BPM displacement monitor

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KEKB beam monitor group

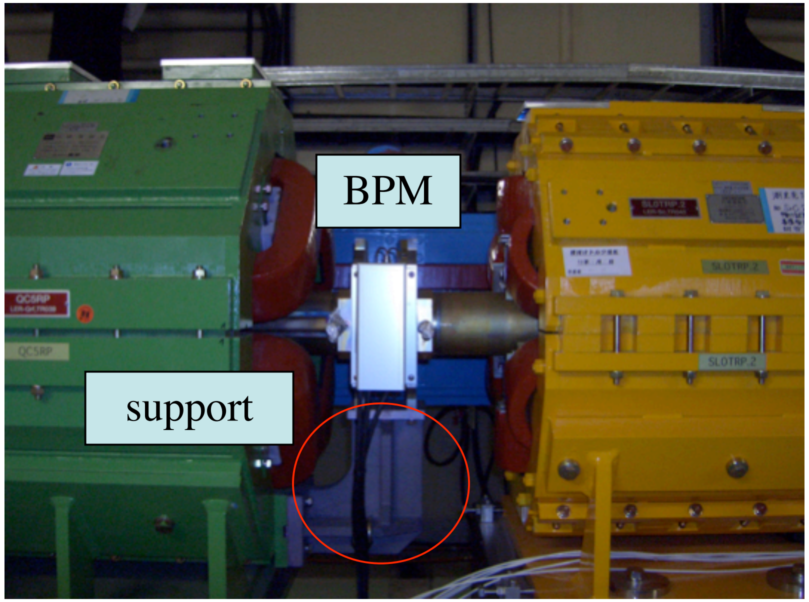
1. Introduction
2. Gap detector and fixing arm
3. Installation plan
4. Summary

1. Introduction

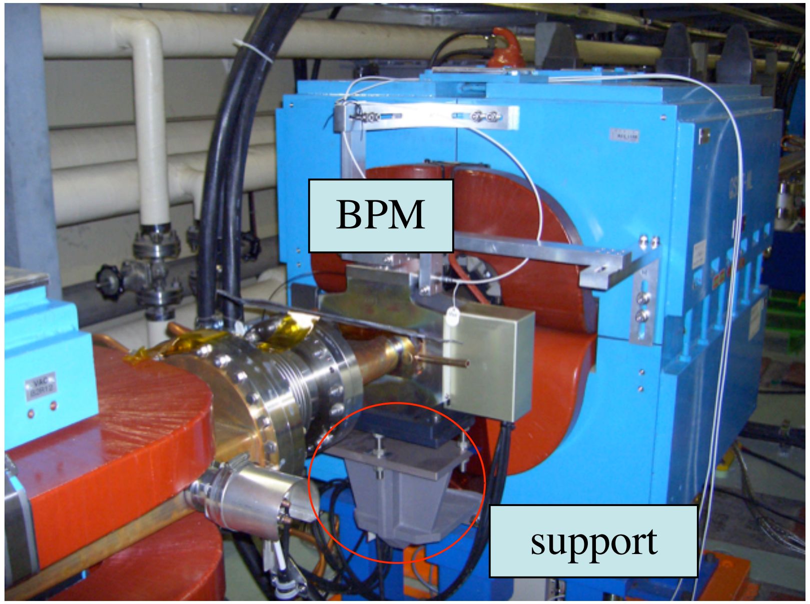
1) Movement of beam position monitors

- The movement of beam position monitors(BPMs) due to the thermal stress of vacuum chambers has been observed both in LER and HER even though they are fixed to quadrupoles.

