Accuracy of the orbit measurement by KEKB BPM system for the study of ILC damping ring

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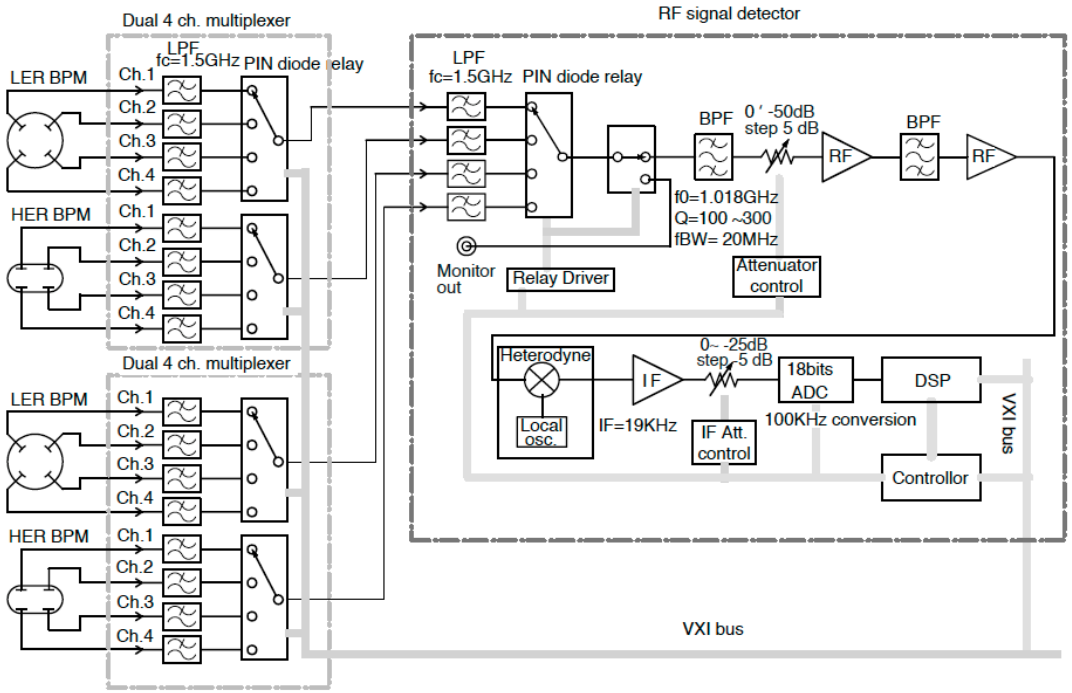
Requirement for the accuracy of BPM data wrt the design orbit, i.e. the magnetic center of magnets : 10μm

by Y. Ohnishi

A. BPM system of KEKB

- The HER and LER are equipped with 443 and 454 pickups, respectively.
- Narrow band system : typical band width 50 Hz
- Sampling speed : a few seconds



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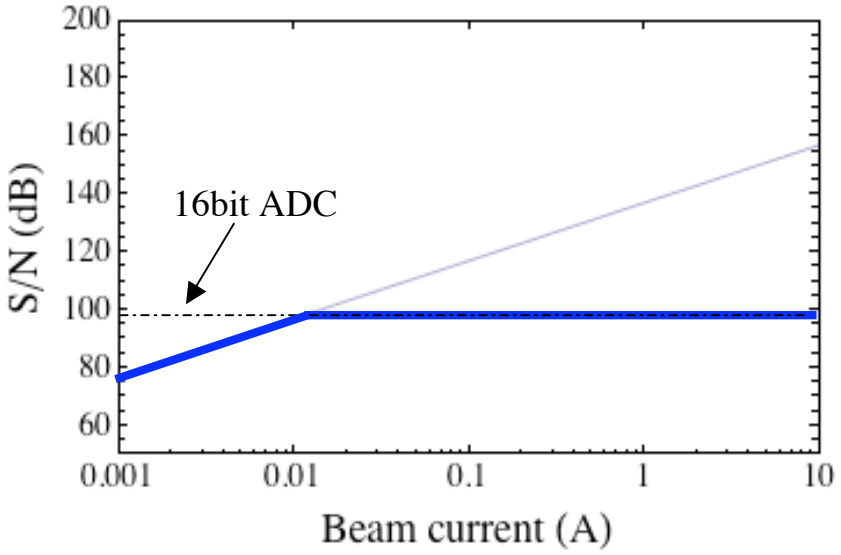
B. Resolution of BPM

