P4

Attempt to measure building deformation using crack displacement transducers

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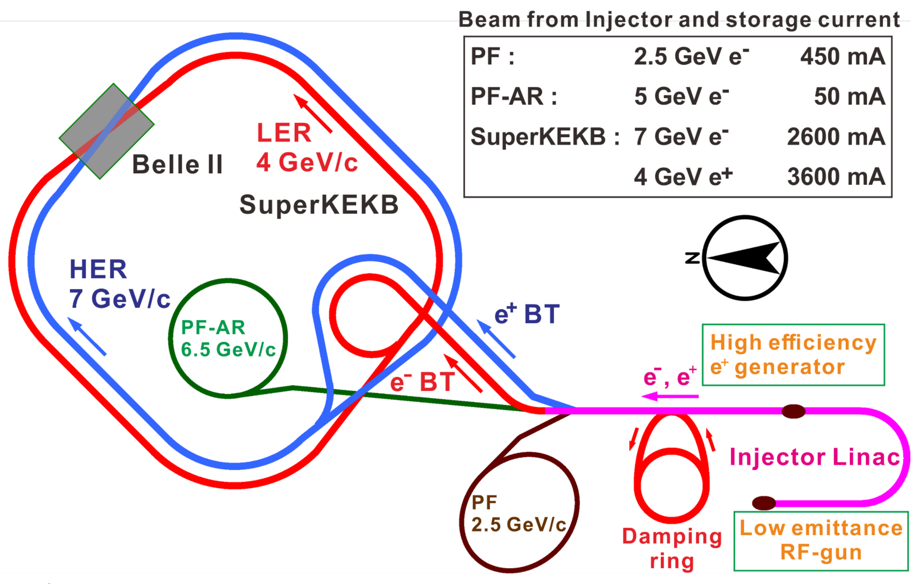
1. Introduction



KEK accelerator complex in Tsukuba :
- Injector linac
- Photon Factory (PF)
- Photon Factory Advanced Ring (PF-AR)
- SuperKEKB HER (e^-) / LER (e^+)

SuperKEKB has set the challenging goal :
"e^- / e^+ collision luminosity of 10^{35} cm^{-2} s^{-1}"
→ Stable e^- / e^+ beams required w/ low emittance :
e^- : 100 (Hor.) / 15 (Ver.) μm
e^+ : 40 (Hor.) / 20 (Ver.) μm

To realize the above challenging goal, the injector linac (645-m long) introduced :
* Conventional control survey w/ the laser tracker & digital level since 2020.
* Weighted network analysis w/ geodetic line corrections.

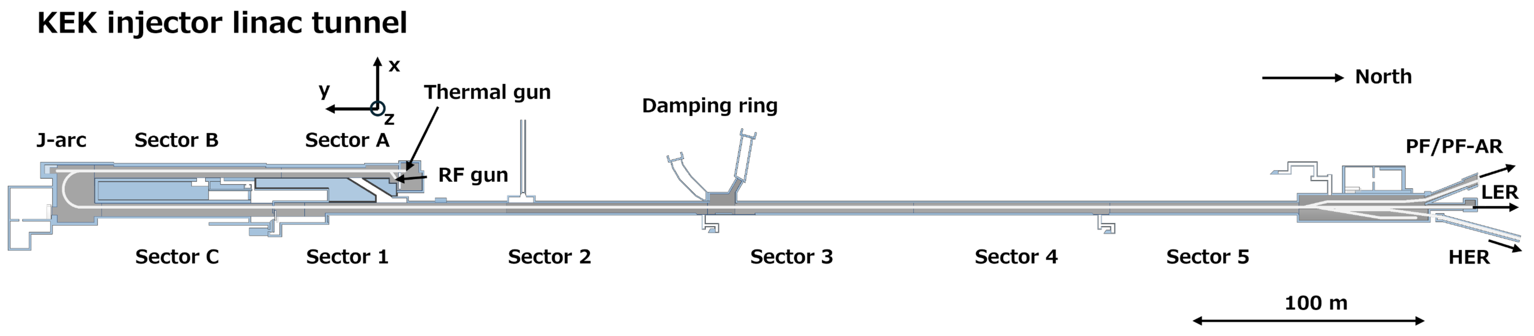
What we learned form the control survey trends…
Gradient of the horizontal x (east-west) increases every year from 400 m above the injector linac.

