Fast Beam-Ion Instability
and
Photoelectron Instability

KEKB machine advisory committee (6/Mar./1998)

KEK H. Fukuma

Work after last MAC

The Internal Workshop on Multibunch Instabilities in Future Electron and Positron Accelerators
(July 15-18, 1997, KEK)

1. Fast Beam-Ion instability
   - Experiment at PLS
   - Data analysis of AR experiment

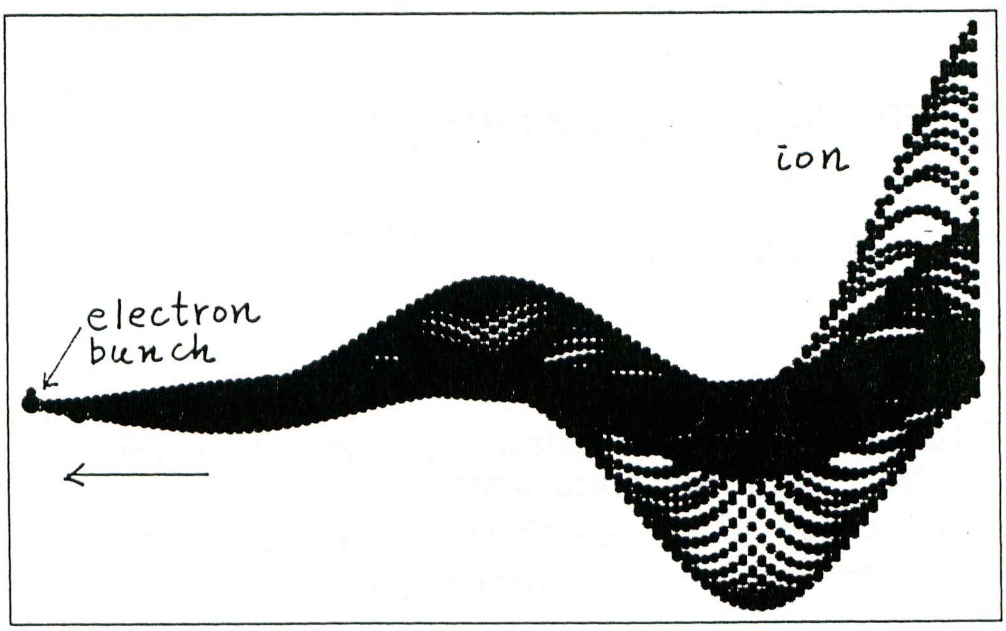
2. Photoelectron Instability
   - Measurement of secondary emission yield of Cu chamber
   - Data analysis of BEPC experiment
   - Simulation
   - Solenoid system for sweeping Photoelectron
     Design and fabrication of winding machine
   - Permanent magnet for sweeping Photoelectron

Fast Beam-Ion instability (FBII)

1. Introduction

FBII : Transient multibunch instability caused by beam-ion interaction

The ions created by the head of the bunch train affect to the tail.



Characteristics of the FBII

• Unstable mode of the oscillation

$$y_n = a_n e^{i(\Theta n - ks)} , \quad \Theta = \sqrt{\frac{2 z N m r_e L}{A M_N \Sigma_y (\Sigma_x + \Sigma_y)}}$$

(n : bunch id)

• Amplitude growth factor G

$$G = \left| \frac{a_n}{a_o} \right| \approx 1 + \frac{1}{\Gamma} e^{\sqrt{\Gamma}} , \quad \Gamma = \sqrt{\frac{2m}{M_N} \frac{\beta_y \sqrt{L}}{\gamma} \frac{n_g \sigma_i}{\sqrt{A}} \left[\frac{r_e z N}{\Sigma_x \Sigma_y} \right]^{\frac{2}{3}}} \, s n^2$$

• Tune shift along the bunch train

$$\Delta \nu_y = R K n , \quad K = \frac{z n_i r_e \beta_y}{\gamma \Sigma_y (\Sigma_x + \Sigma_y)}$$

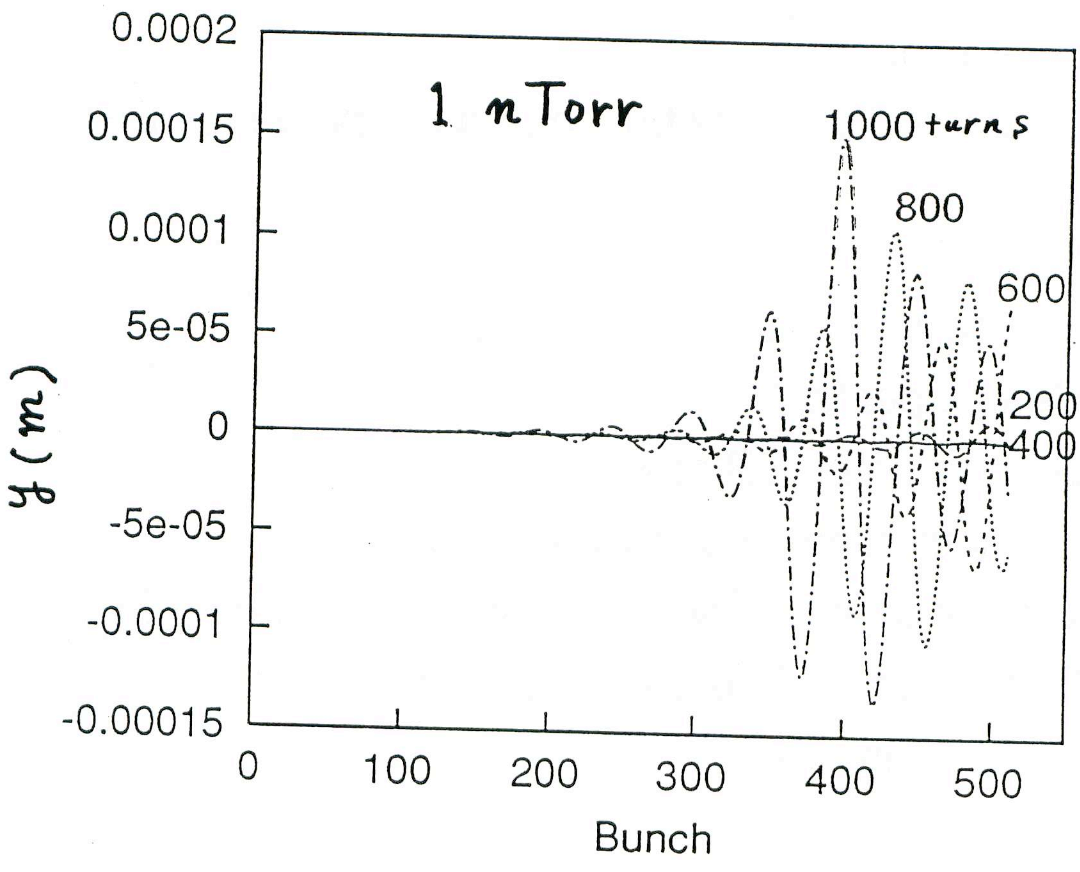
L : distance between bunches, N : number of electrons / bunch,
m, M_N : electron and nucleon mass,
$\Sigma_{x,y}$: convolution of beam size of electrons and ions,
k : betatron wave number; σ_i : ionization cross section,

n_g : number density of the residual gas.

Effect on KEKB

- Simulation (K. Ohmi)

Growth rate : 1ms



2. Experiment

1) ALS(LBL)

- He gas injection
- Beam spectrum
- Beam size by SR monitor
- Oscillation amplitude by scraper

2) AR(KEK)

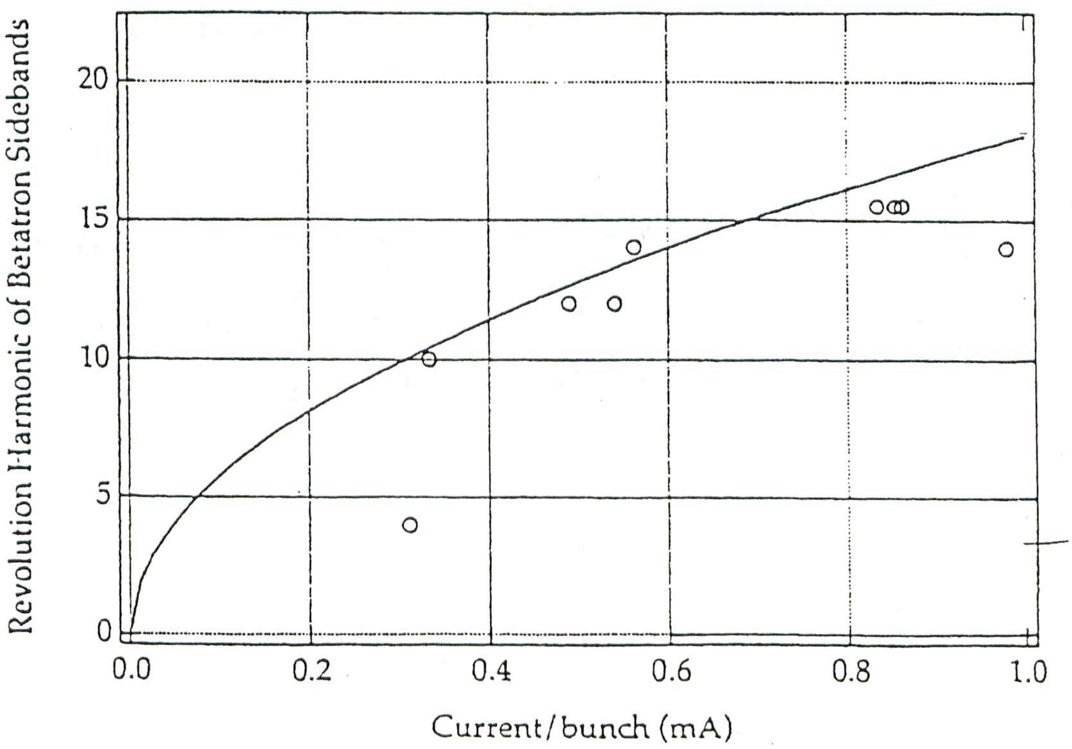
- N_2 gas injection
- Beam spectrum
- Oscillation of every bunch and every turn by BPM

3) PLS(PAL)

- He gas injection
- Beam spectrum
- Beam size by SR monitor
- Oscillation amplitude by scraper
- Oscillation of every bunch and every turn by BPM
- Oscillation and beam size along bunch train by streak camera

1) ALS (J. Byrd et al.)

- He was injected.
- Peak position of spectrum distribution agrees with theoretical ion frequency.
- Change of He peak with beam current agrees with theory.
- Oscillation amplitude grows along the bunch train(indirect observation by scraper).
- Instability threshold is very close to expected value.
- Beam size saturates at 2-3 σ_y.



2) AR

- N_2 was injected.

- Amplitude of the bunch oscillation along the bunch train increases from the head to the tail.

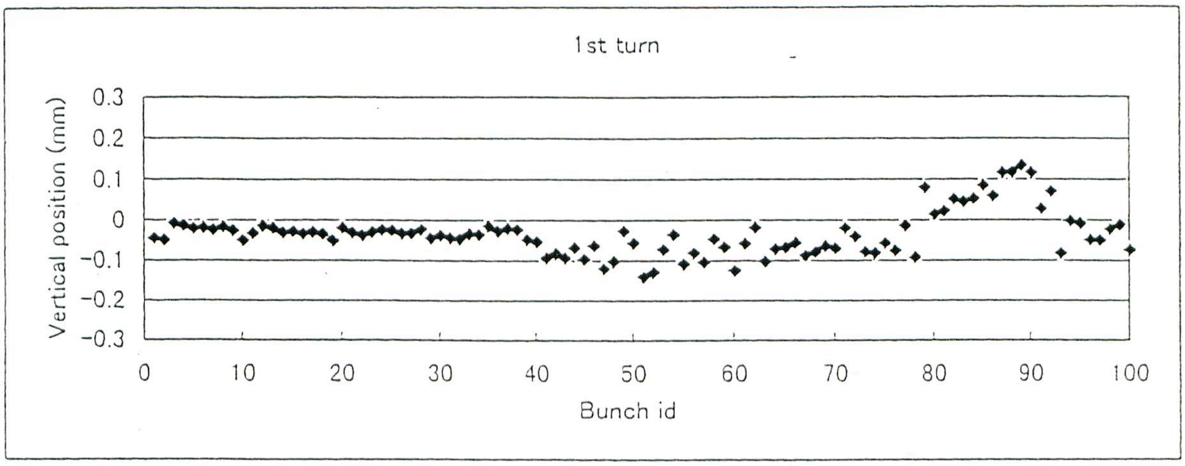
- Normalized phase advance of the bunch oscillation along the bunch train is about factor of 2 smaller than that of prediction by the linear theory.

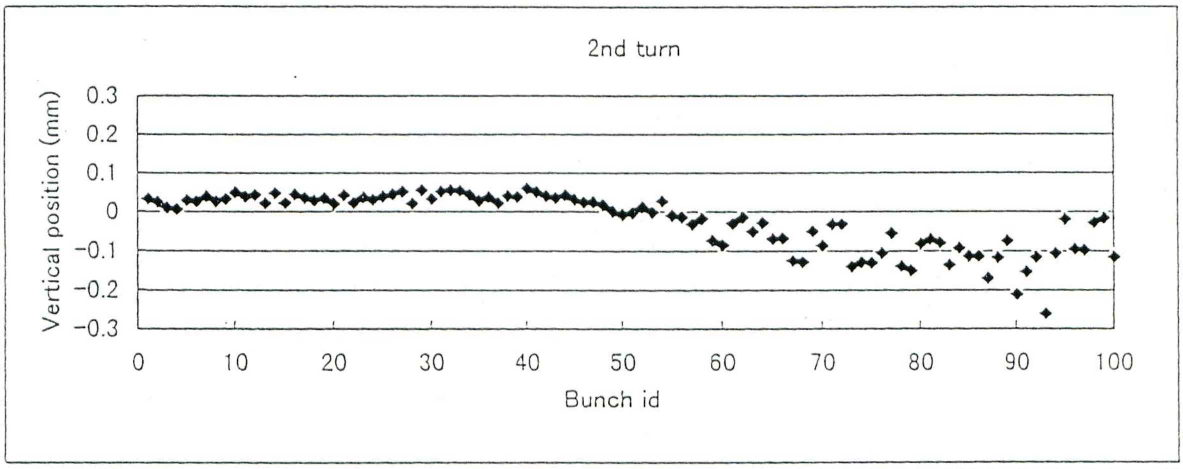
- Amplitude growth after turning off the bunch feedback is consistent with the simulation.