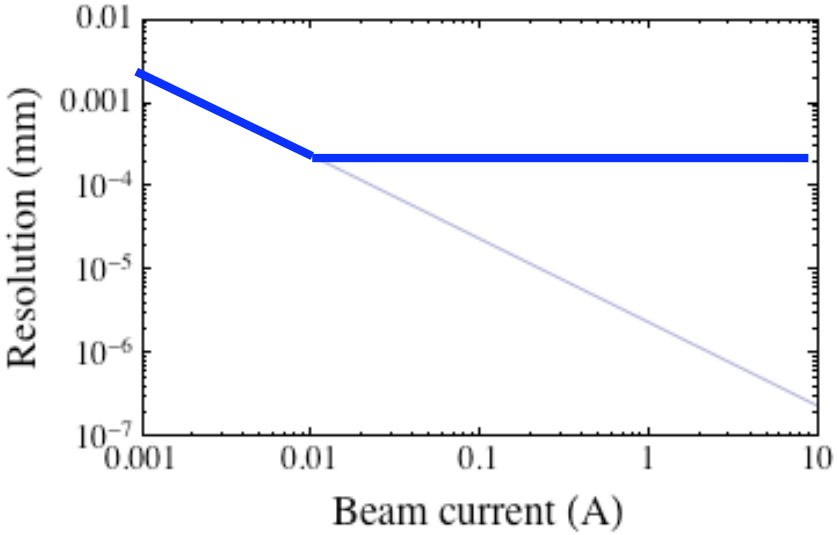
Estimated resolution taking into account thermal noise

Band width : 50 Hz, cable length :100m

S/N



Resolution



Resolution is better than 1μm at 10mA.

Measurement

Measurement at a test bench

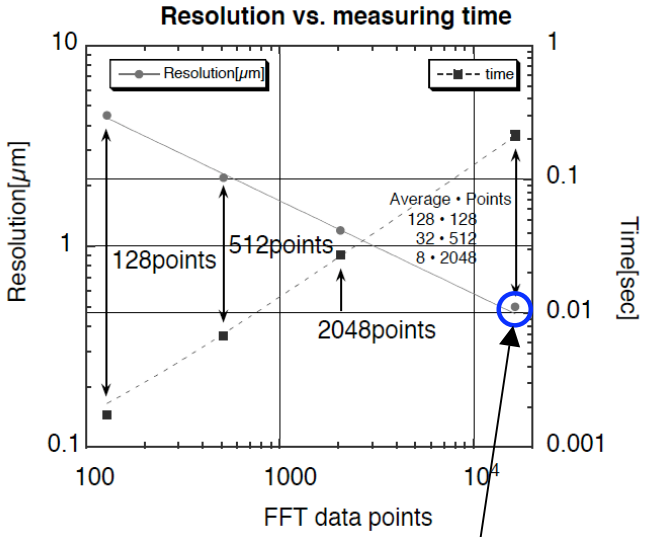


Fig. 8. Resolution and measuring time evaluated at the test bench.

Input level corresponding to 10mA

A resolution is 0.5μm by averaging 8 times of 2048-points FFT results.