Possible candidates are :
1) Accumulation of numerical errors in the network analysis. Lack of constraints comparing to ring-type accelerators [4].
2) Displacements in the injector linac.

Crack displacement transducers installed as a trial to confirm whether the building is actually moving or not.

2. Control survey trends

KEK injector linac tunnel



Sector name	A	B	J-arc	C	1	2	3	4	5
Length [m]	48.0	76.8	36.1	81.6	83.3	92.9	69.9	79.5	76.8
# of units	4	8	1	8	7	7	8	8	8
# of magnets	65	14	35	18	74	90	20	16	34
# of monuments	15	19	10	21	32	32	17	19	20

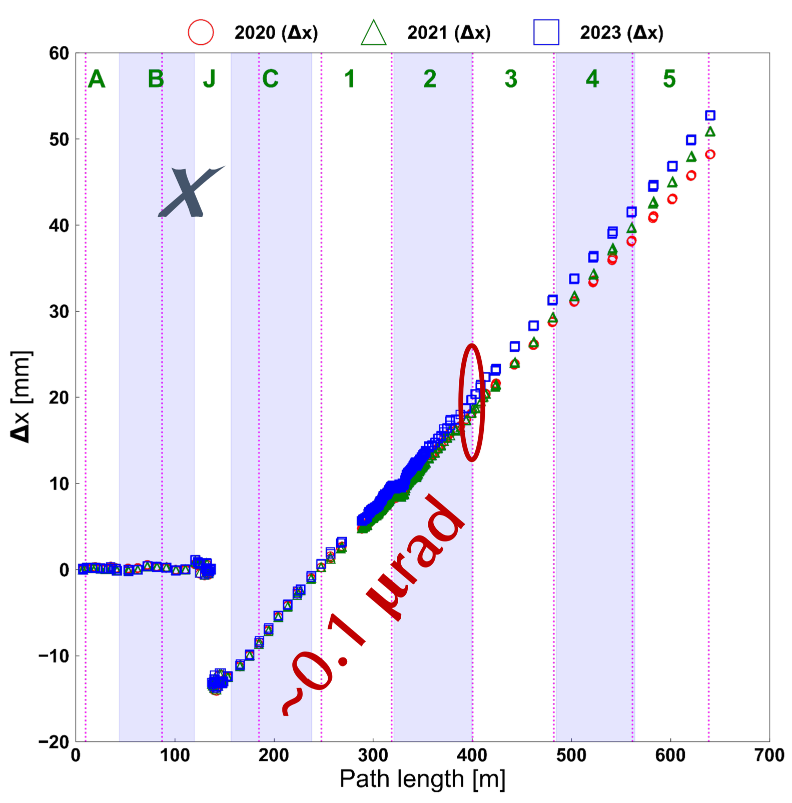
Instruments :
* Leica AT-401 (3D), 62 station points w/ 10 m interval
* Trimble DiNi0.3 (level only), 43 station points (round-trip) w/ ~16 m interval
* He-Ne light sources w/ Quadrant Photo-Diode sensors (QPD)