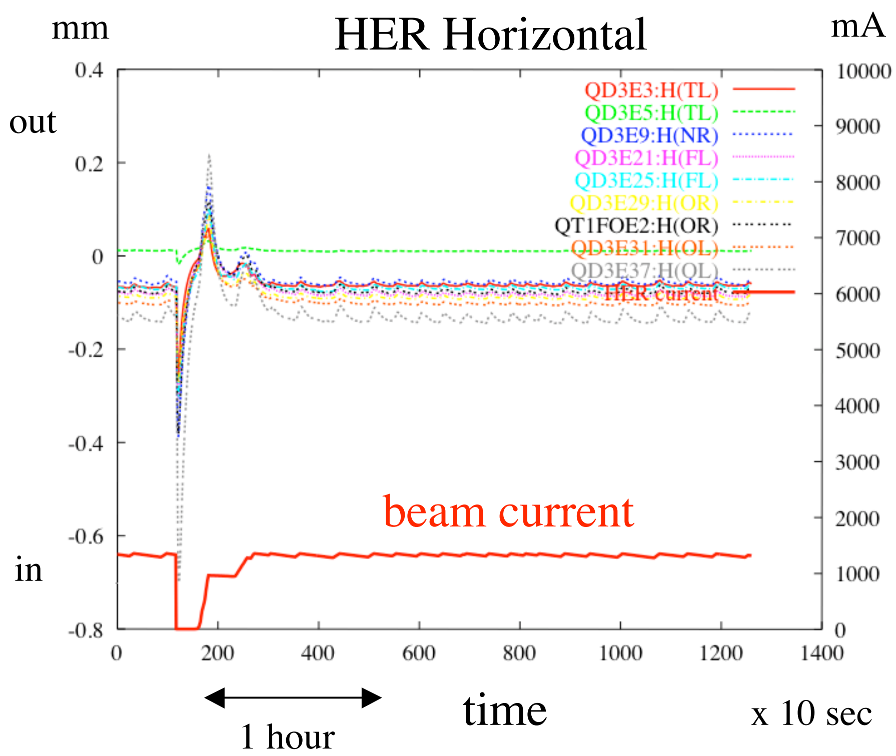
LER

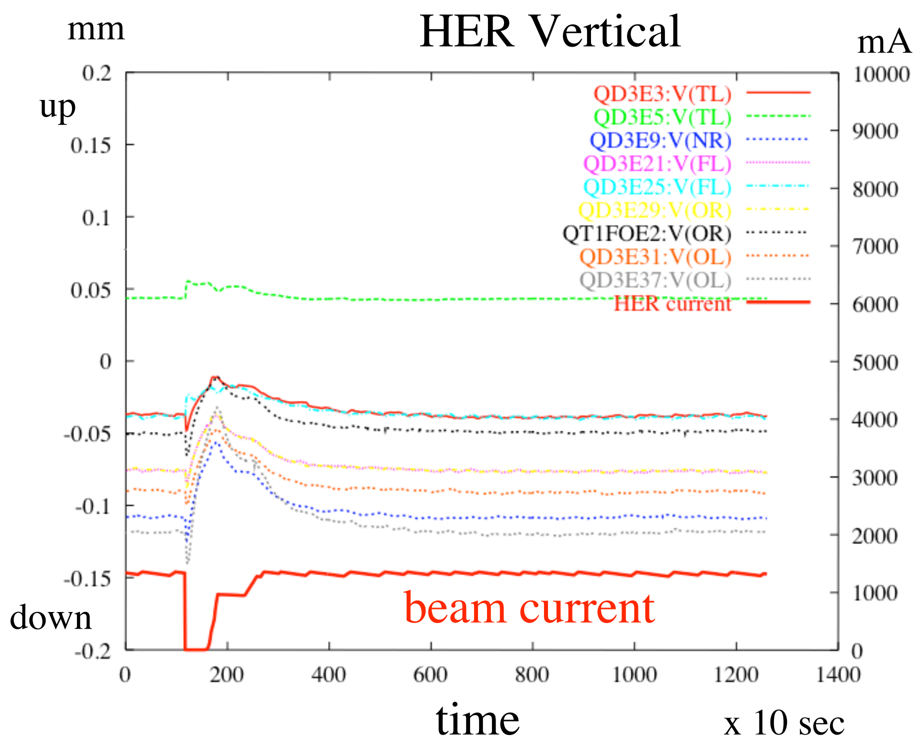


HER



a) Movement of arc BPMs relative to nearby sextupoles at a beam abort in HER

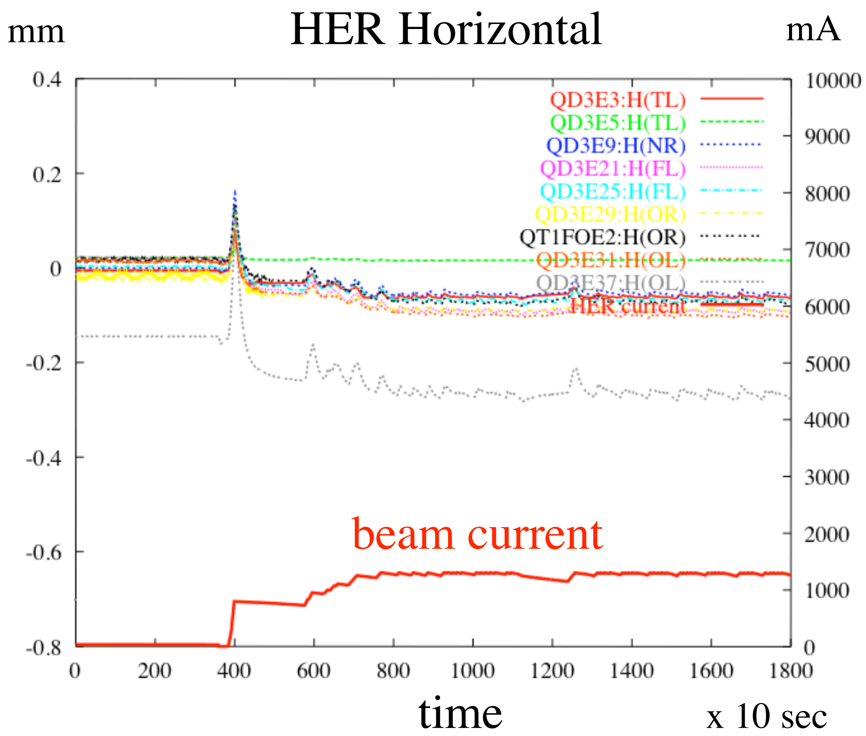


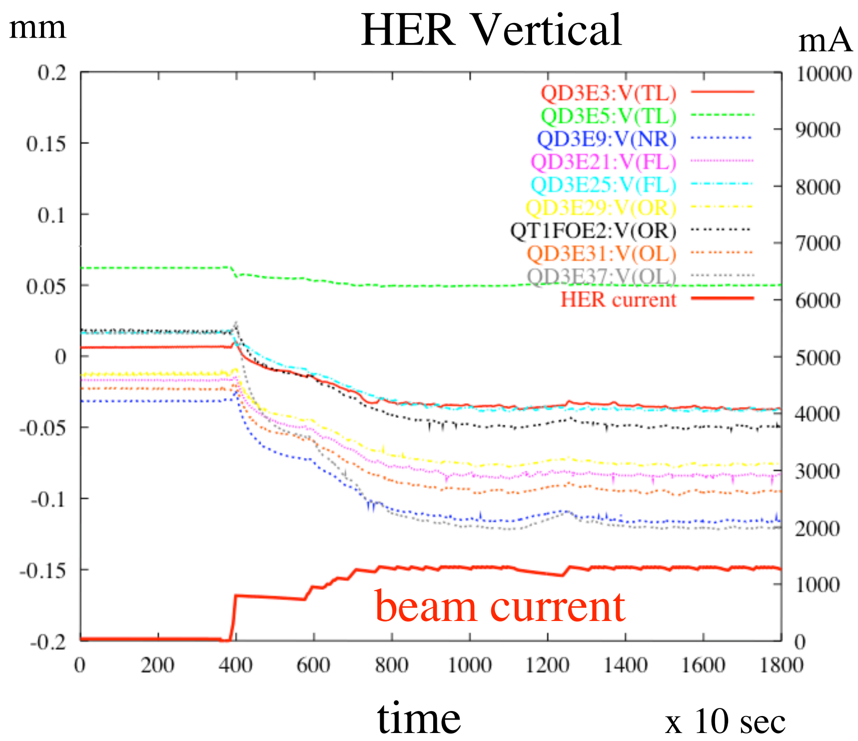


- BPMs move 0.9mm (max.) horizontally and 0.1mm (max.) vertically.
- It takes 30 to 40 min. to reach steady state after the following injection.

  The BPMs move 0.3mm (max.) horizontally and 0.06mm (max.) vertically during transient.
- Movement of the BPM depends on beam current.

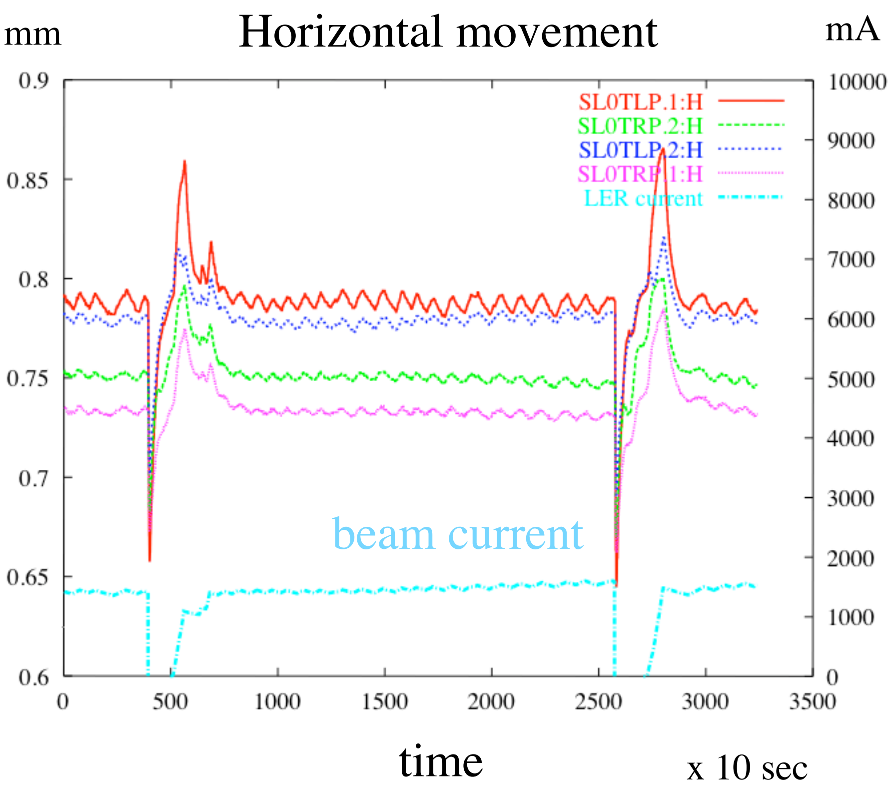
b) Startup after 8 hours-maintenance-time

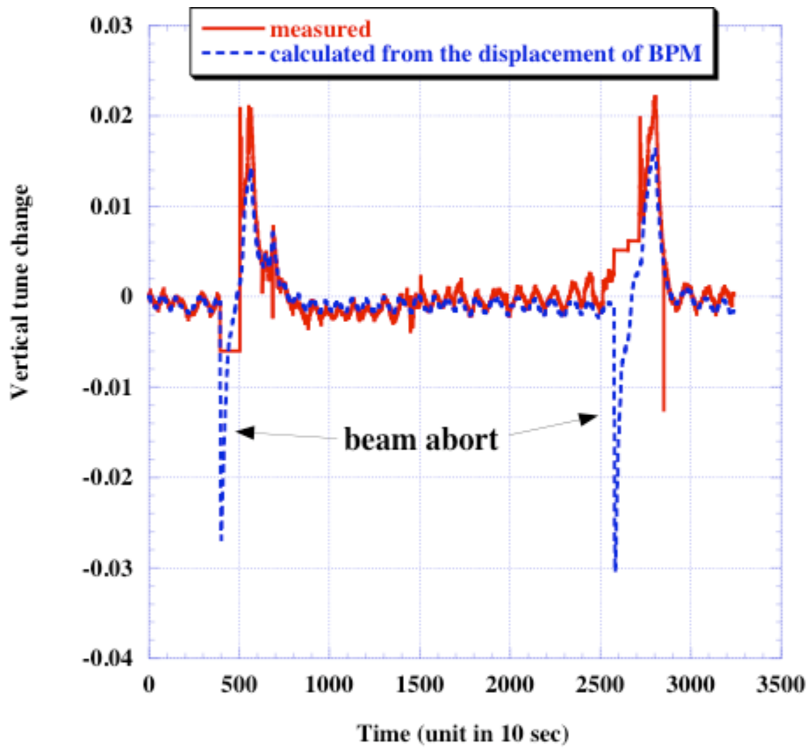




The BPMs move about 0.1mm (max.) relative to sextupoles horizontally and vertically.