Measurement with beam

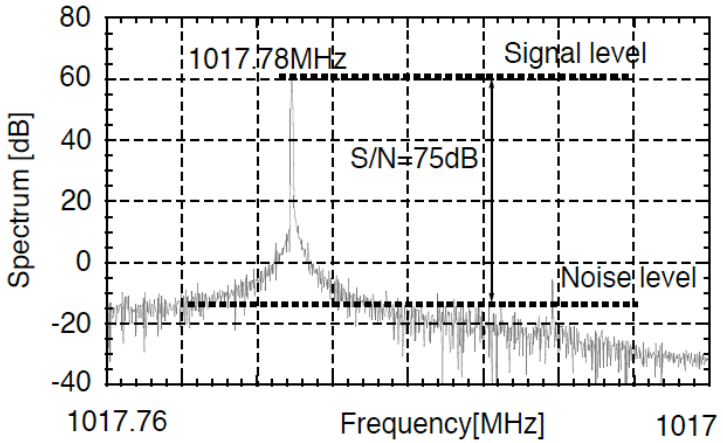


Fig. 9. Spectrum data of FFT analysis at DSP.

Resolution is about 1μm.

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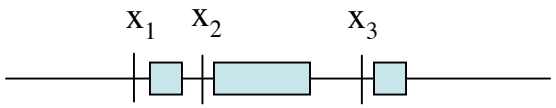
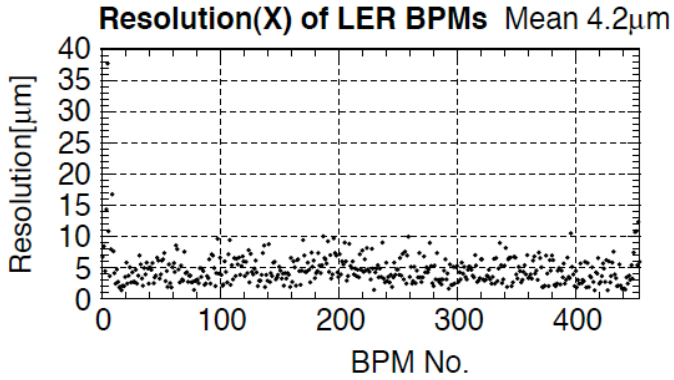
Measurement of the resolution by 3-BPM method

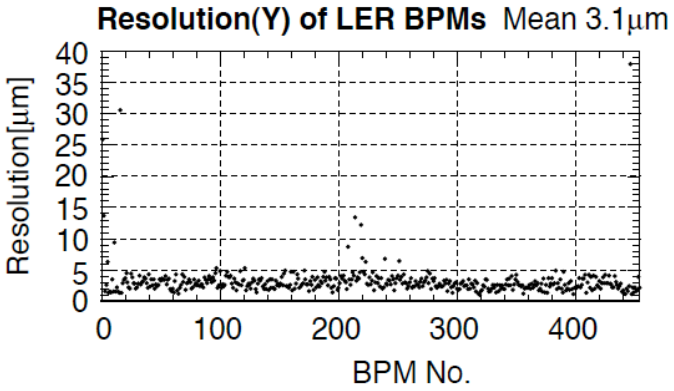


$$x_3 = Ax_1 + Bx_2$$

$$\sigma = \sqrt{\frac{\frac{1}{N}\sum_{n=1}^{N}\left\{x_{3n} - \left(Ax_{1n} + Bx_{2n}\right)\right\}^2}{1 + A^2 + B^2}}$$