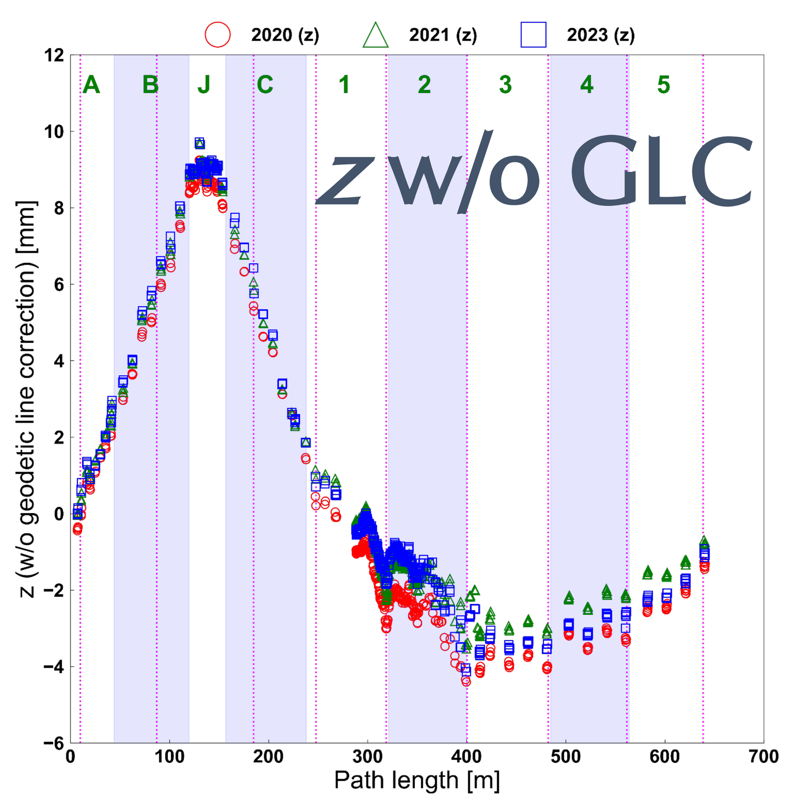
Analysis :
* Weighted network analysis w/ New River Kinematics Spatial Analyzer (SA)
* Currently weight factor is only applied to the digital level data.
* Geodetic line corrections (GLC) w/ QPD data applied to level (z) [1, 2].

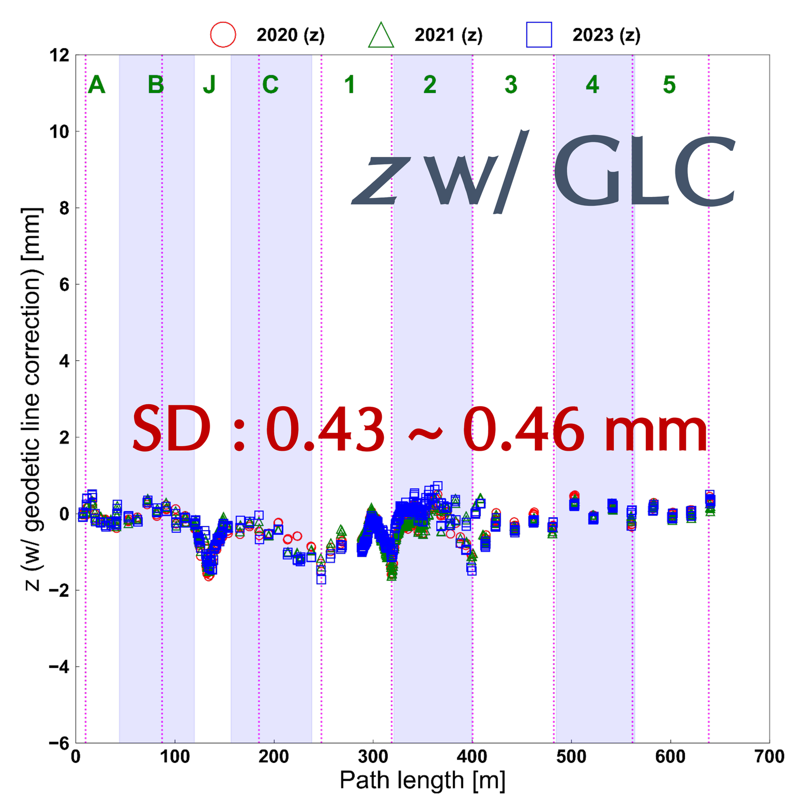
Δx @ the expansion joint b/w Sector 2 & 3;
18.91 mm (2020)
18.21 mm (2021)
19.76 mm (2023)
→ Variation range : 1.57 mm