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





$$\Delta\nu_y = \frac{1}{4\pi}\sum_i \beta_{y,i}\cdot K_{2,i}\cdot \Delta x_i$$

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

2) Effect of BPM movement on the optics

- As the beam orbit is continuously corrected based on the beam position measured by the BPMs, the displacement of the BPMs changes the beam position relative to magnets.

- The movement of BPMs relative to sextupoles deforms a linear optics, then could cause a difficulty of the machine tuning especially after recovery from the beam abort or startup after machine maintenance.

- The effect of the BPM movement on the optics was estimated by SAD.

  ◊Positions of sextupoles were shifted randomly by 0.1mm rms horizontally or vertically.

  ◊Random distribution may not be a good assumption because we expect a correlation of movement which is not much known at present.

  ◊However, the simulation will give an estimate of the effect of the movement.

•Simulation result

Two numbers show the results from different random numbers.

HER

	Hor. disp. : 0.1mm (rms)	Ver. disp.: 0.1mm (rms)
$\Delta\nu_x$	-0.0001/-0.003 *	0.0/-0.0003
$\Delta\nu_y$	0.0029/0.010	0.0/0.0
$\Delta\beta_x^* / \beta_x^* (\%)$	34/-15	-0.1/-0.7
$\Delta\beta_y^* / \beta_y^* (\%)$	2.6/2.9	-0.1/0.1
$\Delta\eta_x^* (mm)$	0.85/-1.4	-0.019/-0.13
$\Delta\eta_y^* (mm)$	0.0/0.0	0.024/-0.008
$\Delta R_1^* (10^{-3})$	-0.02/-0.03	-3.77/-0.93 (2.7/0.67 u)
$\Delta R_2^* (10^{-3} m)$	0.011/0.014	1.46/2.10 (1.9/2.7 u)
$\Delta R_3^* (10^{-3} m^{-1})$	1.45/2.75	6.87/-712 (0.06/6.7 u)
$\Delta R_4^* (10^{-3})$	-2.49/-5.33	-20.3/-537 (0.3/8.4 u)
$< \lvert \Delta\beta_x / \beta_x \rvert >_{ring} (\%)$	20/13.8	0.12/2.0
$< \lvert \Delta\beta_y / \beta_y \rvert >_{ring} (\%)$	1.8/8.2	0.05/0.2
$\varepsilon_y / \varepsilon_x (\%)$	0.0/0.0	0.2/0.5

U is an unit used in machine tuning.
A value of several units is changed to maintain good luminosity.

LER

	Hor. disp. : 0.1mm (rms)	Ver. disp.: 0.1mm (rms)
$\Delta\nu_x$	-0.0017/0.0006	-0.0001/0.0
$\Delta\nu_y$	0.0011/-0.002	0.0/0.0
$\Delta\beta_x^* / \beta_x^* (\%)$	-11/16.5	0.2/1.0
$\Delta\beta_y^* / \beta_y^* (\%)$	-3.9/4.8	0.0/0.0
$\Delta\eta_x^* (mm)$	0.27/0.03	-0.015/0.014
$\Delta\eta_y^* (mm)$	0.0/0.0	-0.052/0.026
$\Delta R_1^* (10^{-3})$	0.0/0.0	4.72/4.35 (1.4/1.3 u)
$\Delta R_2^* (10^{-3} m)$	0.0/0.0	3.14/-0.88 (8.7/-2.4 u)
$\Delta R_3^* (10^{-3} m^{-1})$	0.0/0.0	-529/431 (-3.2/2.6 u)
$\Delta R_4^* (10^{-3})$	0.004/-0.005	-54.4/-15.1 (-1.7/-0.5 u)
$< \lvert \Delta\beta_x / \beta_x \rvert >_{ring} (\%)$	10.3/17.3	1.2/0.63
$< \lvert \Delta\beta_y / \beta_y \rvert >_{ring} (\%)$	3.1/4.8	0.04/0.02
$\varepsilon_y / \varepsilon_x (\%)$	0.0/0.0	0.3/0.14

Sextupoles for local chromaticity correction are not included in the calculation.

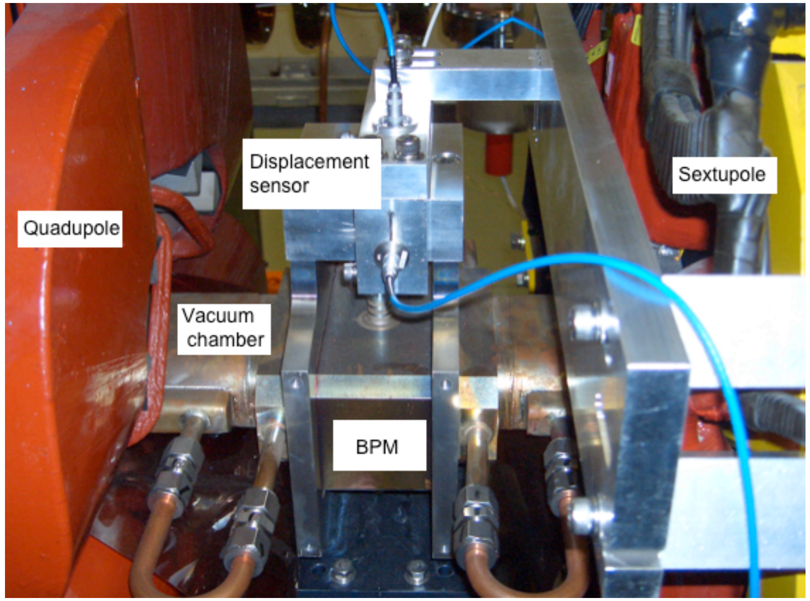
- According to the simulation, the movement of several 10 μm could give a sizeable effect on the optics.
- As fixing BPMs firmly to magnets will give large stress to BPM chambers and tight fixing may be difficult due to large thermal stress, we decided to measure the movement of a BPM relative to a nearby sextupole then apply a correction to beam position data.
- As commercial gap detectors are expensive, a gap detector which is low cost but has enough performance, was developed.

2. Gap detector and fixing arm

1) Gap detector

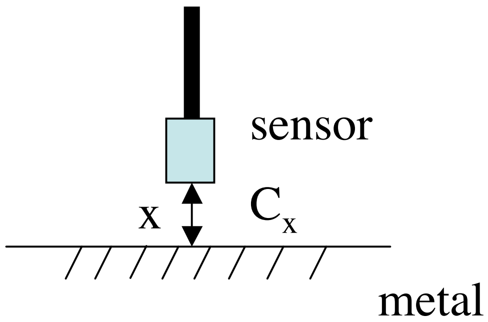
a) Specifications

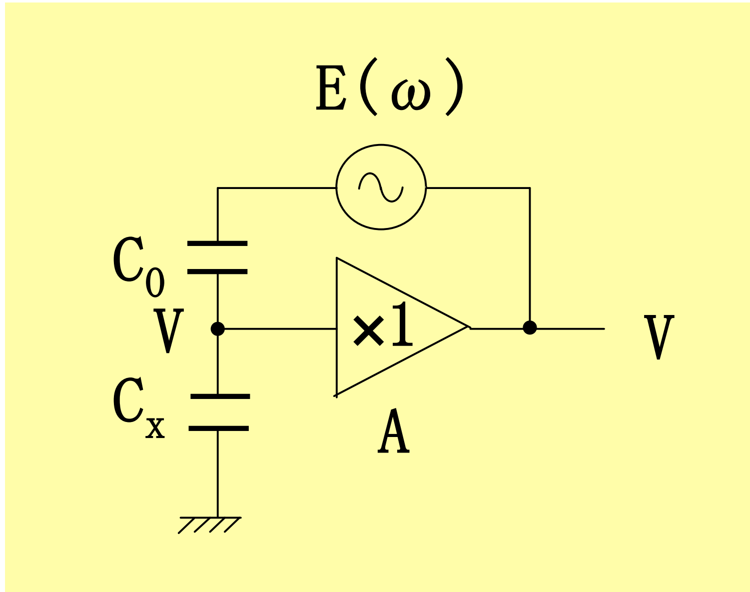
method	electrostatic (capacitive)
channels	2
range (mm)	0.5 - 2.5
resolution (μm)	< 0.2
nonlinearity (%)	< ±0.3
frequency response (Hz)	0 - 100
temperature coefficient (μm/deg.)	< 0.2



b) Principle

Electrostatic capacitive sensor





$$C_x = \varepsilon_0 \frac{S}{x}, \quad V = \frac{C_0}{C_x} E = \frac{C_0 E}{\varepsilon_0 S} x$$