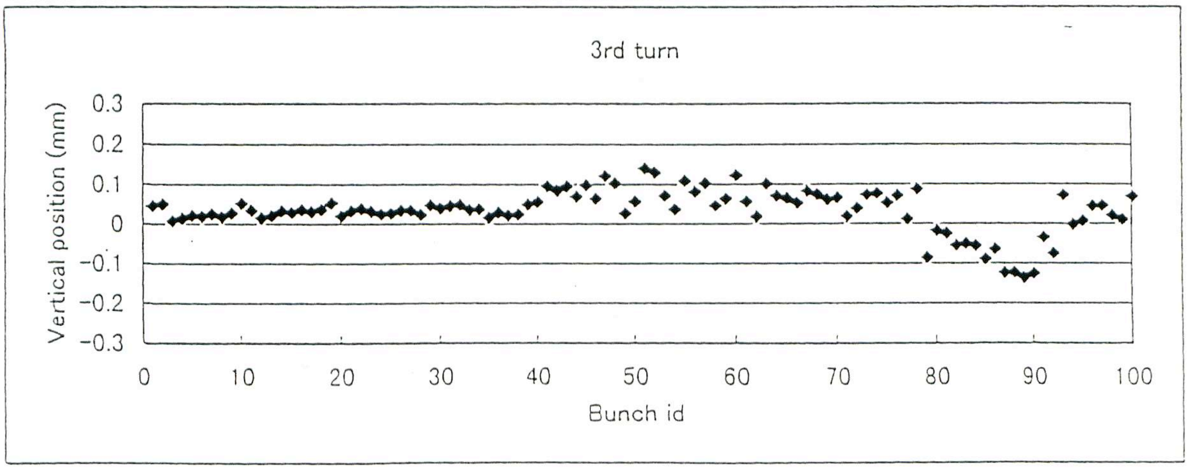
- Saturation of the oscillation amplitude was observed.

- Tune shift of the bunch along the bunch train does not increase towards the end of the train, which is not explained by the linear theory.

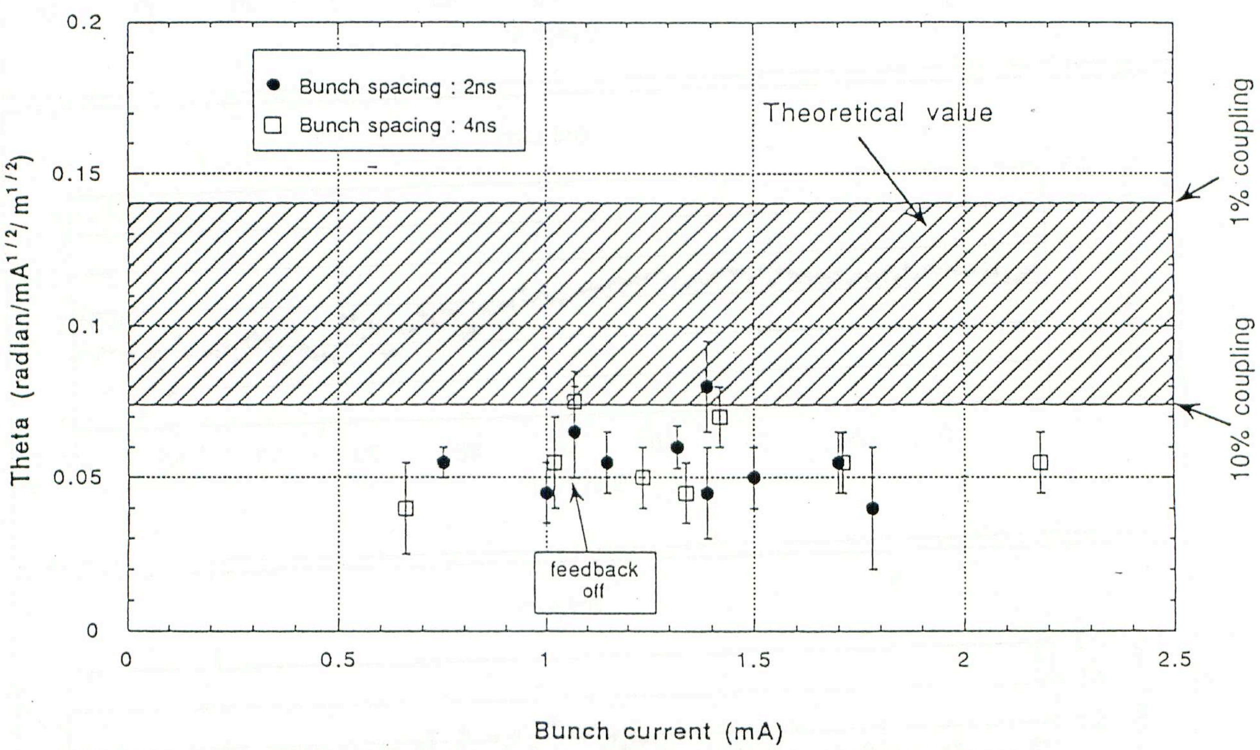
100 bunches, 2 ns bunch spacing, 170 mA,
feedback damping time 1.9 ms, vacuum pressure 16.1 μPa



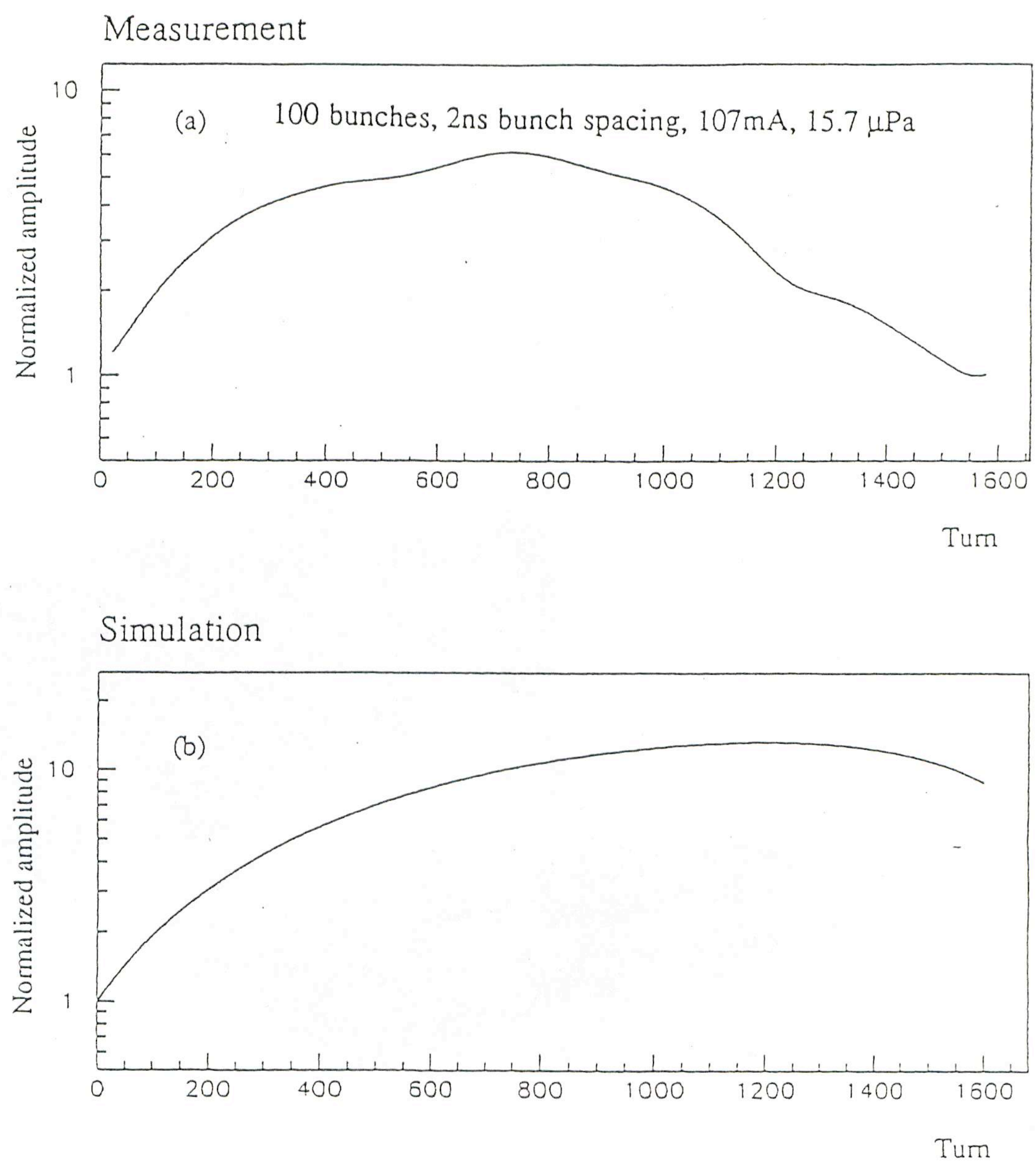




Oscillation pattern along the bunch train.

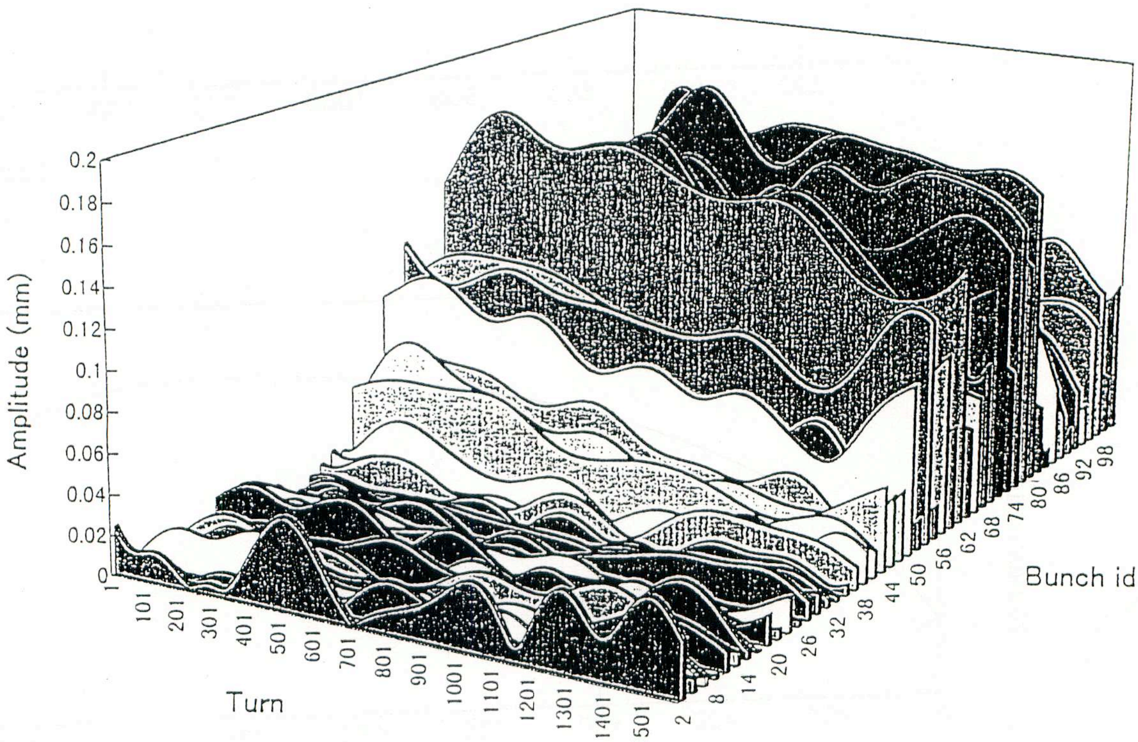


Normalized phase advance of the bunch oscillation.