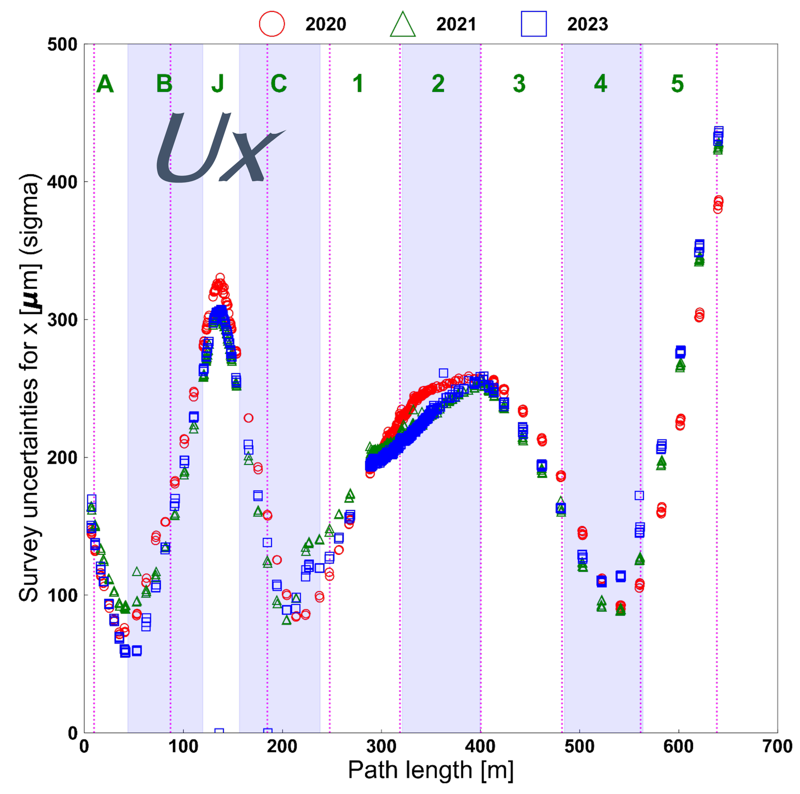
Gradient of ~0.1 μrad from J-arc exit to Sector 5 end was already recognized at the construction phase.

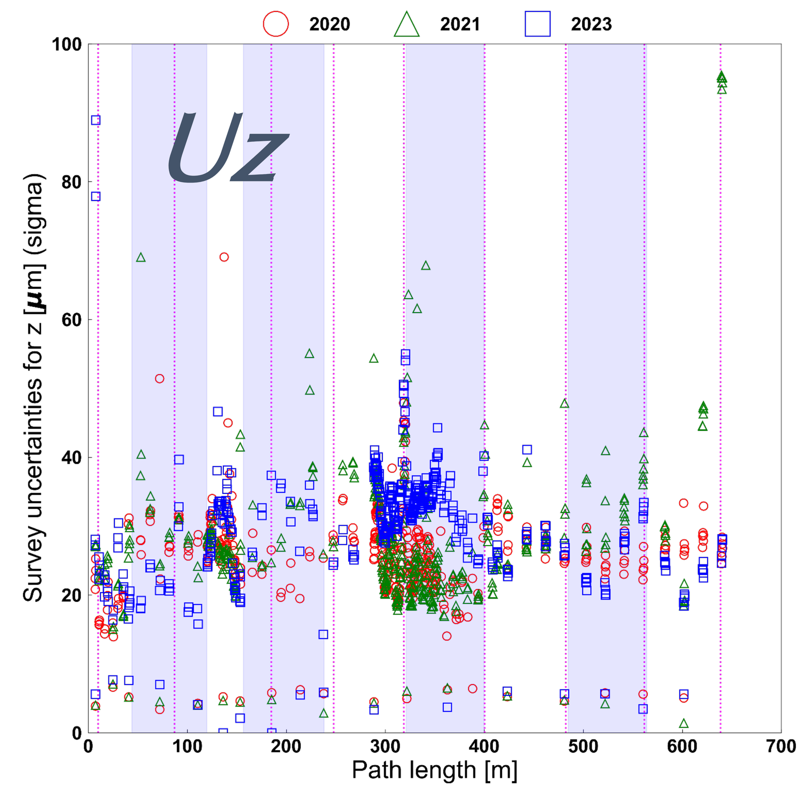
GLC for Sector A-B & C-5 levels drastically improve their variances to 0.43 ~ 0.46 mm.