S: Area of sensor

S = 50.3 mm^2, x = 0.5 - 2.5 mm ⇨ C_x = 0.89 - 0.18 pF

c) Circuit (S. Hiramatsu, M. Arinaga)

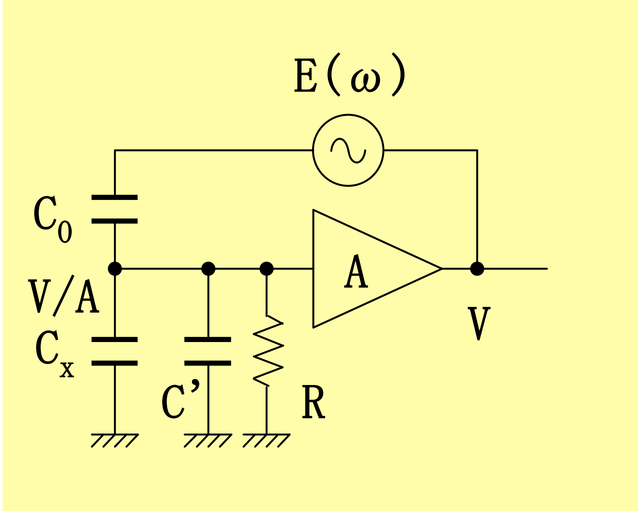
$$C' = C_{amp} + C_{sensor} + C_{cable}$$

C_{amp} : input capacitance of amp.

C_{sensor} : capacitance between sensor and ground

C_{cable} : capacitance between signal wire and ground

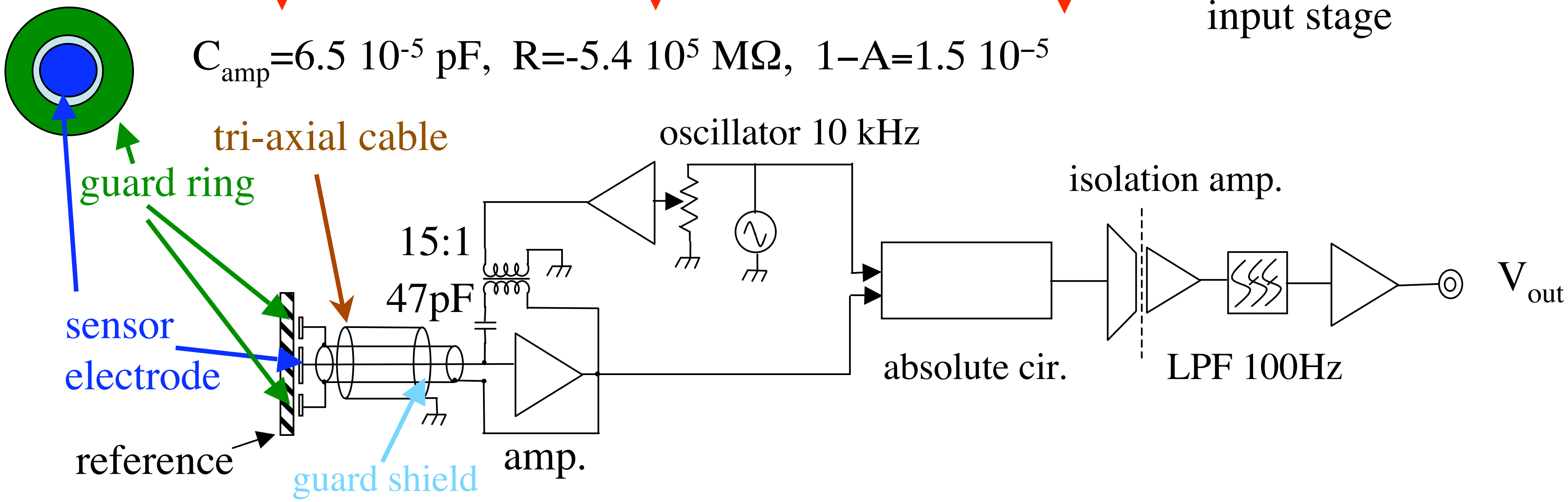
$$V = \left(1 + \frac{1}{j\omega C_x R} + \frac{C'}{C_x} + \frac{C_0}{C_x}(1-A)\right)^{-1} \cdot A\frac{C_0}{C_x}E$$



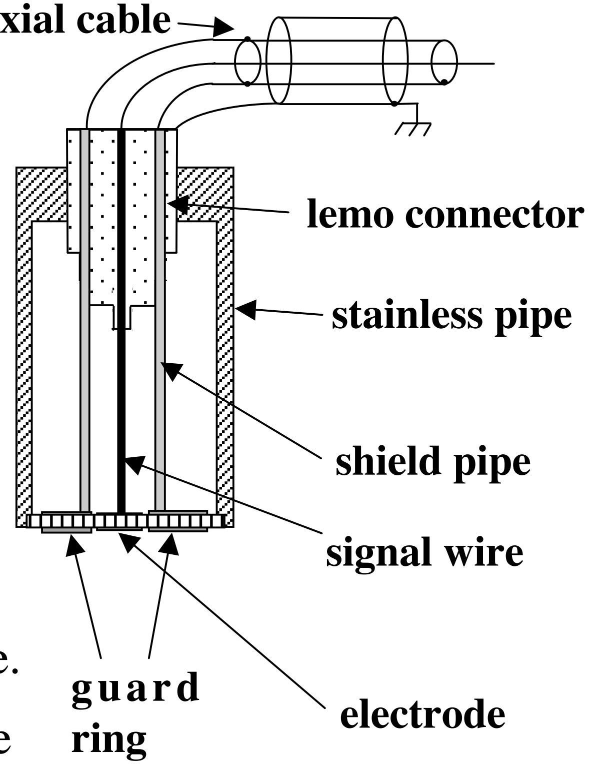
$$\Rightarrow \quad \frac{C'}{C_x} << 1,\ \omega C_x \cdot R >> 1,\ 1 - A << 1$$

C_{sensor}↓ → guard ring, C_{cable}↓ → guard shield, C_{amp}↓, R↑ → bootstrap circuits in FET input stage

C_{amp}=6.5 10^{-5} pF, R=-5.4 10^{5} MΩ, 1−A=1.5 10^{-5}



d) Sensor head



- Shield pipe to reduce the leakage capacitance.
- Electrodes made of a printed board to reduce the cost.
- Polyethylene cable against radiation.

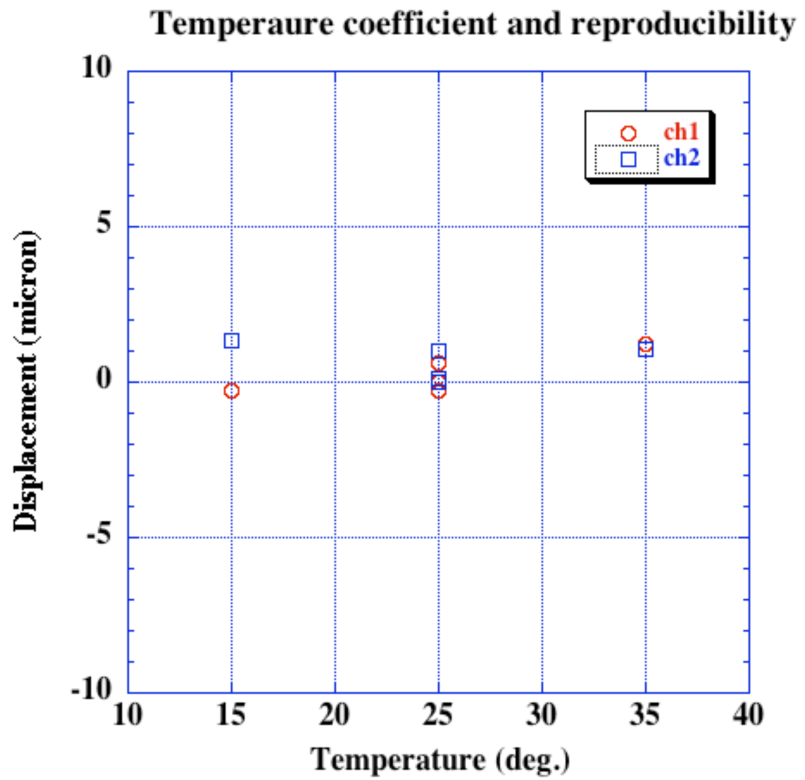
e) Signal cable

- Insulator : Polyethylene ⇦ Radiation resistance
- Outer sheath : PEEK (Poly-ether-ether-ketones)

f) Temperature coefficient and reproducibility

- Measurement in KEK

Heat cycle 25 deg. ⇨ 35 deg. ⇨ 25 deg. ⇨ 15 deg. ⇨ 25 deg.