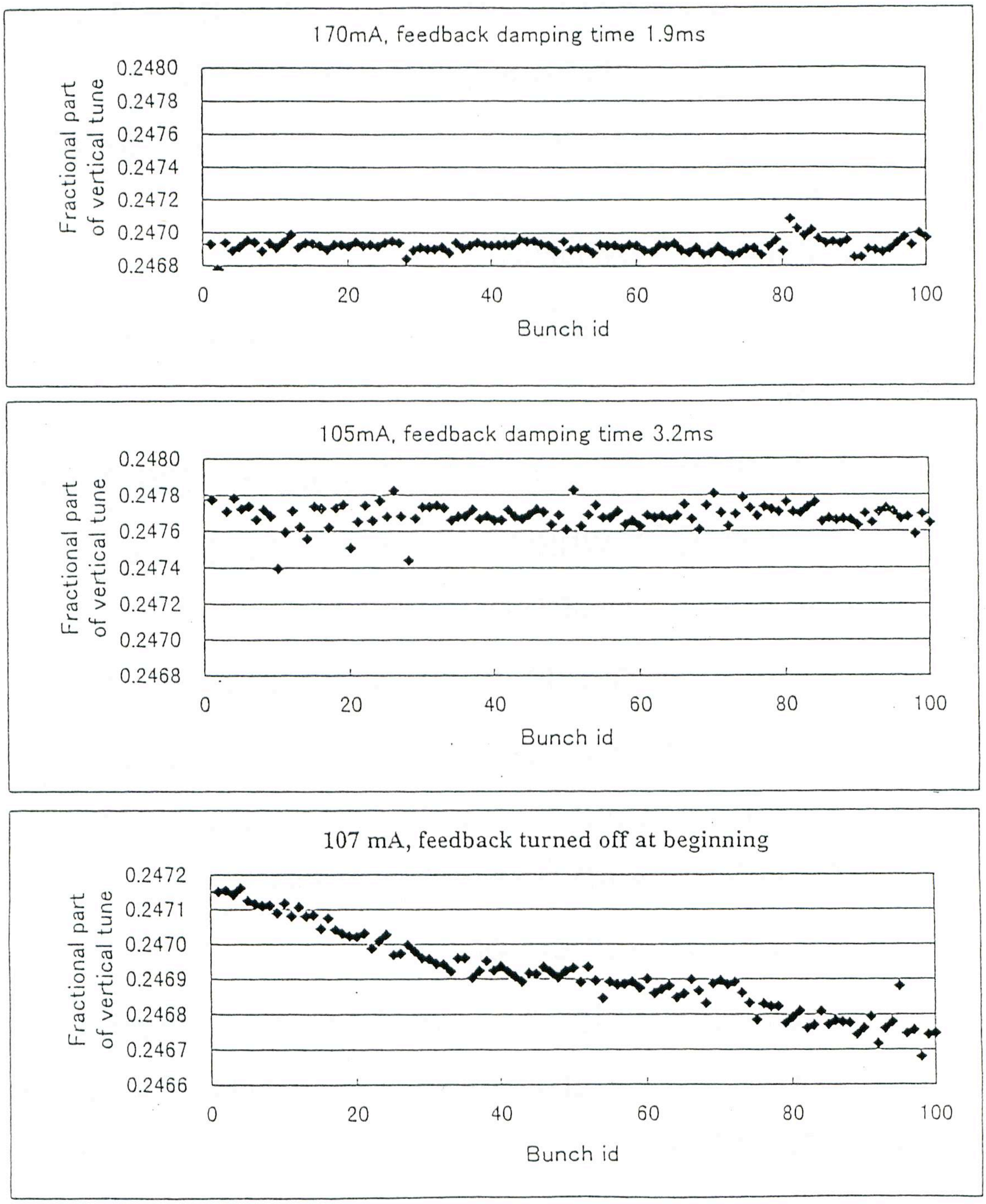
Amplitude growth of a bunch after turning off the bunch feedback.

100 bunches, 2 ns bunch spacing, 170 mA,
feedback damping time 1.9 ms, vacuum pressure 16.1 μPa



Amplitude of the bunch oscillation as a function of time and bunch id.

100 bunches, 2 ns bunch spacing,
vacuum pressure 16.1 μPa



Tune of the bunch along the bunch train.

3) PLS (M. Kwon, Y. H. Chin et al.)

- Peak position of spectrum distribution
  He : agrees with theoretical ion frequency
  CO : factor 2 smaller than theory
- Change of He peak with beam current agrees with theory.
- Observation by BPM
  - Oscillation amplitude increases along the bunch train.
  - Oscillation phase decreases by 4 π rad along the bunch train, which is consistent with theory.
- Observation by streak camera
  - Without He gas injection and turning off all ion pumps, clear snake-tail oscillation with the wave length of about 57m was observed, which is consistent with BPM observation.
  - With He gas injection,
    oscillation which has smaller wave length appeared. Ion frequency was 7 MHz (beam-He interaction).
  - Beam size grows along the train and saturated at about 2 σ_y.

- Effect of bunch gap on bunch oscillation
  - Two bunch trains with a gap were stored .
  - All ion pumps were turned off (Major ions are CO).
  - Bunch oscillation was observed by streak camera.
  - Result

    1) Single bunch train

    ♦ 264 bunches + 200 empty buckets(e.b.)

    Oscillation was observed.

    2) Two bunch train

    ♦ 134 bunches + 25 e.b. + 134 bunches + 175 e.b.

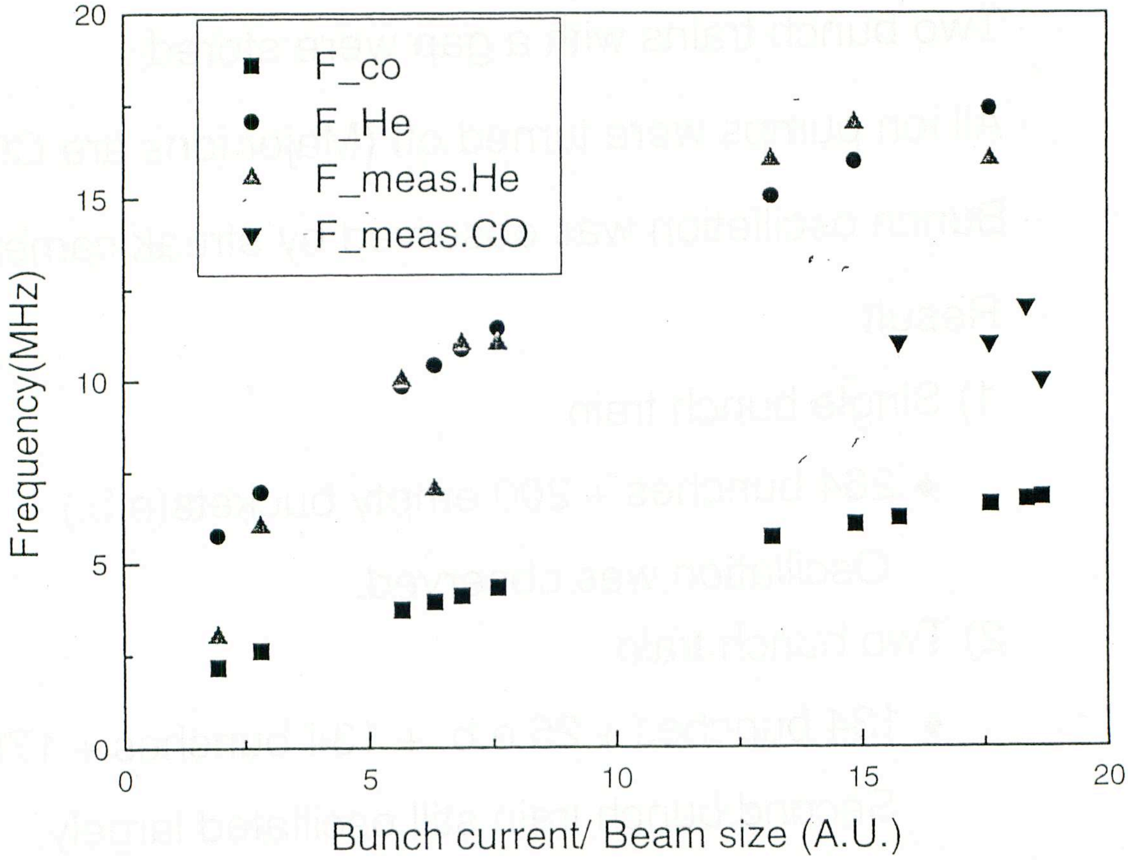
    Second bunch train still oscillated largely.

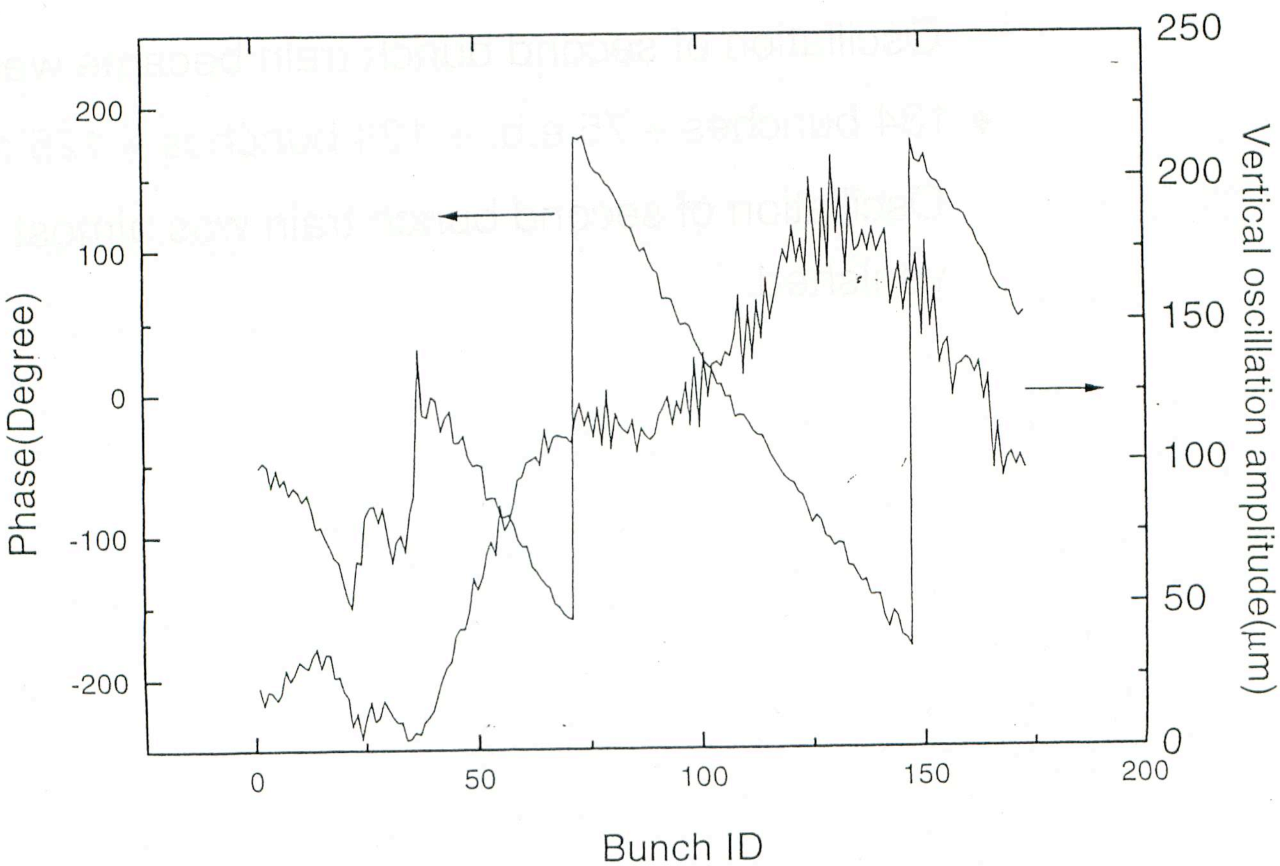
    ♦ 134 bunches + 50 e.b. + 134 bunches + 150 e.b.

    Oscillation of second bunch train became weaker.

    ♦ 134 bunches + 75 e.b. + 134 bunches + 125 e.b.

    Oscillation of second bunch train was almost vanished.

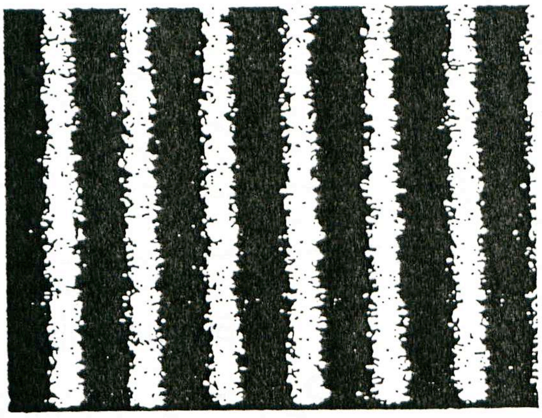

F_co
F_He
F_meas.He
F_meas.CO
Frequency(MHz)
Bunch current/ Beam size (A.U.)
0
5
10
15
20


Phase(Degree)
Vertical oscillation amplitude(μm)
Bunch ID
200
100
0
-100
-200
250
150
50
0
50
100
150
200

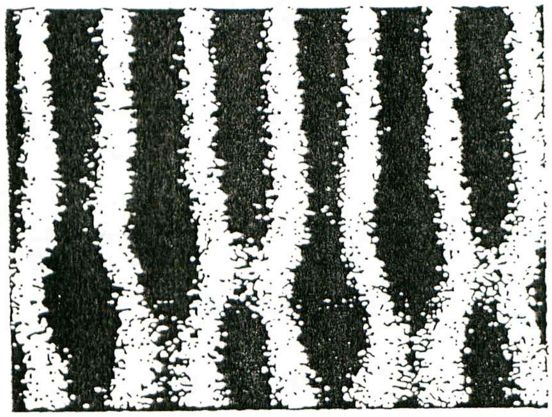
Observation by streak camera

P = 0.4 n Torr (normal)

P = 1 n Torr (Turn off ion pumps)



(a)

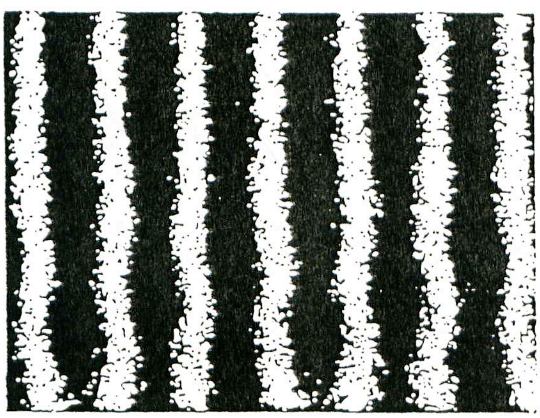


(b)