resolution





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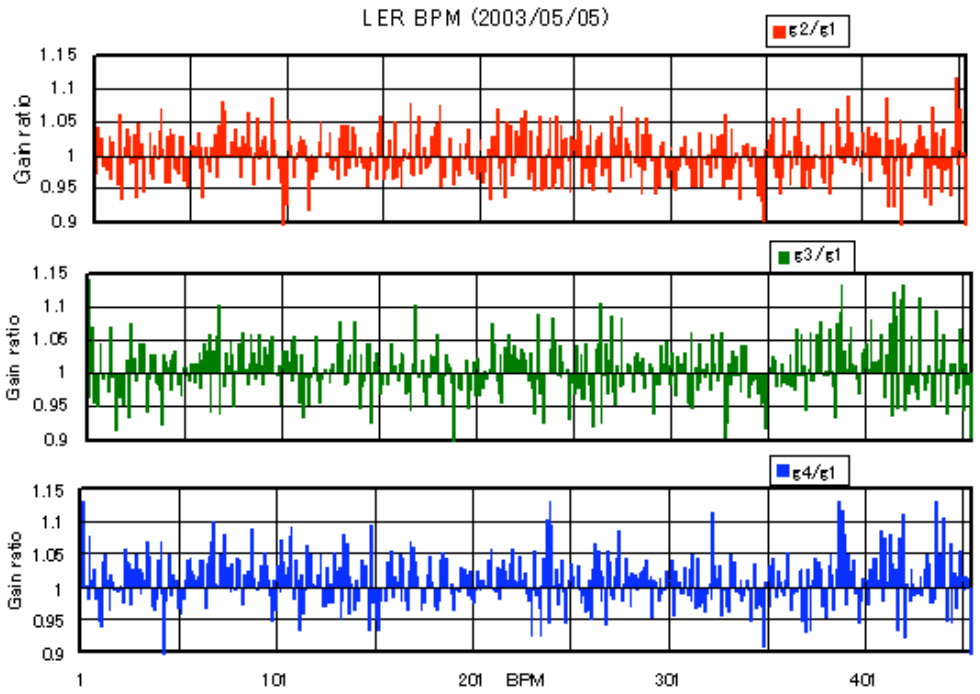
Resolution is less than 10 μm.

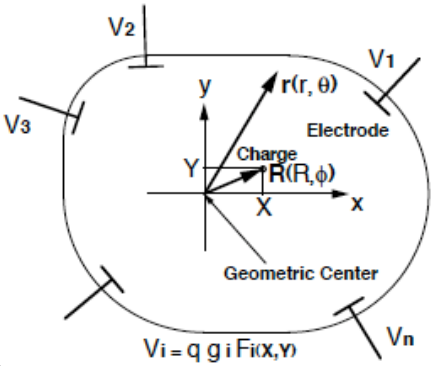
Measurement may be affected by oscillation of the orbit.

C. Absolute position of BPM with respect to magnets

1) Definition of the geometric center of a BPM head (K. Satoh, M. Tejima)

"Gain" calibration by beam





gain

$$V_{ij} = g_i \cdot q_j \cdot F_i(x_j, y_j) \equiv V(i, j; \mathbf{a}),$$
$$i = 1, ..., 4, \quad j = 1, ..., m,$$
$$\mathbf{a} = (g_2, g_3, g_4, q_1, x_1, y_1, ..., q_m, x_m, y_m)$$

determined by fitting

$$\chi^2(\mathbf{a}) = \sum_{i=1}^{4} \sum_{j=1}^{m} \frac{[V_{ij} - V(i, j; \mathbf{a})]^2}{\sigma_{ij}^2}$$

minimize

Fitting error of beam position x_m, y_m: 3μm (M. Tejima)

2) BPM offset from the adjacent quad

Beam based alignment ("Quad-BPM" method)