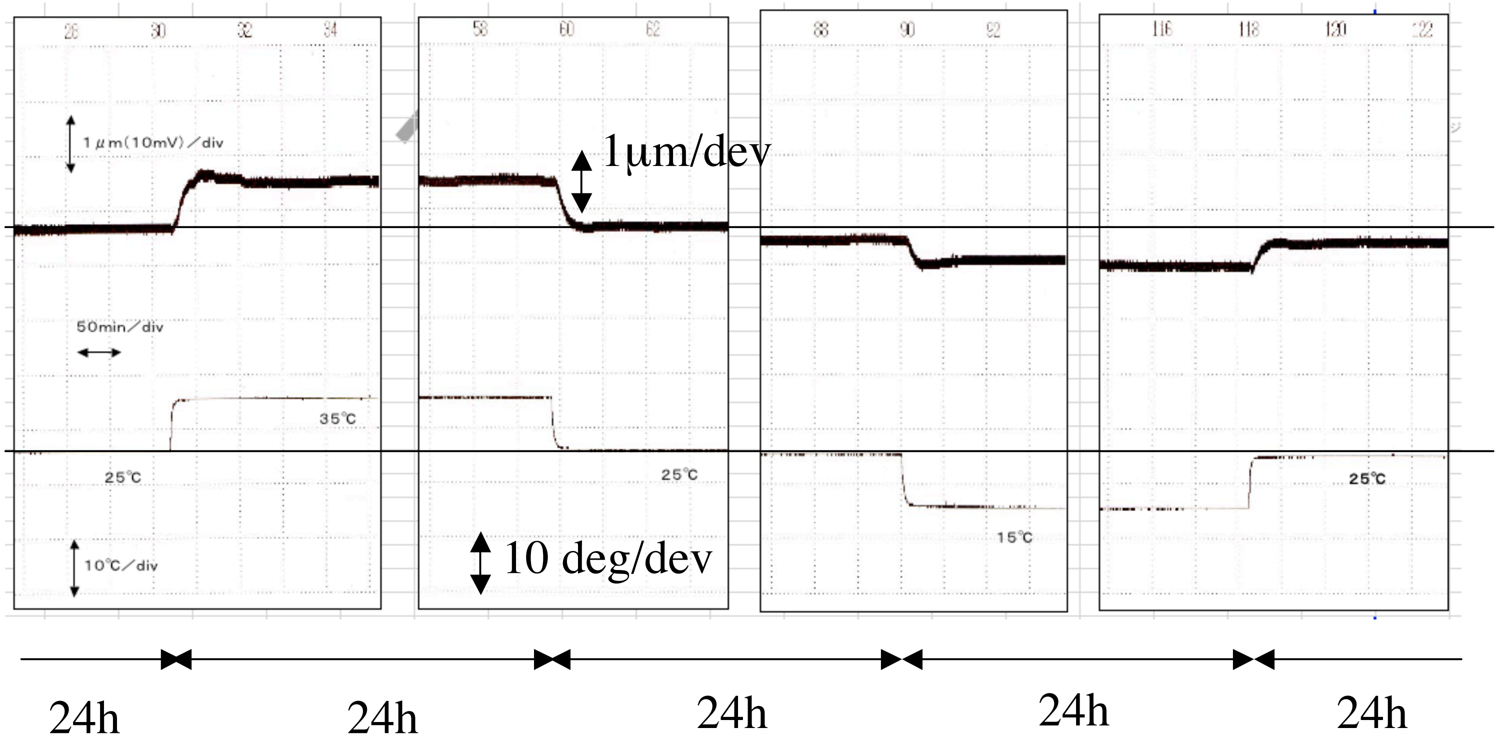


Temperature coefficient < 0.15 μm/deg.

Reproducibility in a temperature cycle of 15 - 35 deg. < 1 μm.

•Measurement by the maker

Heat cycle 25 deg. ⇨ 35 deg. ⇨ 25 deg. ⇨ 15 deg. ⇨ 25 deg.



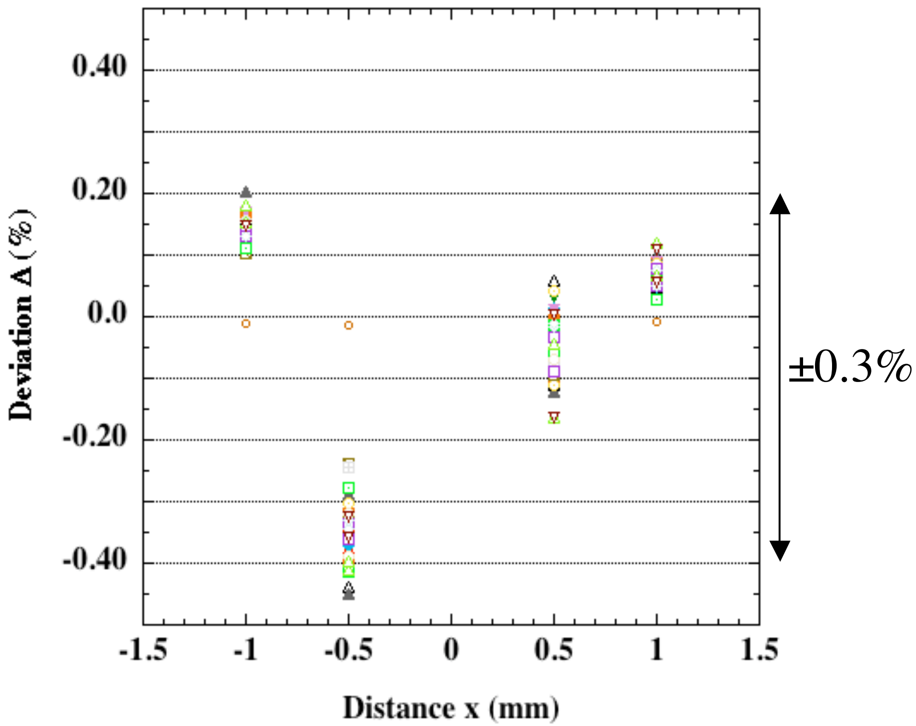
Temperature coefficient < 0.15 μm/deg.

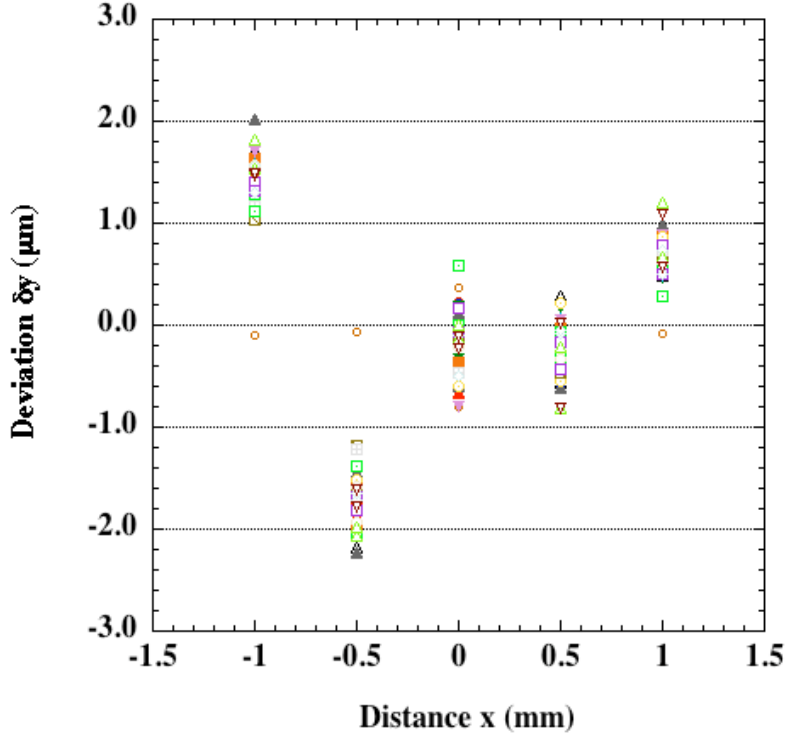
Reproducibility in a temperature cycle of 15 - 35 deg. < 1 μm.