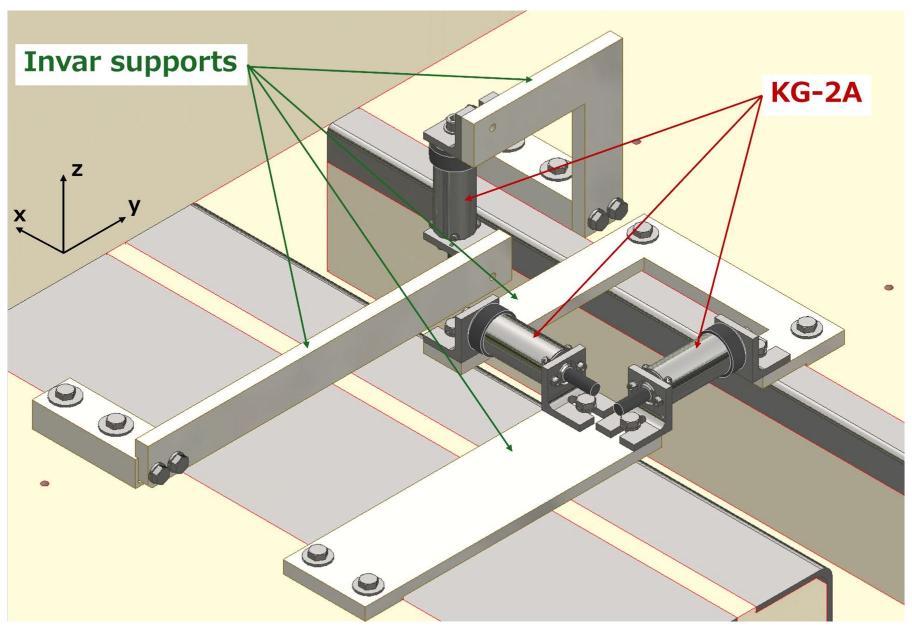


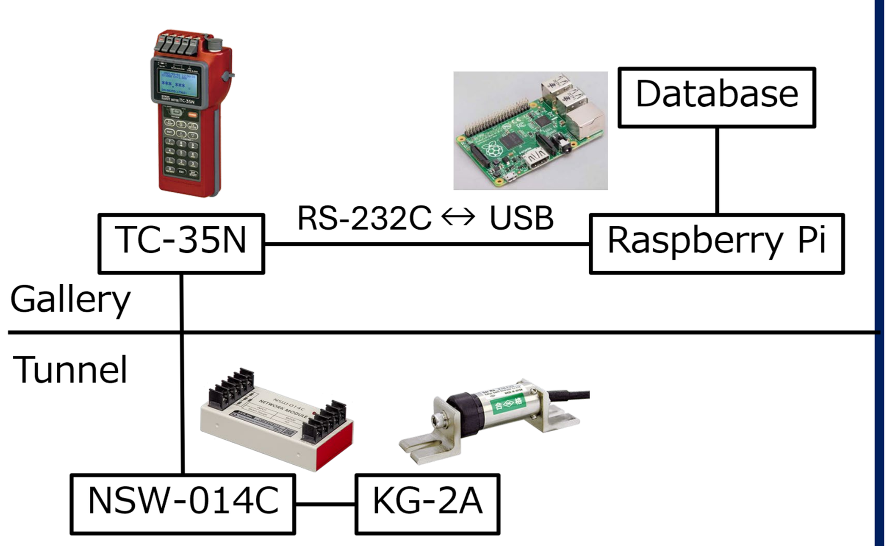




Uncertainties (Ux & Uz):
Ux has unique peak structures comparing to Uz.
In ring-type accelerators w/ all control points arranged periodically, the distributions of Ux, Uy, and Uz are all sine-curve shaped & nearly uniform around the entire circumference [4].