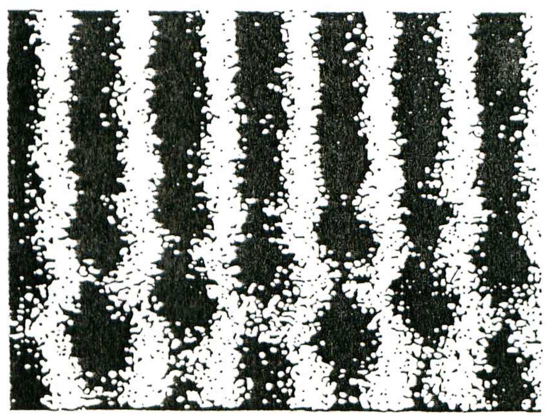
After He injection

P_{He} = 0.2 n Torr

P_{He} = 3.34 n Torr

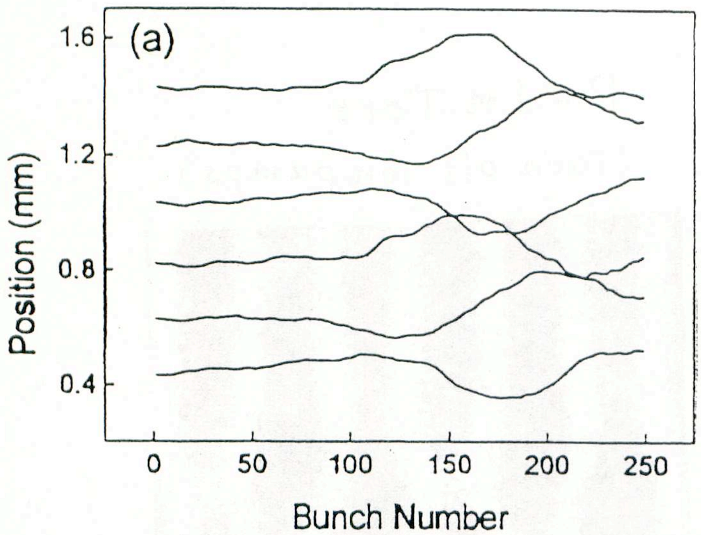


(a)

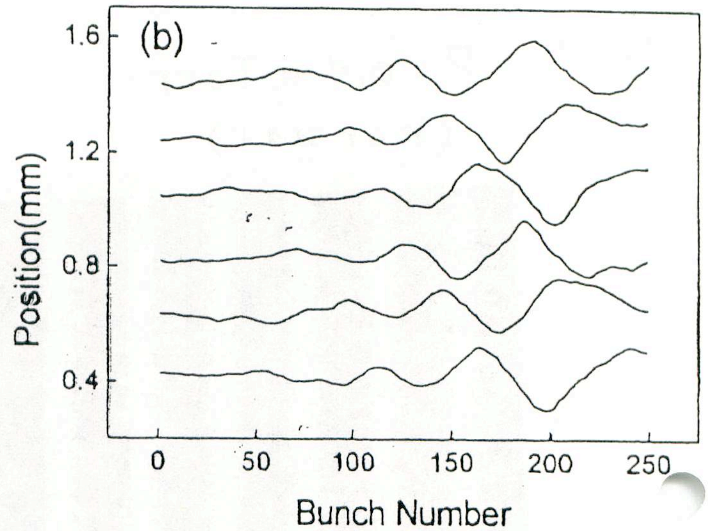


(b)

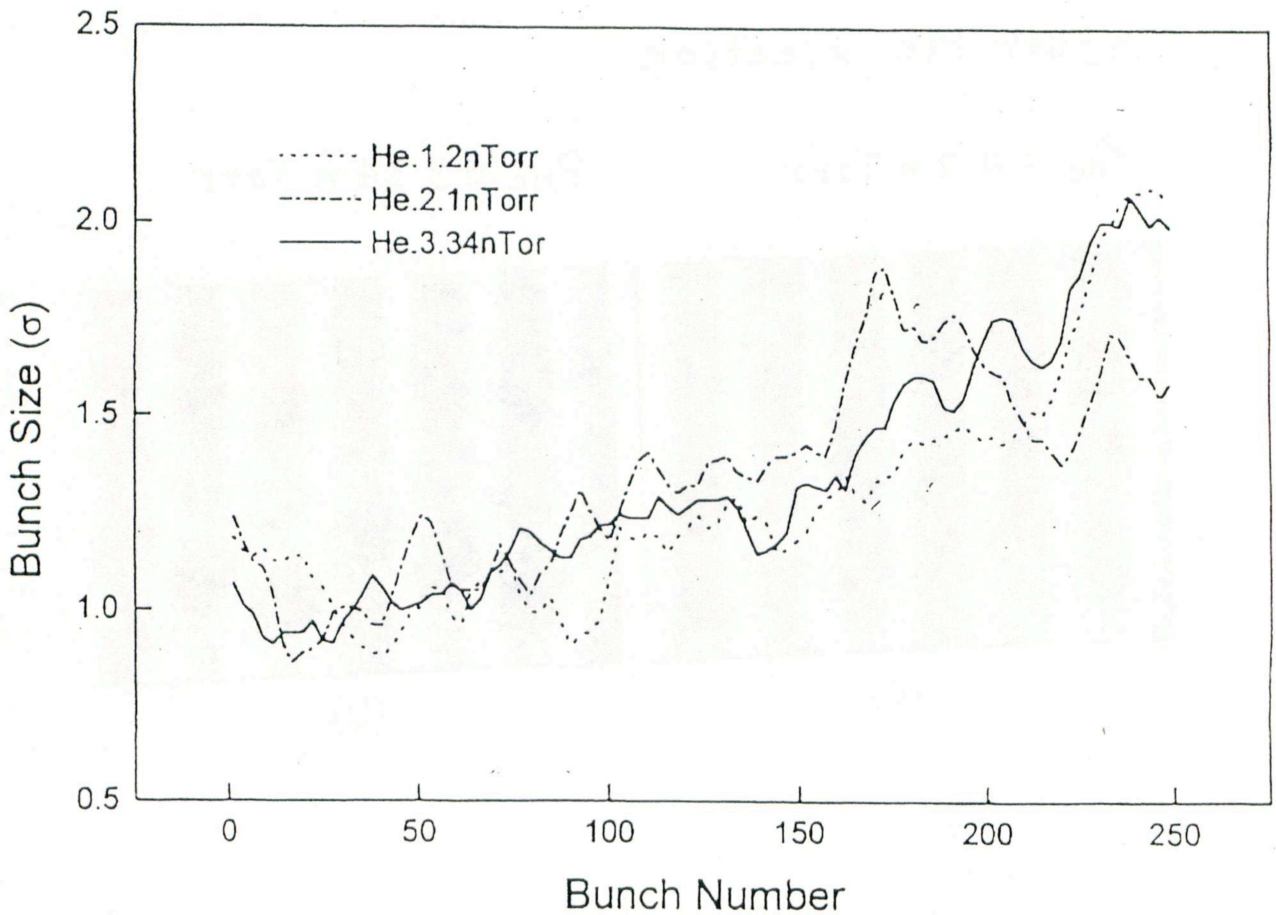
Montain views (The amplitude is 5 times magnified.)



P = 1 n Torr
without He injection



P_{He} = 3.34 n Torr



3. Cure

According to Ohmi's simulation,

Growth rate of FBII is ≈ 1 ms for train of 500 bunches.

1) Bunch feedback system

Damping time of transverse feedback system of HER is≈ 1 ms.

Damping time of bunch feedback system is marginal to suppress FBII.

2) Bunch gap

By simulation, 100 vacant buckets after train of 500 bunch is enough to avoid FBII.

The experiment at PLS supports this solution.

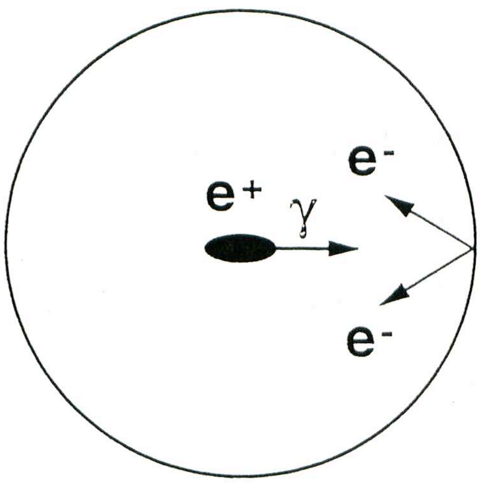
4. Summary

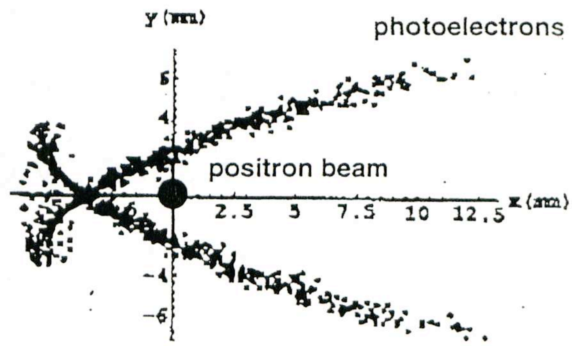
1) According to the experiments, there is a good possibility that FBII is really exists.

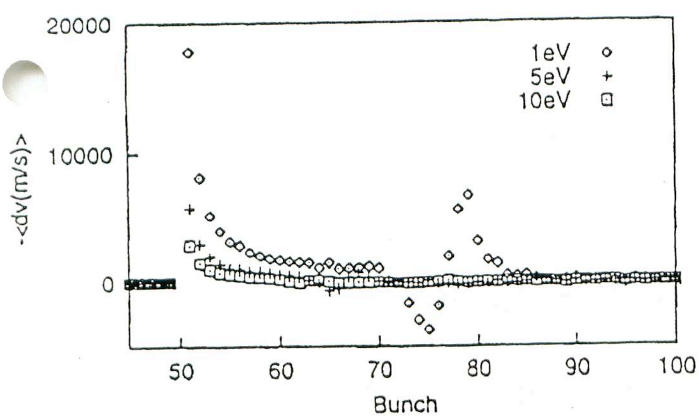
2) In KEKB, FBII will be cured by the bunch feedback system and introduction of the bunch gap.

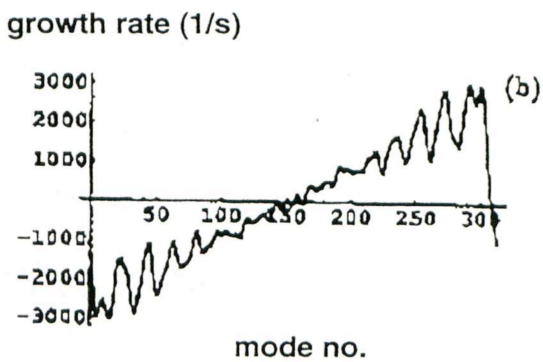
Photoelectron Instability (PEI)

1. Introduction









2. Measurement of secondary emission yield δ

(S. Kato et al.)

- Secondary emission yield of Cu vacuum chamber was measured.

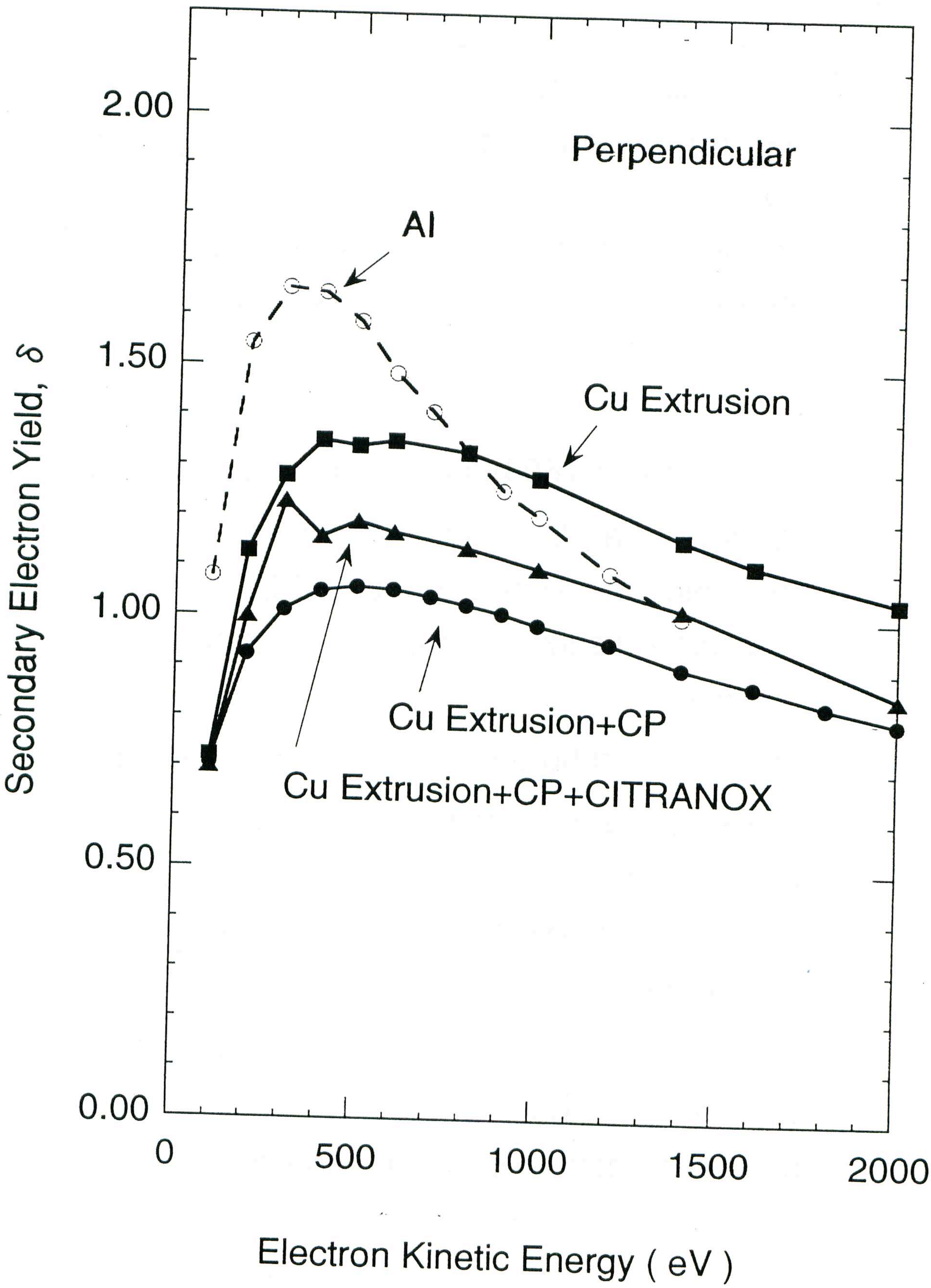
- KEKB Cu vacuum chamber

1) Extrusion + Chemical polishing (CP)
   (730 m of straight section)
   · Polished by CP by ≈ 1100 nm
   · Thin (2 nm) CuO on surface
   · $\delta \approx$ **1.05**