g) Linearity

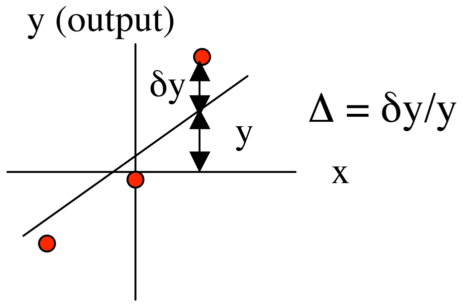
Deviation of output from a linearly fitted line for 20 sensors

$\Delta = \delta y/y$



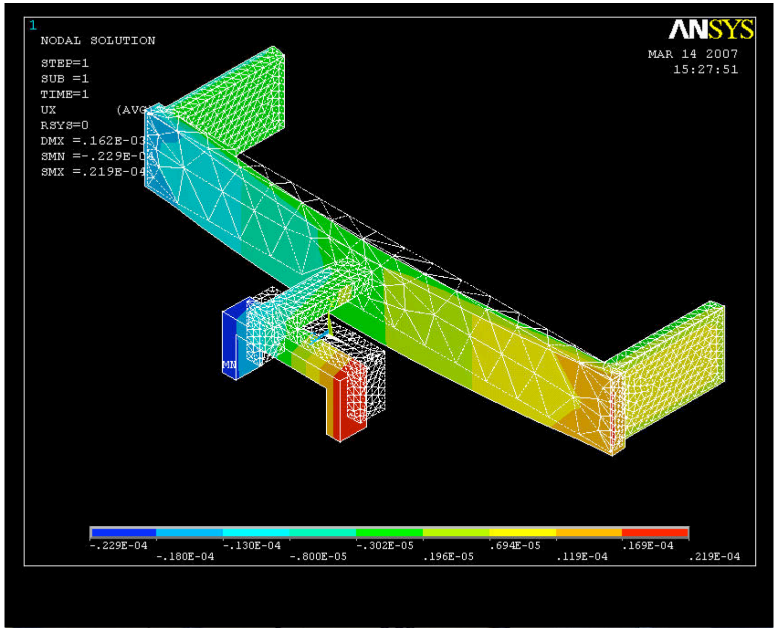


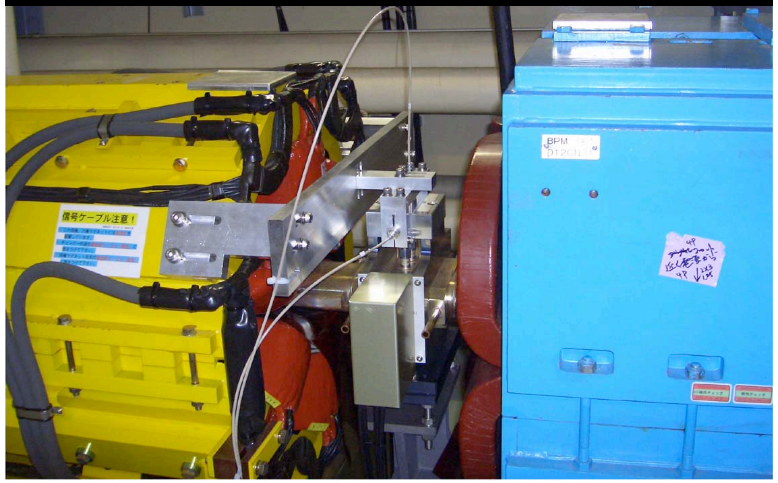
- Linearity Δ of most sensors is within ±0.3%.
- Some sensors have slightly larger linearity than the range of ±0.3%.
- Systematic large deviation at -0.5 mm is under investigation.



2) Fixing arm (M. Arinaga)

- A fixing arm is made of aluminum because of easy fabrication.
- Deformation of the fixing arm by temperature change was estimated by ANSYS.





- Result

Horizontal movement at a horizontal sensor

20μm/10 deg.

Vertical movement at a vertical sensor

5μm/10 deg.

- Stability of the tunnel temperature in operation is less than 1 deg..

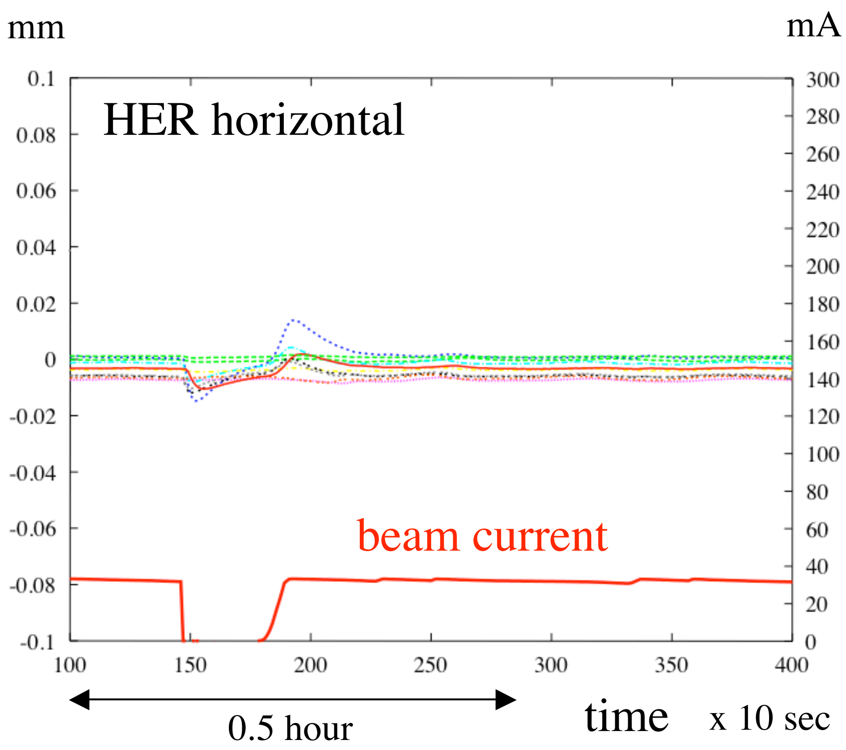
⇨ Horizontal and vertical measurement errors by the fixing arm are estimated to be less than 2μm and 0.5μm respectively.

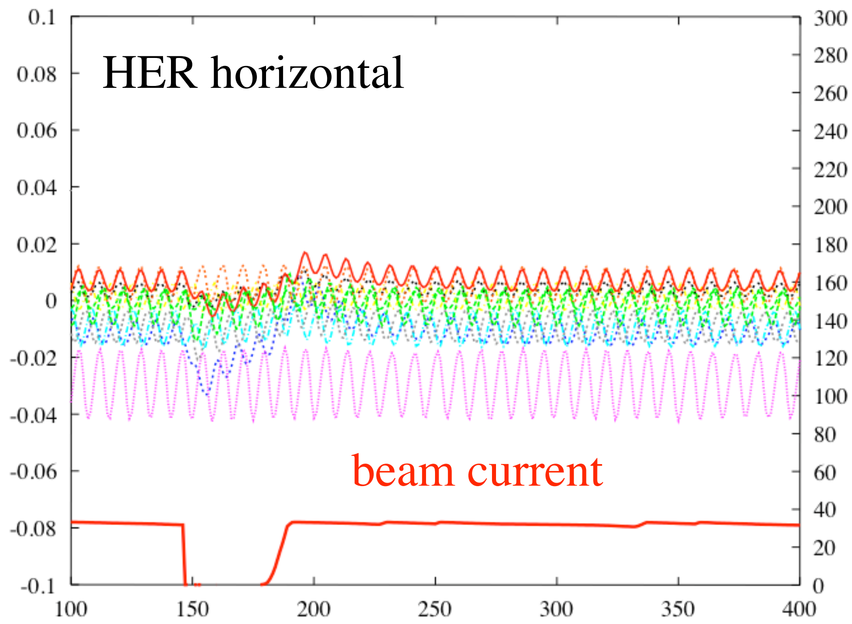
- The errors would be reduced by using materials which have a low linear expansion coefficient.

3) Recent data from the displacement monitors

- The 100 sensors were delivered in this fiscal year and 54 and 11 sensors have been installed in HER and LER, respectively.

- KEKB is being operated with low beam currents since this February, thus the displacement of BPMs is small.