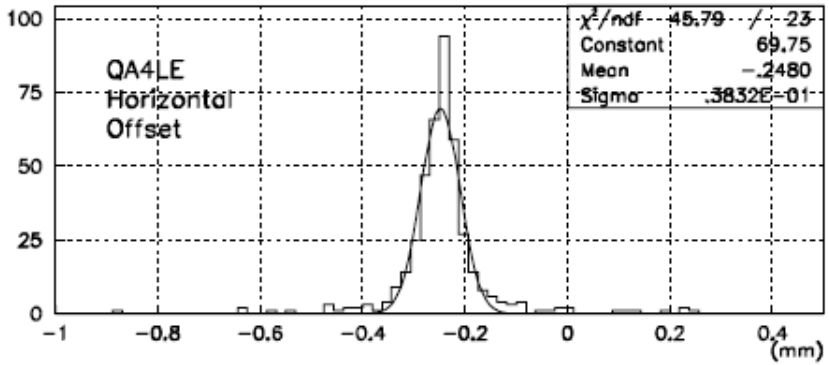


Figure 2: The beam position which is insensitive to a ΔI of the adjacent quadrupole magnet, QA4LE. The beam position change is monitored by every BPM in HER when QA4LE strength is changed.

Find BPM reading x_Q at a quad Q in

$$\delta x / \Delta I_Q = 0$$

↑ orbit change

x_Q can be obtained by any BPM reading δx_i.

RMS of $x_{Q,i}$'s may be a measure of the measurement error.

Error of the measurement : 40μm

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Movement of BPM from the adjacent quad by thermal stress

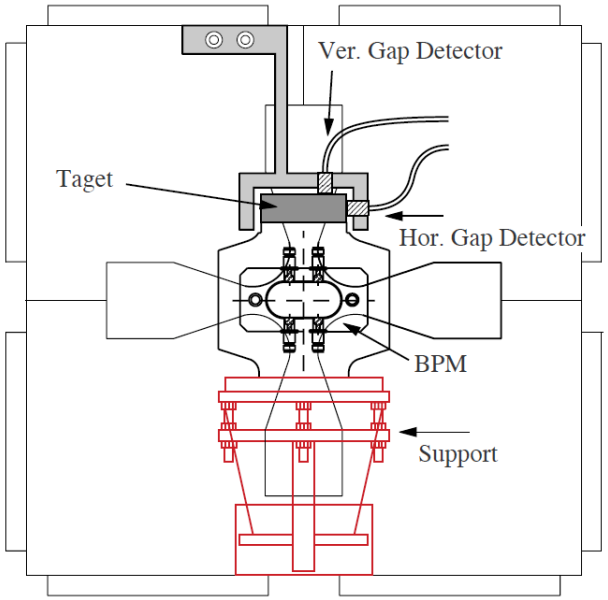


Figure 2: Gap detectors attached to QM

HER

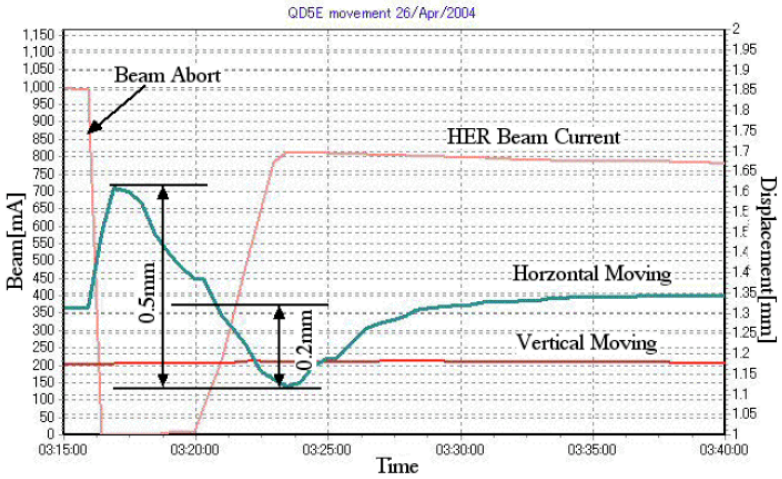


Figure 3: Readings of gap detectors after a beam abort.