2) Extrusion + CP + CITRANOX polishing
   (1731 m of arc section)
   · Graphitized after exposed to the air
   · $\delta \approx$ **1.2**

3) Extrusion + CITRANOX polishing
   (465 m of arc section)
   · Polished by CITRANOX ≈ 20 nm
   · Contaminated thick oxide on surface
   · **$1.2 < \delta < 1.4$**

Measurement of Secondary Electron Yield



3. Simulation study of PEI experiment at BEPC
(Z. Y. Guo)

- Ohmi's code was used.
- whole ring is assumed to be constructed by field free region.
- Linear wake method was used after confirmed that it gives same results as tracking method.

- Result
  - · Growth time in 160 bunch-filling is consistent with calculated Landau damping time.
    (In experimental condition at BEPC,
    a calculation shows that Landau damping is dominant.)
  - · Growth time in 80 bunch-filling (i.e. every two buckets are vacant) is almost same as in 160 bunch-filling.
    In experiment no broad band spectrum was observed in 80 bunch-filling.
  - · Horizontal oscillation as well as vertical one appears in simulation.
    In experiment no broad band spectrum was observed in horizontal plane.

- Next experiment

  1) Bunch oscillation will be observed by single pass BPM system.

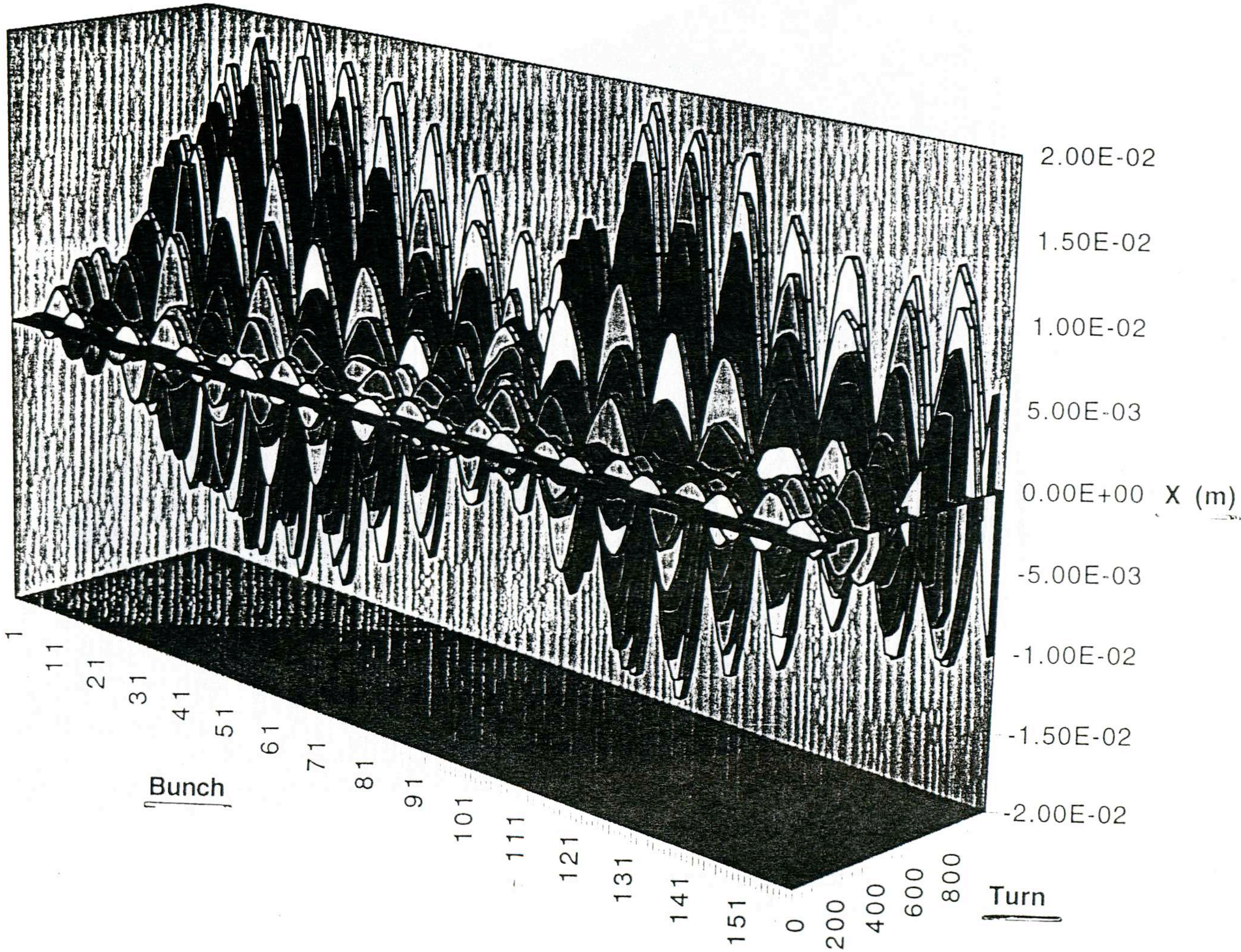
  2) Damping time will be measured to get the PEI growth rate.

  3) Schedule is not fixed (probably this May).

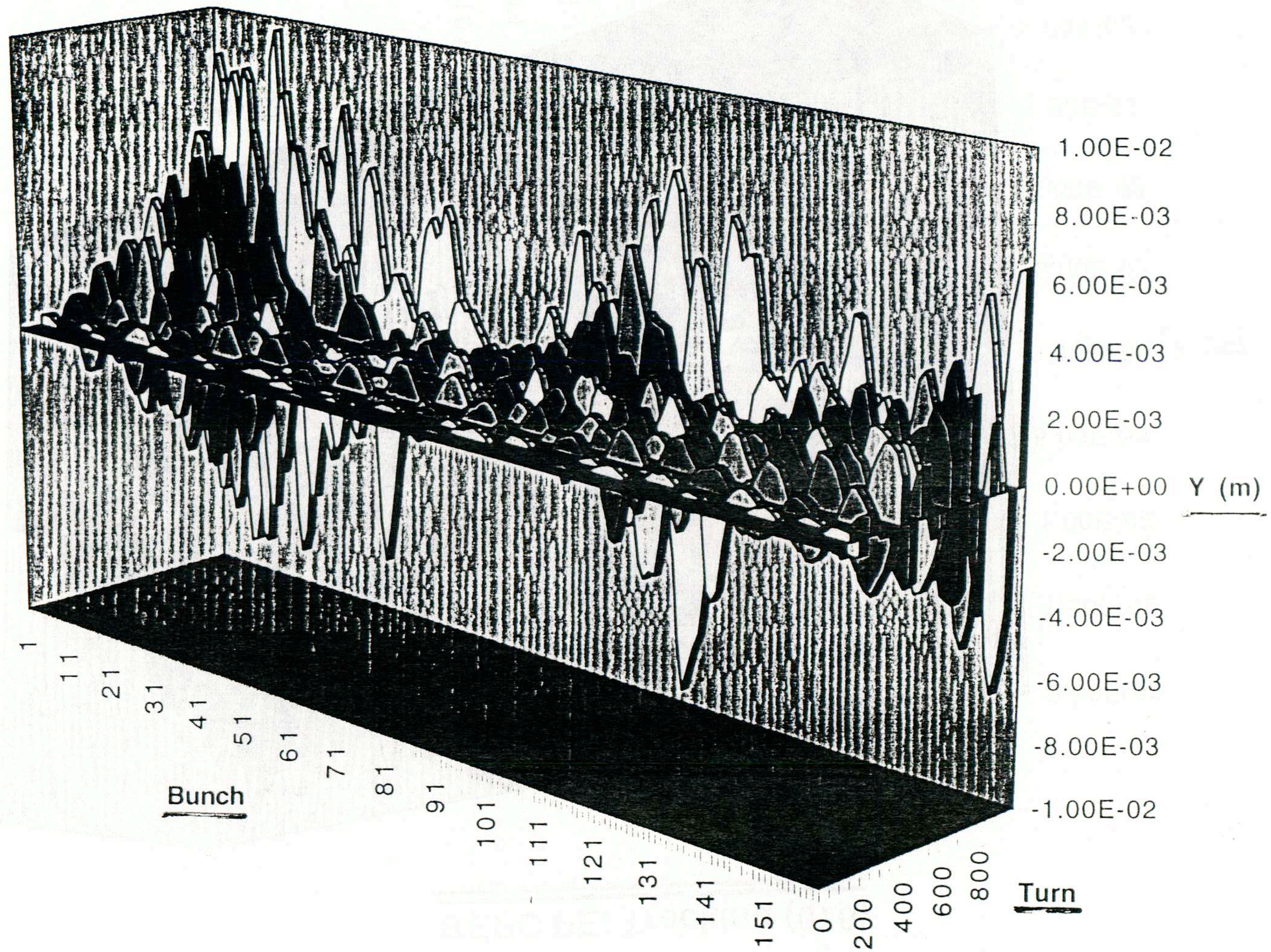
Growth rate of PEI by simulation (BEPC)

E GeV	e^+/bunch E8	ε_x E-7 (m)	ε_y E-7 (m)	ξ_{xy}	τ_{growth} ms	τ_{Landau} ms
1.3	2.65	1.35	0.068	4	15	9
1.3	3.17	1.36	0.014	4	10	9
1.3	3.47	1.25	0.151	4	9	9
1.3	3.49	1.29	0.130	4	9	9
1.3	3.51	1.35	0.068	4	8	9
1.3	3.95	1.36	0.014	4	7	9
1.3	5.46	1.90	0.100	8	3	5
1.3	5.68	3.08	0.155	4	3	9
1.55	3.14	1.92	0.097	7.5	11	4
1.7	3.14	2.31	0.117	6.5	11	3
1.85	3.14	2.74	0.138	7	11	3

BEPC PEI Tracking (076)



BEPC PEI Tracking (076)



20 I_0

1000 Turn

4. Progress of Simulation work(K. Ohmi)

1) Development of tracking method

Linear wake method

Assuming linearity & superposition of wake force

•Tracking method

Free from above assumptions

(, but time consuming)

⇒ Two methods give the almost same growth rate.

This justifies the assumption of the linear wake.

2) Comparison of experiment and simulation about the instability at KEK PF

- Experiment

  Growth time < 350 turns at beam current 300 mA.

  (Landau damping time ≈ 350 turns)

- Simulation

  Assuming Y(photoelectron conversion rate) = 0.1 and taking into account space charge effect, growth time is 500 turns.

Result of simulation and experiment is consistent each other.

3) Comparison of growth time by three simulation codes

Codes by M. Furman, K. Ohmi and F. Zimmermann

		KEKB		PEP II
Y		0.2	1	Y(eff)=0.01
space charge		no	yes	no
growth time(ms)	Furman	0.30	0.04	1.2
	Ohmi	0.46	0.02	1.2
	Zimmermann	-	0.06	0.3

The results by three codes are consistent each other.