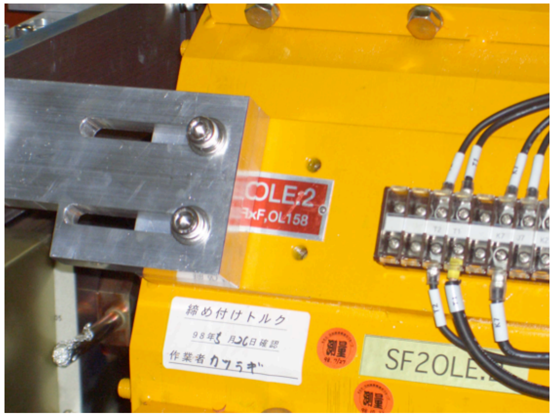
A small oscillation of a period about 90 sec is observed.

3. Installation plan

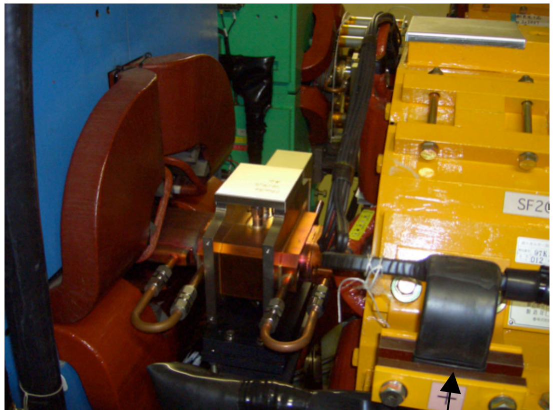
- The sensors will be installed at all sextupole magnets both in HER and LER.
- The number of the sextupoles is 108 in LER and 104 in HER.

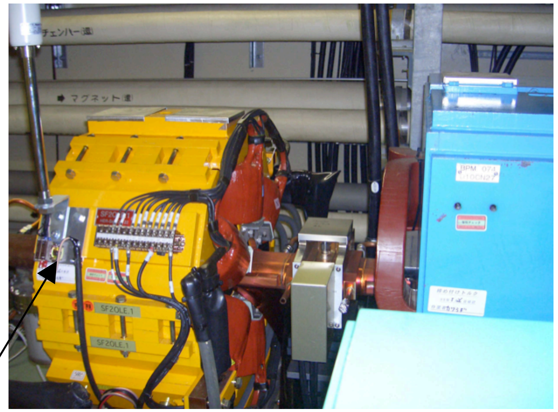
1) Problem

- The "standard" fixing arm can not be adapted for many sextupoles especially in LER.



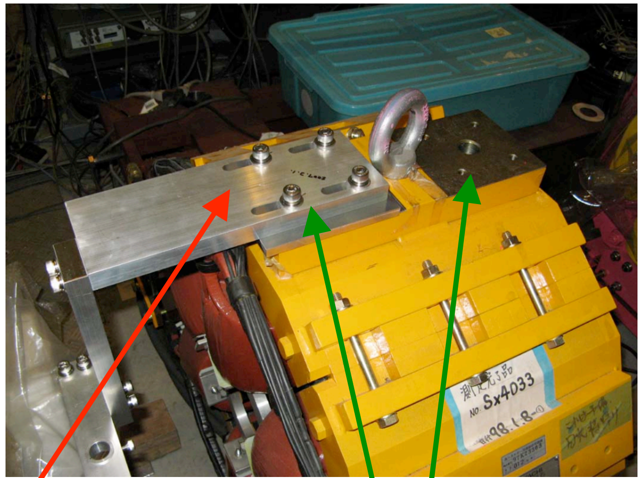
Interference with a name plate





Obstacles

- We are now discussing with the magnet group to use reference planes for the alignment of the sextupole.
- The magnet group needs time until this summer to investigate the damage of the reference planes and judge whether the reference planes can be used or not.
- Recently we started a discussion to find other ways to fix the sensor to the sextupole which do not use the reference planes.
- The design of a new fixing arm which has less thermal deformation is in progress.



Fixing arm under test.

Reference planes

2) Installation schedule

- The sensors will be installed according to the following priority list from the optics group.

  i) D-sextupoles in HER,

  ii) F-sextupoles at energy analyzers in HER and LER,

  iii) the remainder in order of the magnetic strength.

- The 100 sensors were delivered in this fiscal year and 54 and 11 sensors have been installed in HER and LER, respectively.

- The 120 sensors will be ordered in next fiscal year and delivered at the end of this September.

- If the problem to attach the fixing arm is resolved,

  the 35 sensors will be installed in this summer shut down and

  the remaining about 100 sensors will be installed in machine maintenance time in this autumn.

4. Summary

- Movement of BPMs has been observed in KEKB rings.
- The observed maximum movement is 0.9mm horizontally and 0.1mm vertically at a beam abort.
- The movement affects to the optics. We suspect that it disturbs the operation.
- A low cost electrostatic gap detector was developed in order to measure the movement of the BPM relative to the nearby sextupole and apply a correction to the BPM data.
- The gap detector has a positional resolution of 0.2μm and temperature coefficient less than 0.2μm/deg. At present, temperature dependence of the gap measurement is about 2μm/deg. due to the thermal expansion of the fixing arm. The systematic error by the nonlinearity of the gap detector is ± 2μm if a correction by a calibration curve is not applied.
- The gap detectors will be installed at all BPMs near sextupoles in both rings, hopefully in next fiscal year.

Supplement

to "BPM displacement monitor"

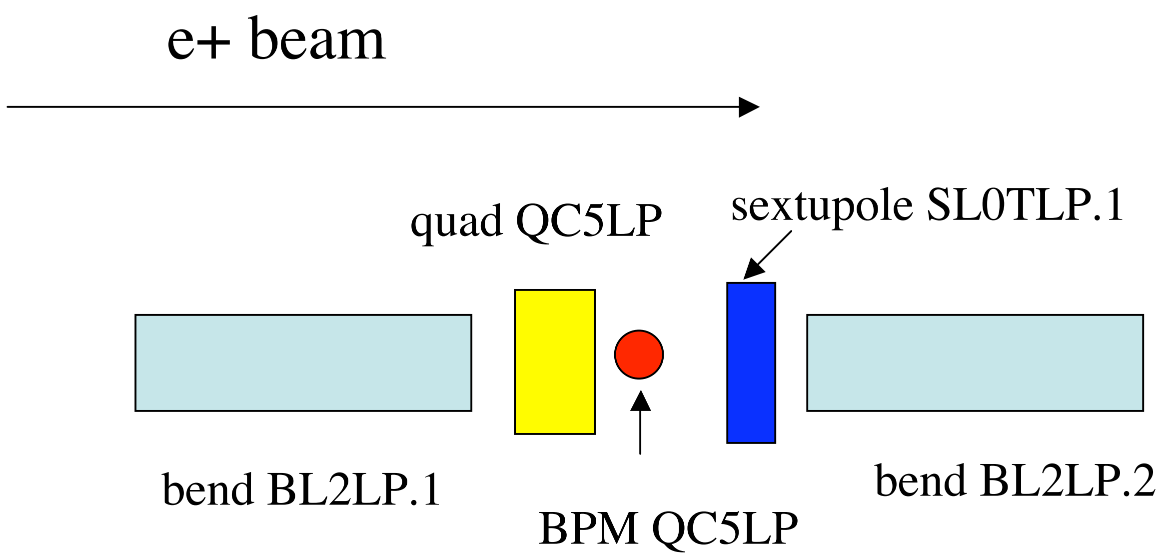
Movement of BPMs in the region of local chromaticity correction in LER

The horizontal movement of two BPMs was measured relative to nearby sextupoles and quadrupoles simultaneously.