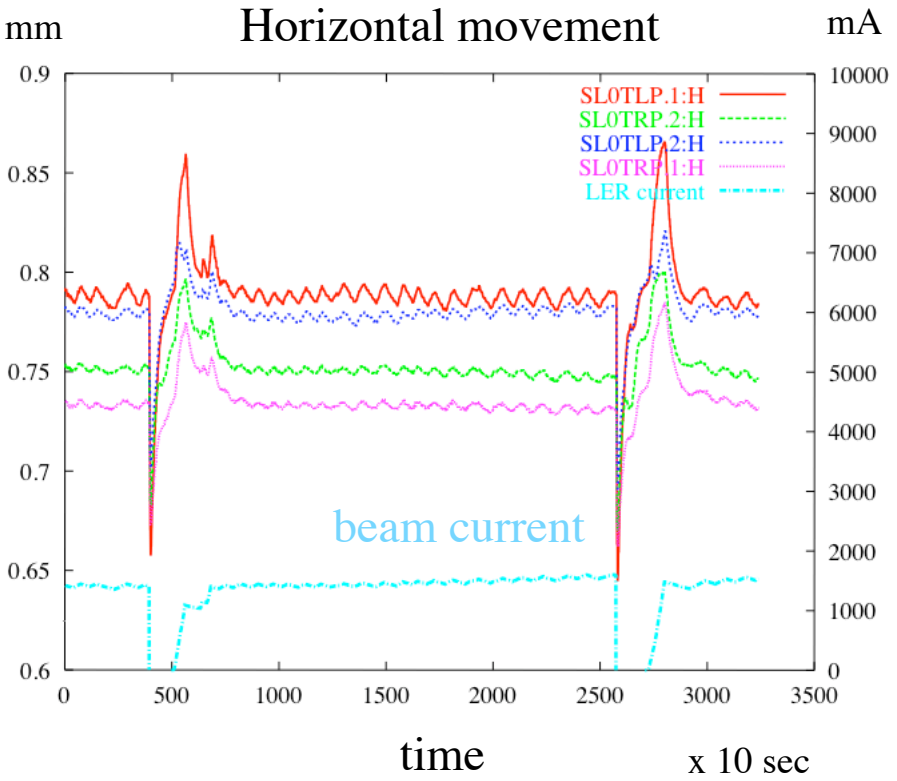
M. Tejima et al., PAC05

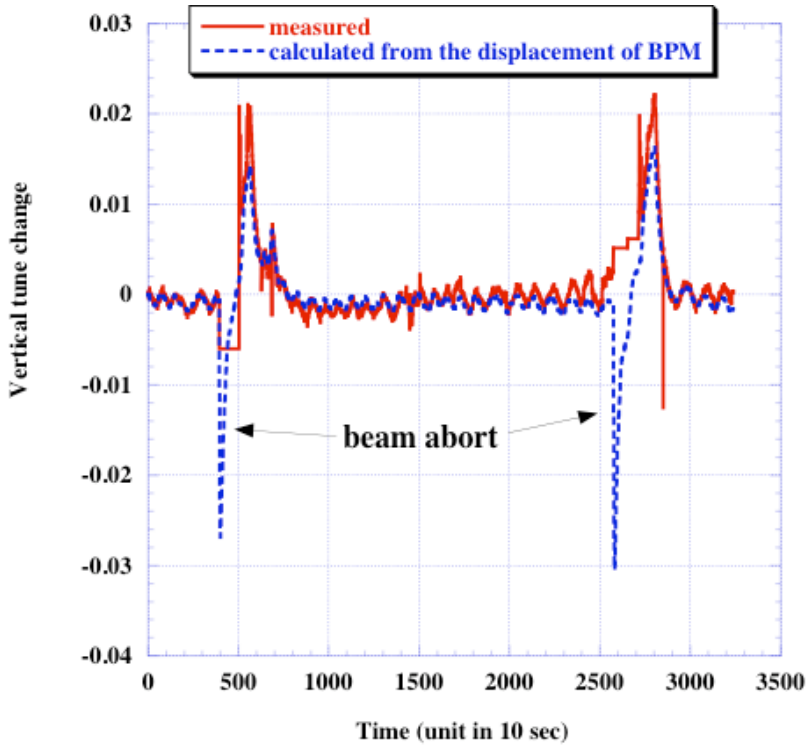
Movement of several hundred microns at the beam abort.