4) Simulation results in KEKB

- Growth time

  Beam current 2.6A, with space charge effect

  Photoelectrons generated in field free regions

Y'	1	0.2
Growth time(ms)	0.03	0.15

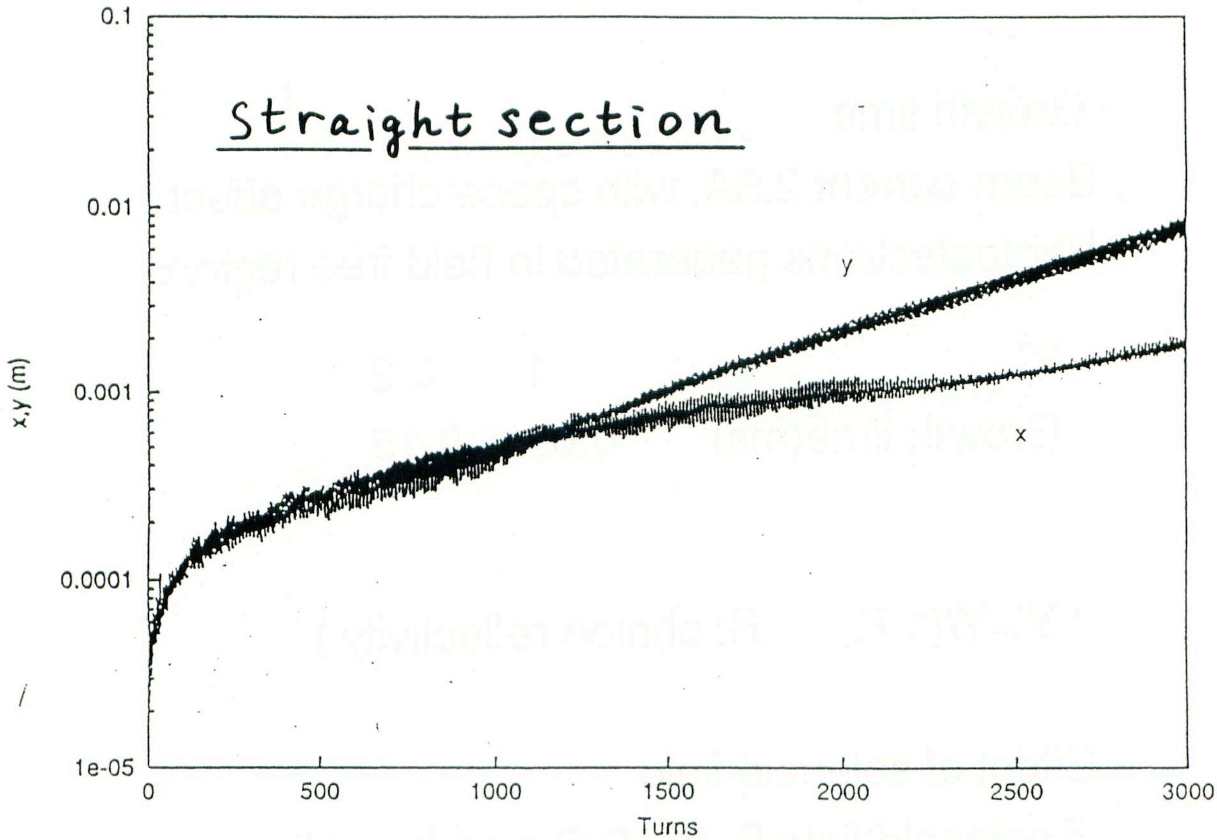
(Y'=Y/(1-R)   R: photon reflectivity)

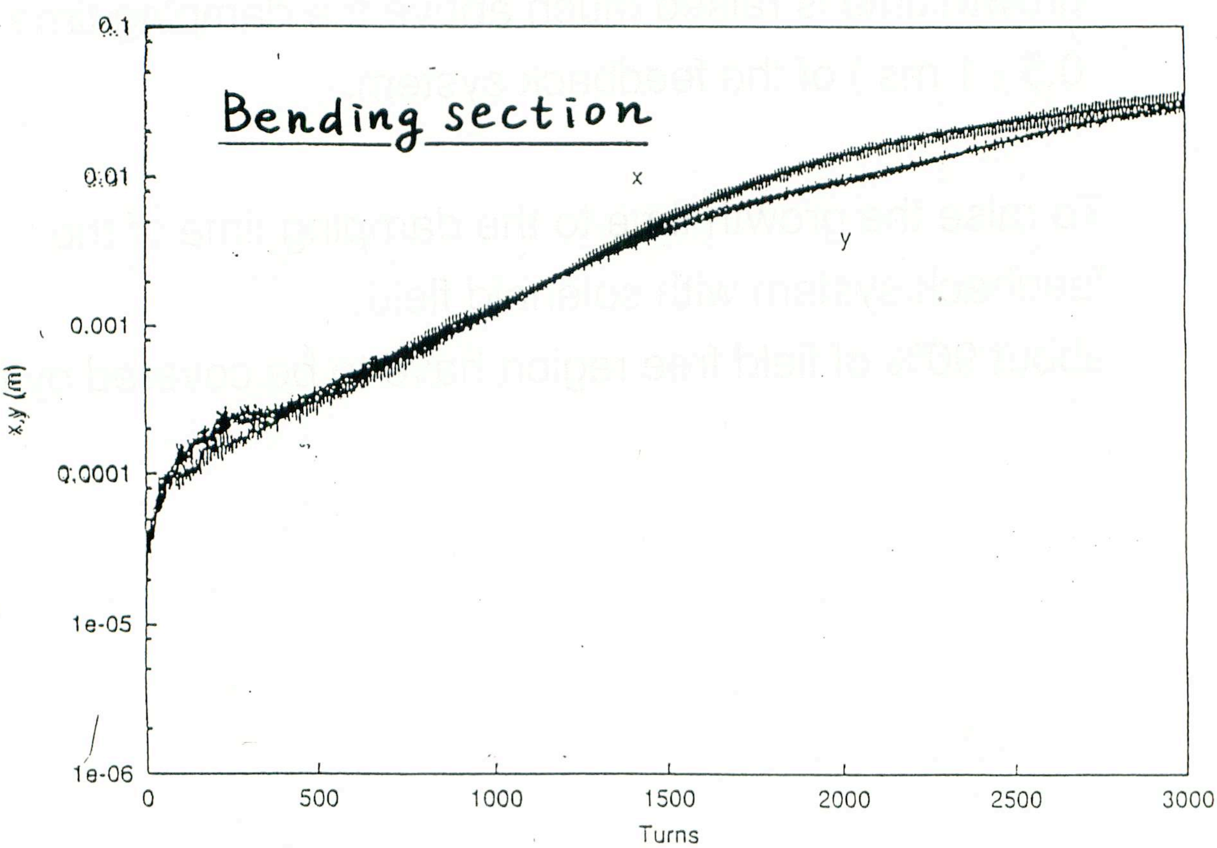
- Effect of solenoid field

  If solenoid field B_z of 30 Gauss is applied,
  growth time is raised much above the damping time (0.5 - 1 ms) of the feedback system.

To raise the growth time to the damping time of the feedback system with solenoid field,
about 90% of field free region have to be covered by it.

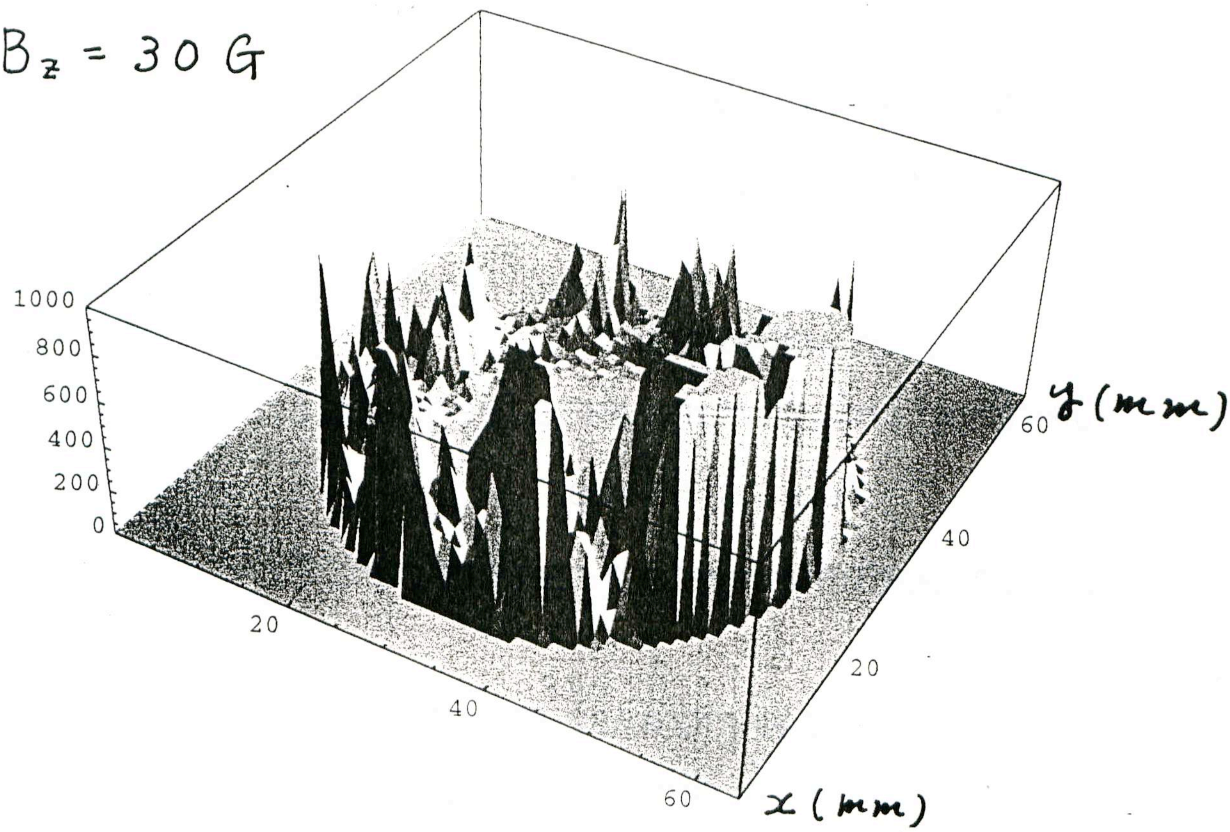
I = 300 mA (PF) (Simulation)



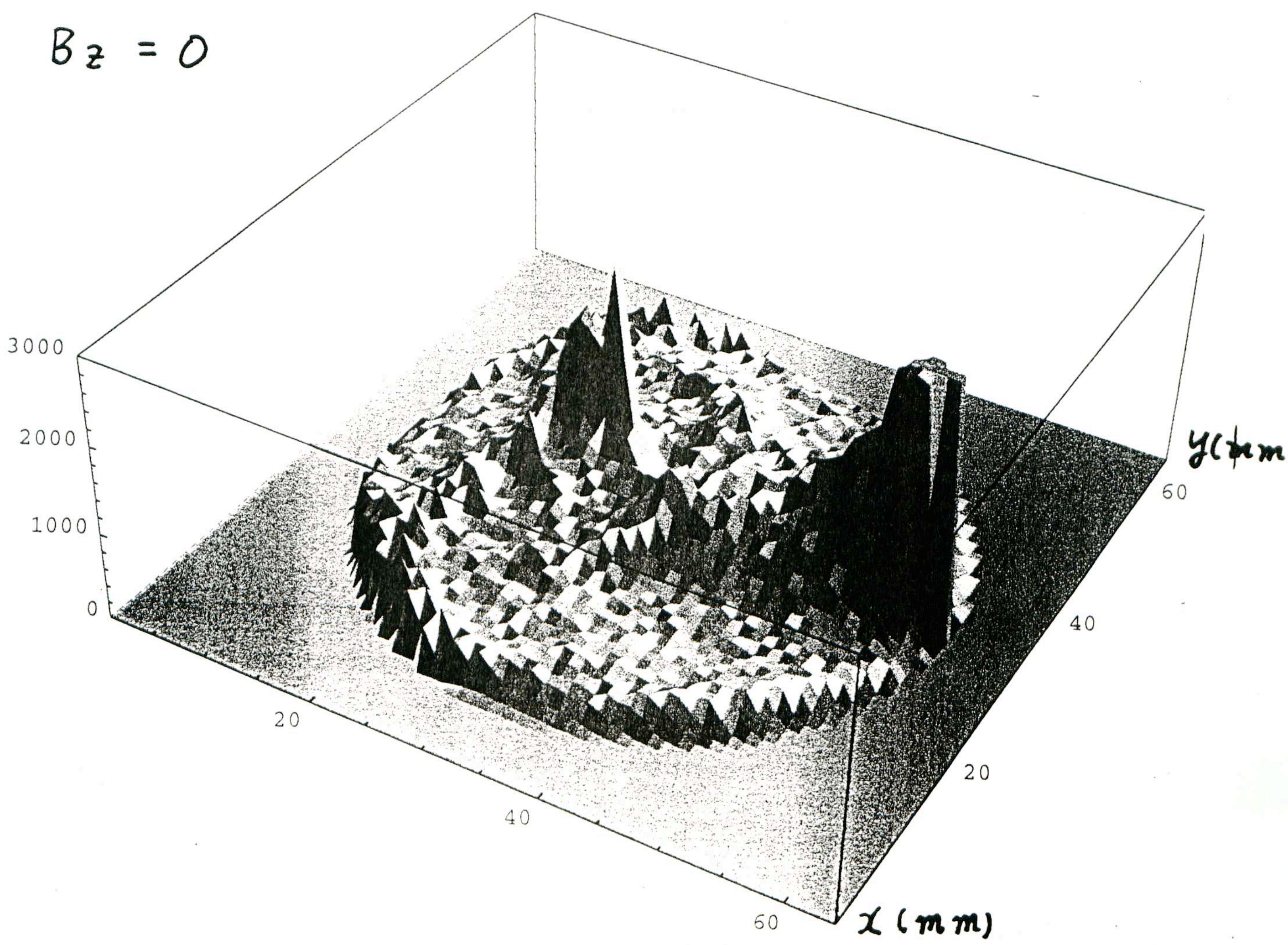


Photoelectron distribution

$B_z = 30\ G$



$B_z = 0$



5. Cure

According to Ohmi's simulation,
Growth rate of PEI is ≈ 0.15 ms.

1) Bunch feedback system

Damping time of transverse feedback system of LER is

0.5 ms ≈ 1 ms.

Bunch feedback system can not cure PEI.

It is necessary to increase the growth time to the manageable level of the feedback system.

⇒ Solenoid

Permanent magnet

2) Solenoid for Sweeping Photo-electrons
(S. Hiramatsu et al.)