A) Location of BPMs

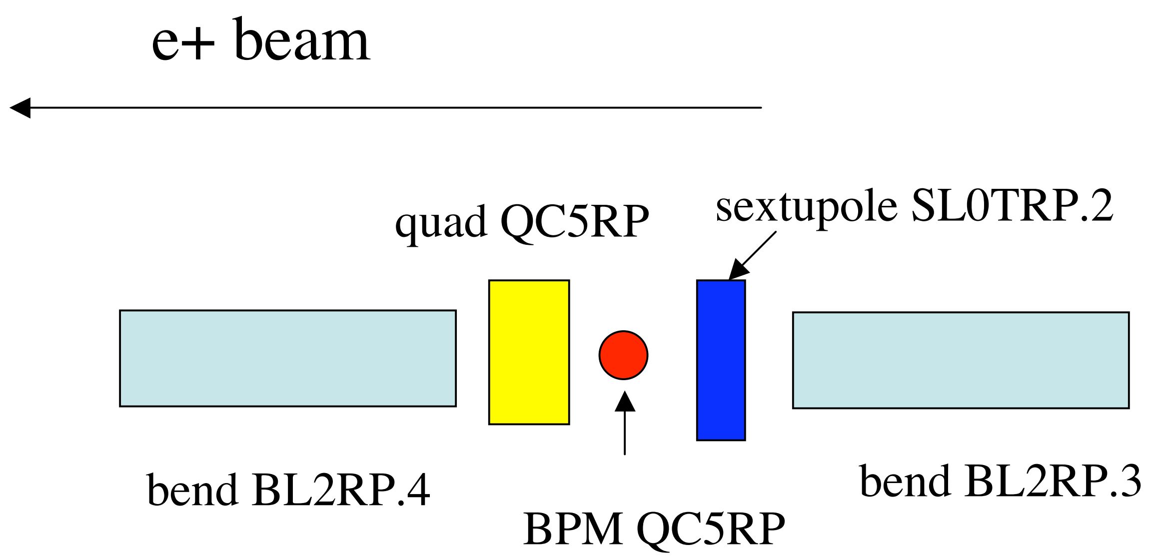
1) BPM QC5LP

Tsukuba straight section (left side)

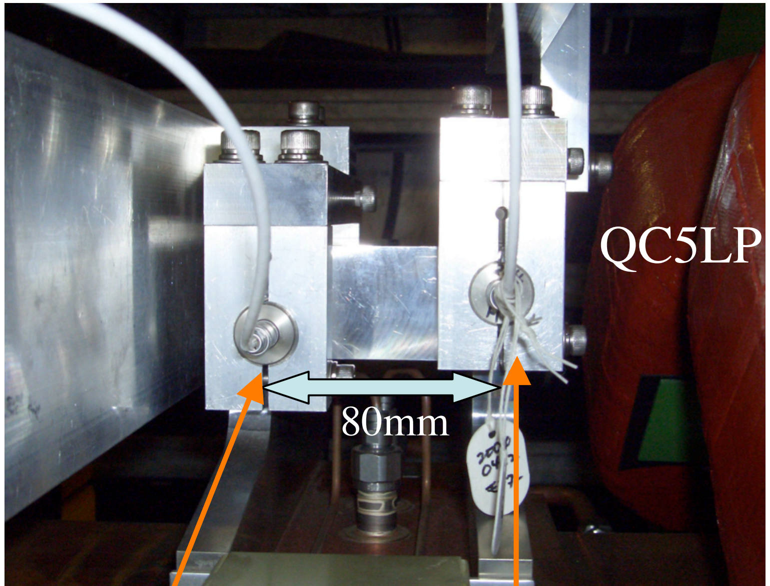


2) BPM QC5RP

Tsukuba straight section (right side)

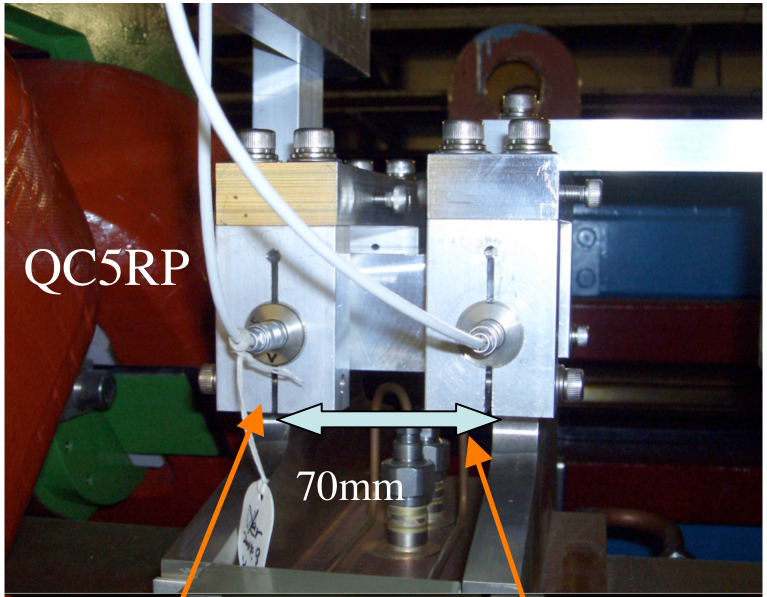


B) Pictures of the sensors



the sensor fixed to the sextupole

the sensor fixed to the quad

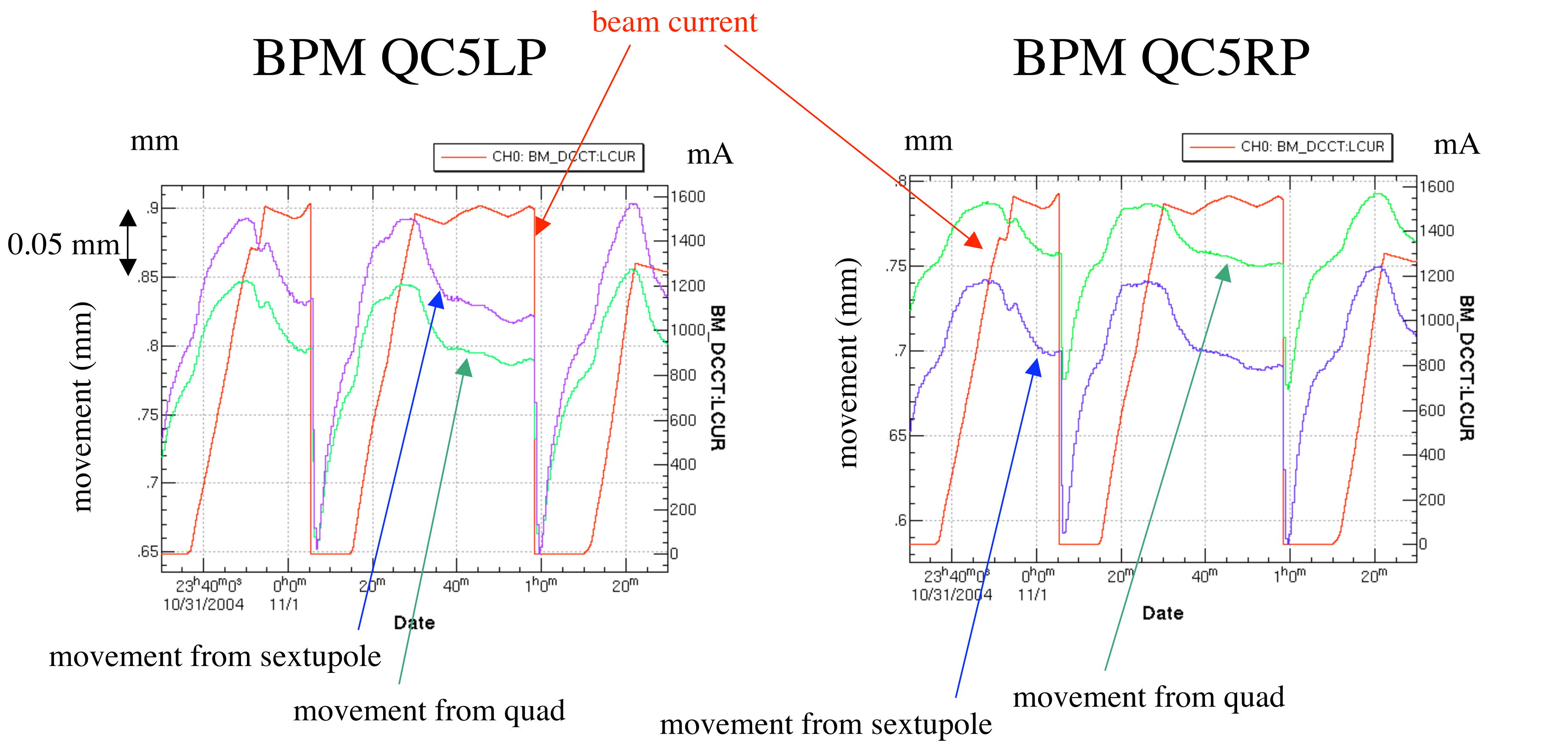


the sensor fixed to the quad

the sensor fixed to the sextupole

BPMs are fixed to quads and free from sextupoles.

C) Data (10/31/2004)



movement from the sextupole
= 1.2 x movement from the quad

movement from the sextupole
= 1.4 x movement from the quad