Survey of the SuperKEKB main ring after the Great East Japan Earthquake

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3. Summary
1. Introduction

• SuperKEKB overview
• Preparation for SuperKEKB magnet alignment
Replace dipoles with longer ones (LER).
Change the wiggler layouts, add more wigglers LER & HER.

Tighter tolerances alignment around the IP
Vibration more critical

Low emittance electrons to inject
Low emittance positrons to inject

New positron target / capture section

\[ L = \frac{\gamma \pm \frac{\sigma_y^*}{\sigma_x^*}}{2e_r e} \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \left( \frac{\beta_y^*}{R_y^*} + \frac{\beta_y^*}{R_y^*} \right) \]

~40 times gain in luminosity
1. Introduction

- SuperKEKB overview
- Preparation for SuperKEKB magnet alignment

Sections with totally different magnet layouts (IR & straight sections)
removal of the KEKB magnets & installation of the new magnets.

The rest of the magnets, about 2/3 of 2000 magnets, mainly in the arc sections, were planned to be used as good and reliable reference points of the network.

LER arc sections dipole magnets (~100) replaced by larger (~4m) ones.
Oct. 28, 2010  Dismantling KEKB LER dipole started

Director general A.Suzuki, director K.Oide etc., untightened the bolts.
Preparation for SuperKEKB magnet alignment
Improving the survey network

Our tunnel is ~3 decades old.
It has served two generations of accelerators,
TRISTAN (single ring) & KEKB (double ring, more crowded).
Lots of junk (cables, pipes,...) ➔ not much space, especially
on the cable rack side.
Very difficult to find space for stable monuments.

New monuments installed on wall and floor.

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The surveying network was constructed as a series of unit rectangles, \(~8\) m in length and \(~2\) m in width. One \(~32\) m-long area (4 unit rectangles) was covered by one tracker setup (station). More than 400 setups to survey the 3 km tunnel.
Preparation for SuperKEKB magnet alignment
Comparison with the design (magnet positions)

The 3 km tunnel was found to be deformed.
This was not a serious problem for KEKB, the preceding project, as the “wavelength” of the deformation is larger than those of the beta functions.

All monuments (new and old) were surveyed to establish their positions, which we were going to use for aligning the new magnets for SuperKEKB. BUT...

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Luminosity boost by colliding super-small beams ($\sigma_y \sim 60$ nm at the IP)

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First beam in JFY 2014

Earthquake
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2. After the earthquake

1. After the earthquake
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A few weeks after March 11th

We were not allowed to go in the tunnel for about a week. We were ordered to stay at home. Some of us did not even have water, lights for a few days. This is nothing compared to what people in the Tohoku area experienced.

The KEK computer system went down and was unusable for a very long time.

We went into the tunnel and did the tunnel level survey and the magnet tilt measurements first, using flashlights at the end of March.

There was also a severe electricity shortage due to the Fukushima nuclear power plant accidents...
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Visible structural damage

Tunnel damage concentrated at exp. joints.

Thermal expansion joints every ~70 m along 3 km.
Visible structural damage

Underground water leaks found in many locations.

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Evidence that magnets moved. The magnets, which we had planned to use as reliable survey reference points, had moved... sigh.
Liquefaction of the ground caused by earthquake? Is the foundation strong enough for a nano-beam collider?

→ Talk by H. Yamaoka this afternoon.

Visible structural damage

The ground above the south arc section of the tunnel. Not as bad as at J-PARC, but still...
Some magnets in the storage area were damaged.
2. After the earthquake

1. After the earthquake
   • Damage
     • Tunnel structure (Main ring)
     • Beam line deformation
     • Survey by laser trackers
     • Level survey by N3
Survey work in presence of thousands of aftershocks

Ibaraki prefecture, where both J-PARC & KEK are located.

SuperKEKB construction must resume.
A quick survey of part of the tunnel done in June 2011, while still shaky, to get some idea of the extent of tunnel (beam line) deformation.
Re-Survey started in April 2012, to re-construct the survey network.

# of earthquakes /month

http://tau.f2u.com/equake/

Not quiet yet.

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Aftershock captured by our camera on April 16th. Not a big one, but...
Aftershock captured:
See how the tunnel sections shake and hear the noise.
A quick survey around the IP & the south arc tunnel in June, 2011

Compared with the 2010 data.

8mm shift

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~8 mm shift indeed.
A quick survey around the IP & the south arc tunnel in June, 2011

Each tunnel section shifted randomly at the expansion joints.

South arc tunnel
Level survey by N3

South arc keeps sinking (or is it the IP keeps rising??).

Will the sinking accelerate due to the earthquake?

➔ Level monitor is needed.
➔ HLS (by T. Kawamoto)
Survey 2012
Re-survey of the entire tunnel a year after the earthquake

Is the tunnel still moving?
When will the tunnel settle?
Surveyed magnet position comparison before (2010) and after the earthquake (2012).

Circumference seems to have become longer due to the earthquake.

Magnets shifted in the NS direction more than in EW direction.
Local deviations of the magnets from the design positions are large at the expansion joints between the straight sections, which have pile foundation, and the arc sections, which do not have piles. These types of local deviations need to be fixed.
Circumference estimated by measuring the distances between quadrupole magnets using TS30, ME5000 and LT.
The tunnel did seem to have been expanded in July 2011, $\Delta \sim 30$ mm.
But is now settling to a level of about $\Delta \sim 15$ mm.
Data from Geospatial Information Authority of Japan (GSI)

GPS point Near KEK
Survey network above ground: First attempt by KEKB

TS30 would be good but there are trees and buildings everywhere, and it can only be partially used.

GPS network has been installed.

⇒ Poster by H. Iinuma
• Eight GPS antennas are mounted on the roofs of the access buildings of the SuperKEKB main ring (3C, 6C, ....) which can access the KEKB tunnel.
• As a fixed point, we use one of the GPS-based control stations (Tsukuba-1) of the Geospatial Information Authority of JAPAN (GSI).
• Distance between Tsukuba-1 and KEKB is 5 km.
• Stability of slope distances between GPS antennas reaches the sub-millimeter level.
• Preliminary analysis indicates good agreement between the GPS network and the underground tunnel network (within 3 mm).

GPS: Leica Geosystems (GS10) L1, L2
Position accuracy: horizontal <3mm, vertical <6mm (from the spec sheet)
3. Summary
The survey network that we prepared in 2010 for the new project, SuperKEKB, was destroyed by the March 11^{th} earthquake. Damage is concentrated at the tunnel expansion joints. The tunnel kept moving for a while but it seems to be settling.

We added more HLS in the south section of the tunnel, which we know has continued sinking over many years. A GPS network was installed and has started operating, in order to compare with the underground survey results by LT, and to monitor the tunnel deformation.

We have to realign ~2000 magnets in the tunnel...
  - We do not need to realign the majority of the magnets exactly to the design positions.
  - We do need to smooth out the local deviations.
  - The interaction region, though, need more precise alignment.
  - Vibration issues to be solved at the IR (poster by H.Yamaoka)
We thank you for all the concern and encouragement after the earthquake.

Any advice/help (sensors) is (are) appreciated.