- Beam pipe in the LER arc-section

  Cu with 94mmϕ circular cross-section
- Required solenoid field is more than 30 Gauss.
- Estimation of available region for solenoids

For 1/4-arc

	component	quantity	length (mm)	extra-length (mm)	total length (m)
A	B	30	816	100	27.5
	QA	85	444	100	46.2
	SxF	14	340	100	6.2
	SxD	12	340	100	5.3
	StV	85	220	100	27.2
	StH	79	220	100	25.3
	BPM	103	170	0	17.5
					155.2
B	NEG	350	203	0	71.1
	IP	55	203	0	11.2
	Bellow	180	160	0	28.8
	Chamber -support	210	80	0	16.8
	Flange	340	25	0	8.5
					136.3

1/4-arc length L: 542m A + B = 291.5 m

Total free space = L - A = 387 m (71% of arc-section)

Maximum available space for solenoid = L - (A+B) = 251 m (46 % of arc-section)

- Solenoids is not enough to decrease the growth rate to the manageable level of the feedback system.
- Growth rate will be decreased to 0.5 ms if whole free space in arc sections is fulfilled by sweep-fields.

  ⇒ permanent magnet

- Solenoid piece

  L=400mm, D=164mmϕ
  B=30Gauss/3A (with n=800turns/m)
  N=320turns
  I=3A(max)
  wire cross-section; 5.5mm^2
  wire weight; 11.5kg
  wire length; 165m
  R=0.55ohm
  V=1.65V(max)

- 2500 solenoid pieces will be required to cover the1000m beam pipe.

  Necessary wire length is 413km.

- Power supply

  3A(max), 110V(max)
  Recycle use of steering magnet power supplies of TRISTAN-MR
  One PS drives 60 solenoid pieces in series.
  50 PSs will be used for 2500 solenoid pieces.

•Winding machine

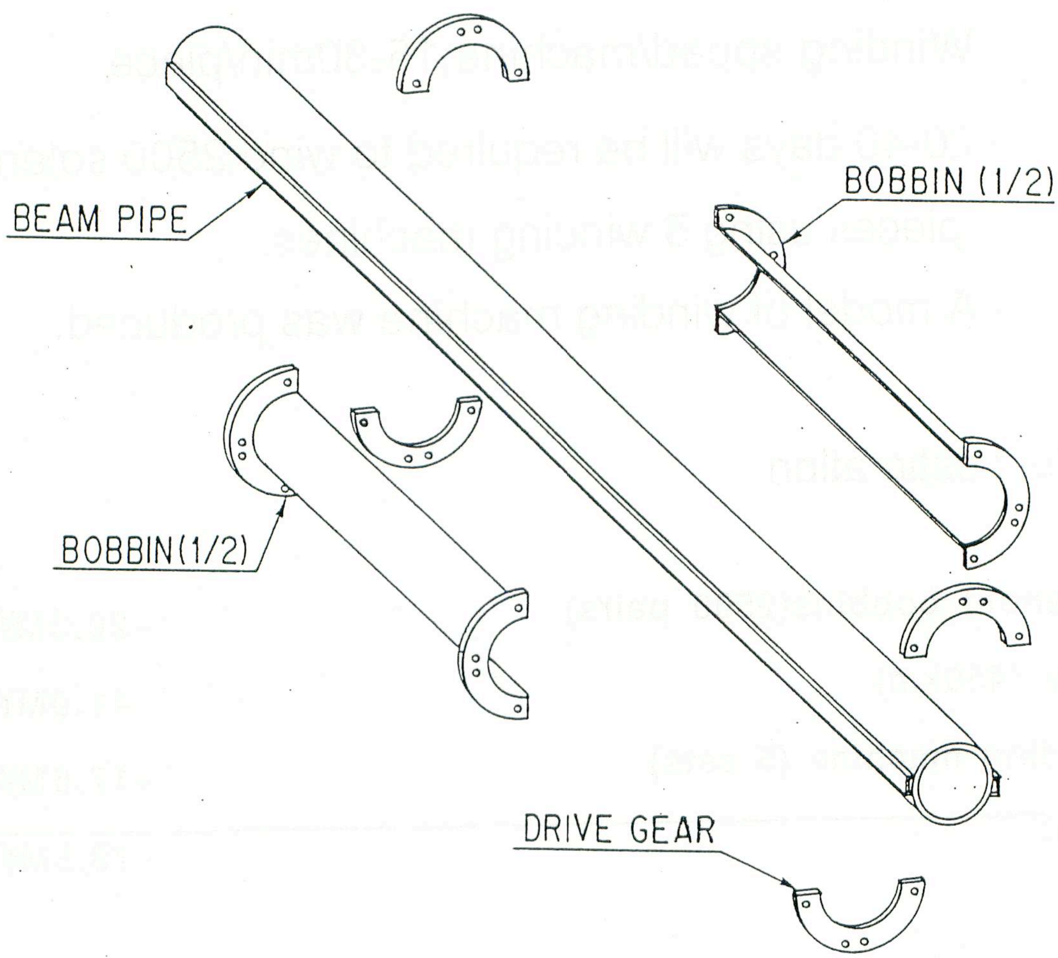
- Solenoid pieces will be wound by winding machines after completion of the LER, if necessary.
- Winding speed/machine;15-30min/piece
- 20-40 days will be required to wind 2500 solenoid pieces using 5 winding machines.
- A model of winding machine was produced.

• Cost estimation

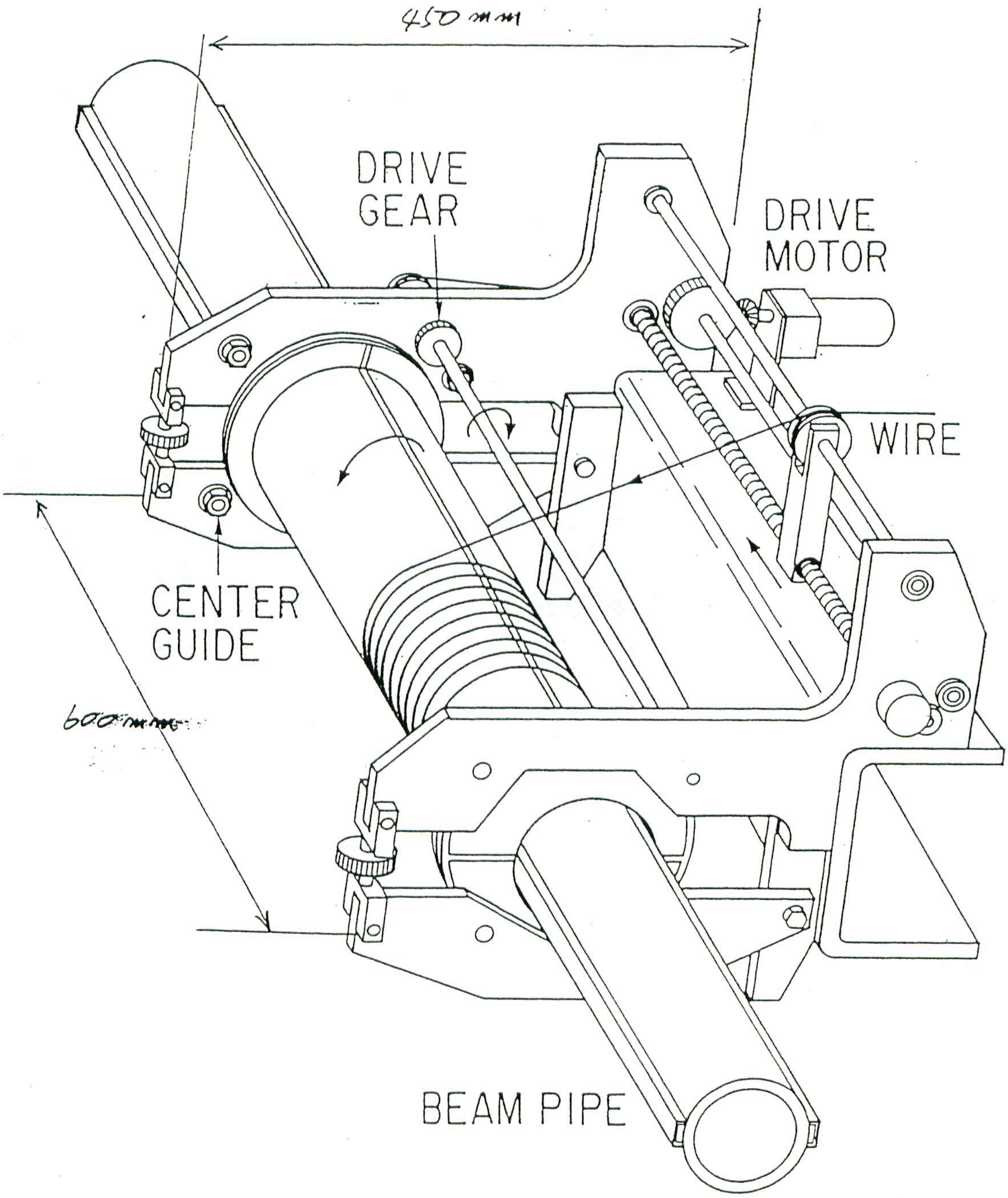
solenoid bobbins(2500 pairs)	**~20.0M¥**
wire (450km)	**~41.0M¥**
winding machine (5 sets)	**~17.5M¥**
total	**~78.5M¥**

additional costs;

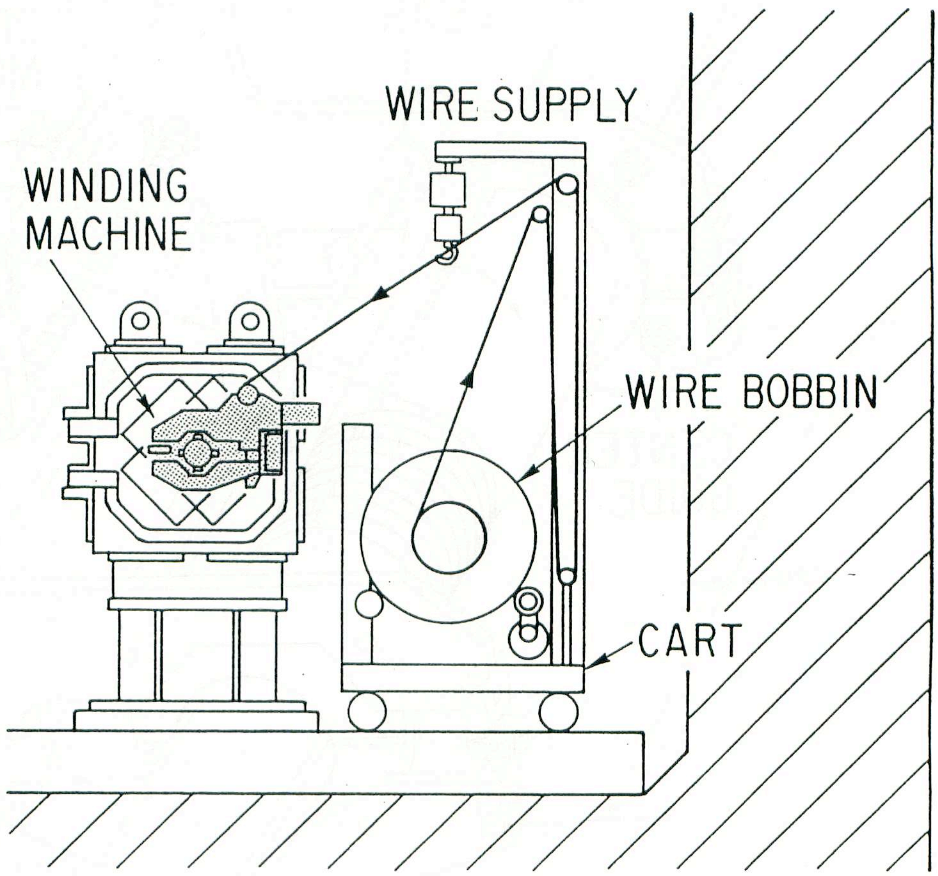
power supply cotrol
setting & wiring of PS
labor for winding



Coil bobbin



Winding machine


WIRE SUPPLY
WINDING MACHINE
WIRE BOBBIN
CART

3) Permanent magnet for Sweeping Photo-electrons

- Merit
  - Available in place where the solenoids can not be wound.
  - Simple (no winding machine & power supply)
  - Power saving

- Field calculation
  - Required field strength

    30 Gauss at the surface of the chamber
  - Material

    Ferrite or alnico   remanent field ≈ 0.2 - 0.5 T
  - Field was calculated in several configurations.

    Ferrite with 1 mm thickness is enough to produce the field of 30 - 40 Gauss at the chamber surface.

