left) and outside air temperature and well depth (right) from October 1st to 2nd .

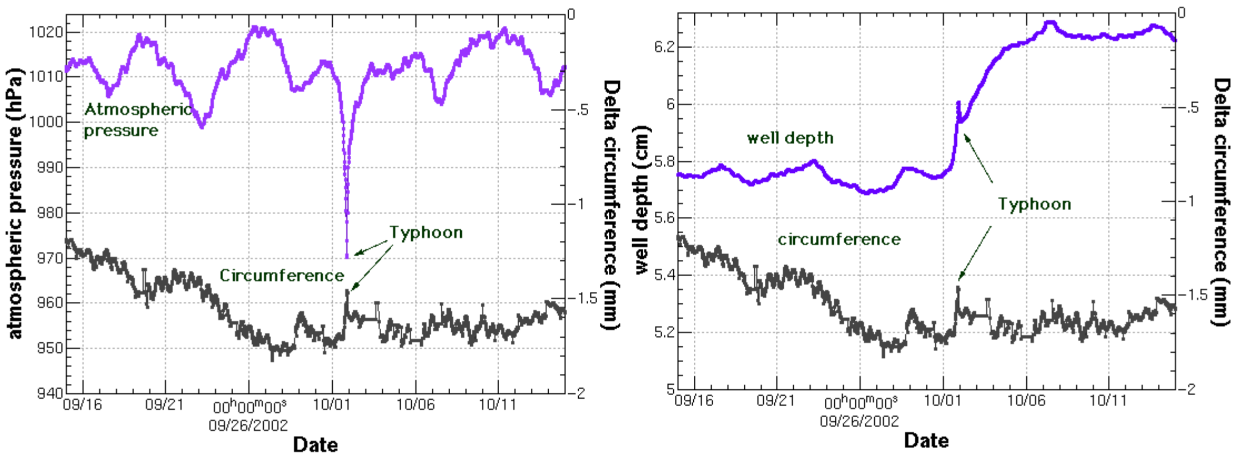

Fig. 7. Longer-term variations of atmospheric pressure, circumference and well depth. No strong correlation between the well depth and the circumference is seen.

5. CONCLUSION

Tidal effects have been observed in circumference variations at KEKB. Lunar and solar semi-diurnal tidal effects have been clearly distinguished. The diurnal component observed in the circumference variation is several times larger than the expected diurnal tidal effect. The outside air temperature might be the main source of the enhancement. A long-term drift in circumference has also been observed. This drift shows more correlation with the outside temperature than with other observed environmental variables. The circumference temporarily expanded by about 200 μm when Typhoon 21 hit the area. The expansion coincides with the corresponding rapid atmospheric pressure drop. Further analysis is required to quantify the contribution of each environmental parameter on the expansion and contraction of the circumference of the rings.

6. REFERENCES

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