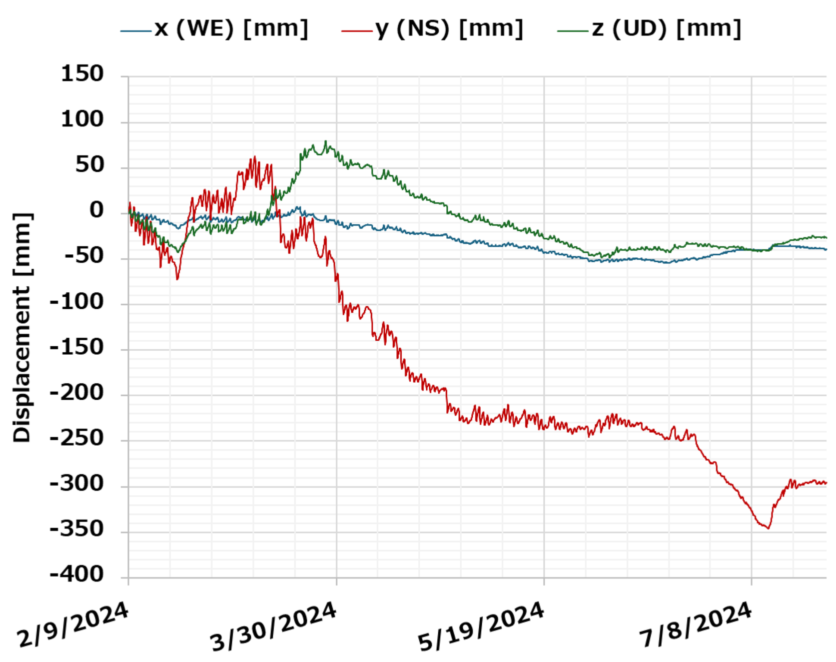
3. Crack displacement Transducers





KG-2A specifications

Capacity	±2 mm
Rated output	Approx. 1.5 mV/V (3000×10^{-6} strain)
Sensitivity	1500×10^{-6} strain/mm
Non-linearity	0.5% RO
Spring force	15 N
Temperature range	-20 to +60 °C
Weight	180 g



Crack displacement transducers (Tokyo Measuring Instruments Laboratory, KG-2A [3]) installed as atrial at the expansion joint b/w Sector 2 & 3 on January 2024.
Measurement Principle of KG-2A is a load cell → it has a thermal expansion coefficient.
Displacements over a period of 5 months;
$-54 < x$ [μm] < 8, $-346 < y$ [μm] < 63, $-49 < z$ [μm] < 80

4. Discussion & conclusion

KG-2A seems possible to measure building movements, though there are fluctuation depending on the thermal expansion coefficient.
Results of the control survey indicate that the expansion joint in Sectors 2 & 3 shifted 1.57 mm westward over a 3-year period.
On the other hand, 5 months of real-time displacement monitoring by KG-2A indicates that the expansion joint opened by 8 μm and shrunk by 54 μm in the east-west direction.
Since the measurement period is short, the validity of the control survey data cannot be directory confirmed by current setups of KG-2A.
It is necessary to set up KG-2A systems at least 2 or 3 more locations downstream from Sector 2 & collect longer-term trend.
Ux has a unique distribution. As far as keeping the current configuration of control points, it is necessary to apply & adjust weight factors to station points of the laser tracker in addition to the digital level to make uncertainty distributions as uniform as possible.

References :

[1] Y. Okayasu et al., Rev. Sci. Instrum., 94, 075107 (2023), doi : 10.1063/5.0155651.
[2] Y. Okayasu et al., "Control survey for KEK e+/e- Injector Linac" in Proceedings of 16th International Workshop on Accelerator Alignment (IWAA2022), Ferney-Voltarie, France, 2022.
[3] Tokyo Measuring Instruments Laboratory Co., Ltd., http://tml.jp/e.
[4] Y. Okayasu et al., J. Instrum. 15, P03033 (2022), doi:10.1088/1748-0221/15/03/P03033