- Work to do
  - Selection of magnetic material

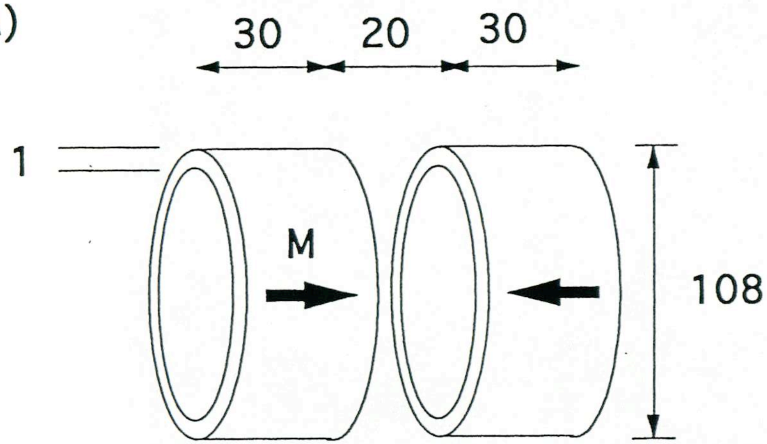
    Demagnetization by radiation, easy fabrication, price
  - Cost estimation
  - Study on the effect of the magnetic field to beam

    Radial field distribution is not solenoid.
  - Study of photoelectron motion

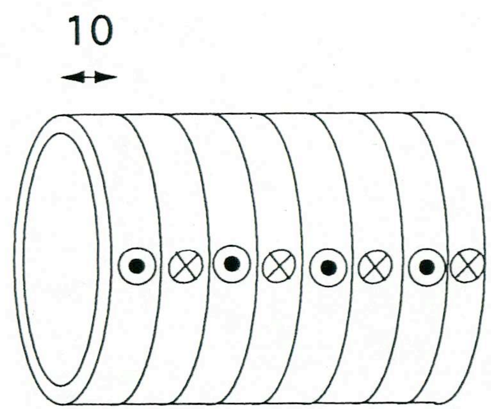
    Necessary size of field region and field strength

Configuration of magnet

A)

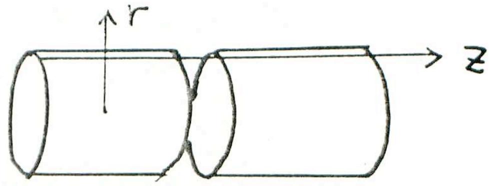


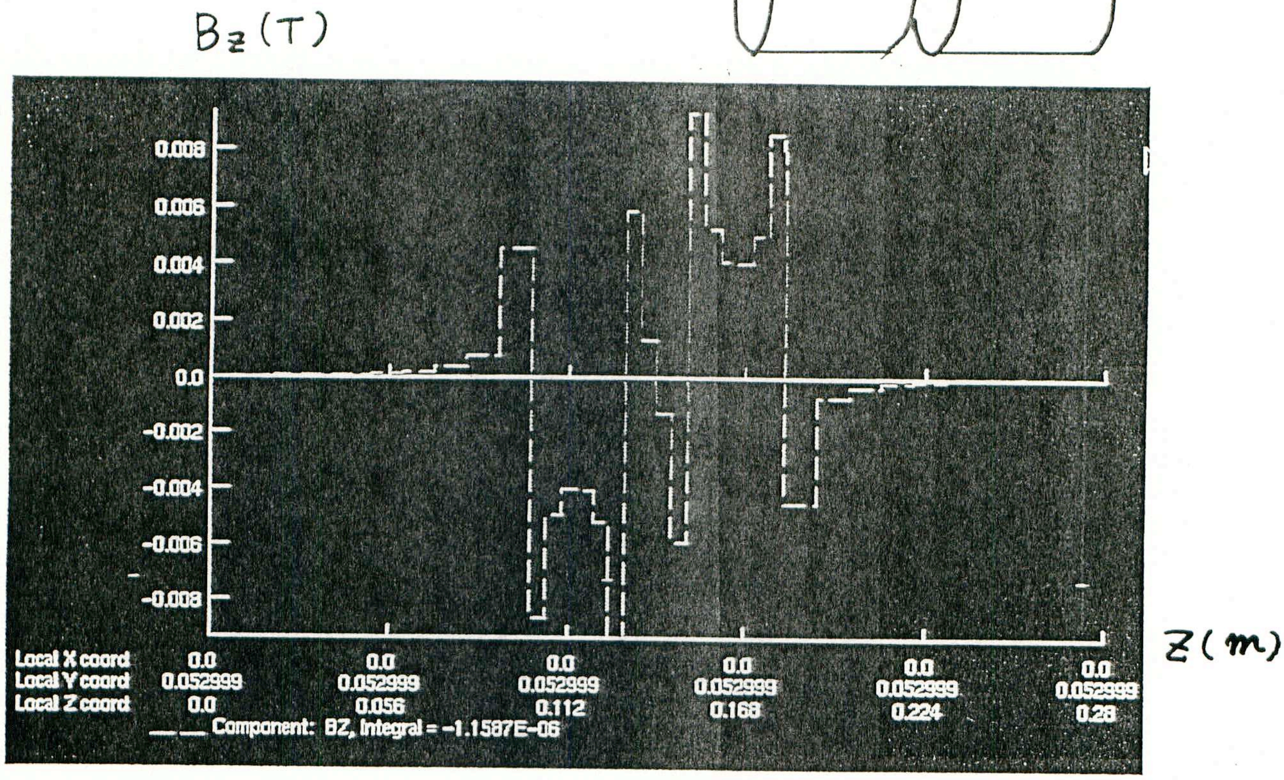
B)

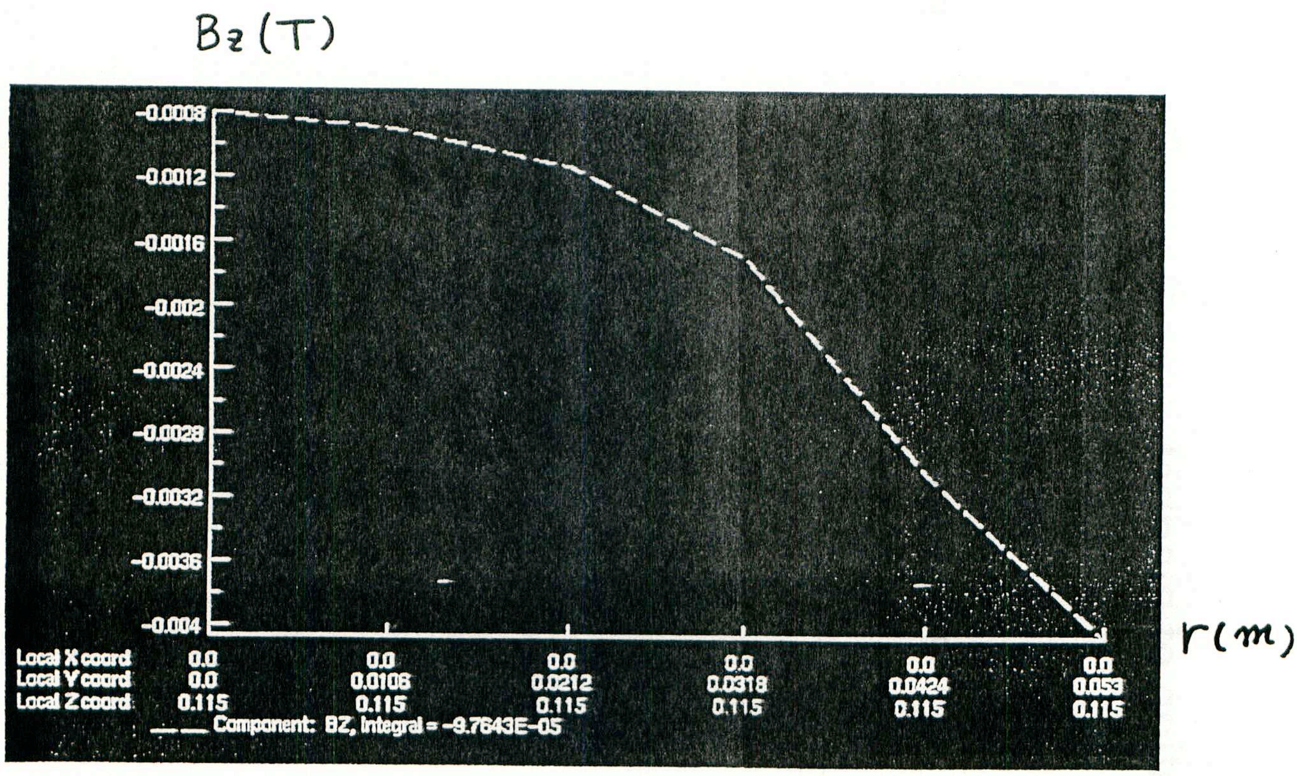


magnetization axis

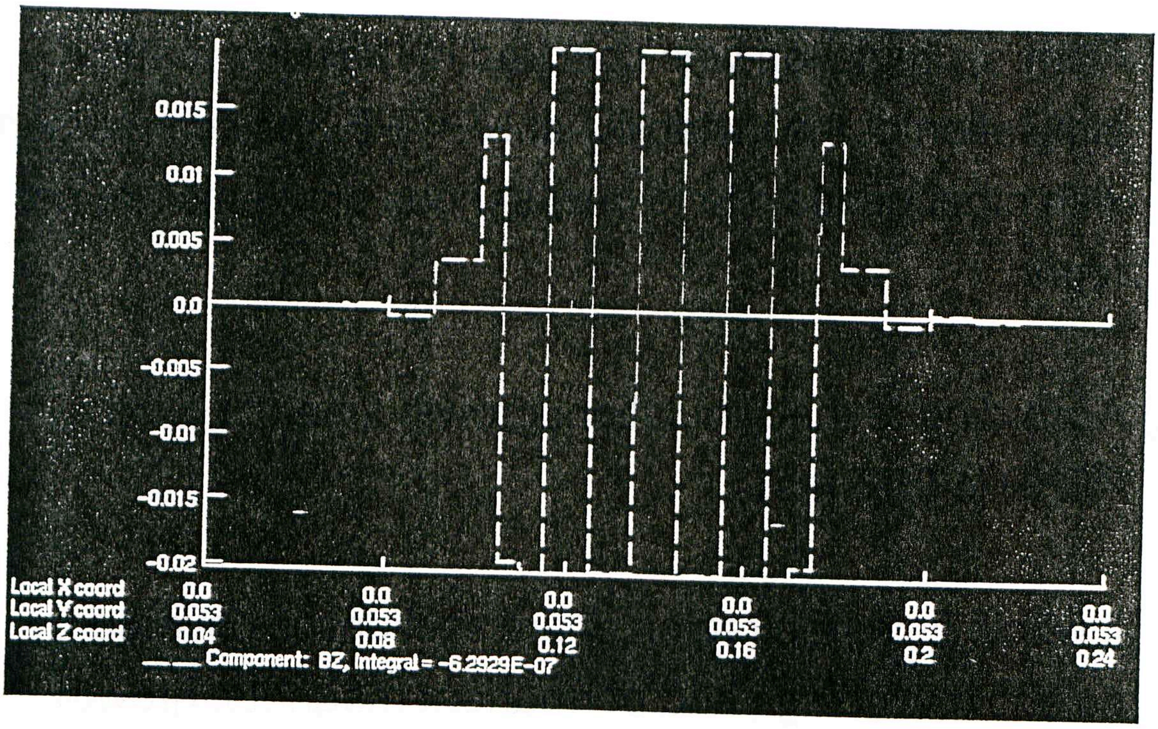
Configuration A



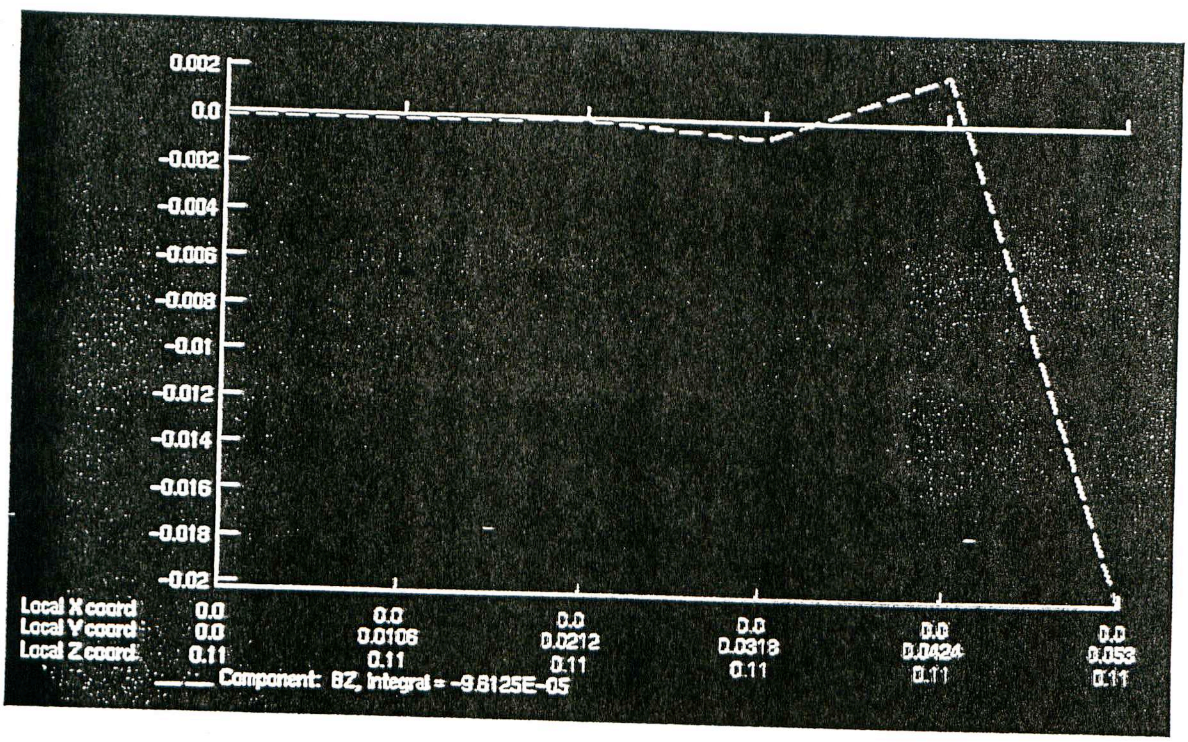




Configuration B



z (m)



r (m)

6. Summary

1) Ohmi's simulation was checked by tracking method, simulation of the instability at KEK PF and comparison with other codes. Up to now serious problems are not found.

2) According to the simulation, growth time of PEI in KEKB is 0.15 ms.

3) If whole field free region of arc sections is covered by solenoid windings and permanent magnets, growth time will be raised to the marginal value for the bunch feedback system.