No data in LER arc sections.

Movement of a BPM from the adjacent sextupole

- Tune change by the orbit deviation at 4 sextupoles for local chromaticity correction in LER



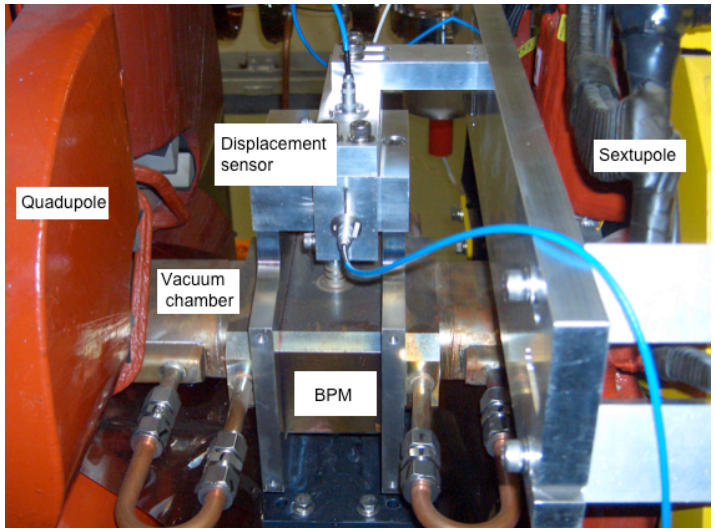


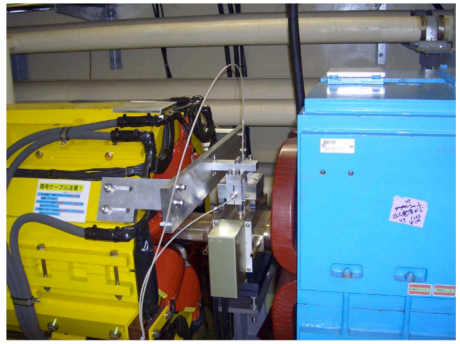
β_y=460 m, K_2=2.4 m^{-2} ⇒ $\Delta\nu_y$=0.0035 for Δx = 10μm, if 4 sextupoles shift same direction.

•212 gap detectors(108 in LER, 104 in HER) have been installed in this summer in order to measure the displacement of the BPM from the adjacent sextupole.

Specifications

method	electrostatic (capacitive)
channels	2
range (mm)	0.5 - 2.5
resolution (μm)	< 0.2
nonlinearity (%)	< ±0.3
frequency response (Hz)	0 - 100
temperature coefficient (μm/deg.)	< 0.2





•Deformation of the fixing arm by temperature change

Horizontal : 1μm/deg, Vertical : 4μm/deg

•Stability of the tunnel temperature in operation < 1 deg

⇨ Error of the measurement :Horizontal : < 1μm, Vertical : < 4μm

D. Summary

1. Resolution
   - < 10μm , typically 5μm
2. Absolute position of BPM with respect to magnets
   - Geometric center of BPM < 3μm
   - BPM position wrt the magnetic center of the quad < 40μm
     (for small beam current of 30mA)
   - Movement of BPM wrt the quad : unknown
   - Movement of BPM wrt the sextupole
     Corrected by displacement sensors below 4μm
   - Effect of orbit oscillation on BPM data : unknown
3. Accuracy of BPM data is estimated to be about 40μm though several unknowns remain.
   - The biggest error comes from the measurement error of the beam based alignment.
   - The estimated accuracy does not fulfill the requirement by Y. Ohnishi.
   - Low current operation may be desirable to avoid the movement of the BPM head wrt the quad.