Fast beam-ion instability

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KEK

(Presented by H. Fukuma)

1.Introduction
2.Simulation study
3.Experiment in TRISTAN AR
4.Summary

1-1 Introduction

In high current and low emittance rings, new type of beam-ion instability named "fast beam-ion instability(FII)" is proposed(T.O. Raubenheimer and F. Zimmermann, Phys. Rev. E 52, 5487(1995) and G.V. Stupakov, T.O. Raubenheimer and F. Zimmermann, Phys. Rev. E 52, 5499(1995)).

The FII occurs in the single passage of the bunch train. The ions created by the head of the bunch train affect to the tail.

In the linear theory by K. Yokoya, the unstable mode of the oscillation is given by

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

(n : bunch id)

Amplitude growth factor G is given by

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

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.

Recently John Byrd et al. at ALS and SLAC reported the experiments in ALS where the results suggest that they observe the FII with 10nTorr of He added to the vacuum.

In KEKB the e-folding time of the amplitude growth is about 70 turns for the number of bunches of 500 and a pressure of 10^{-9} Torr.

1-2 Simulation study

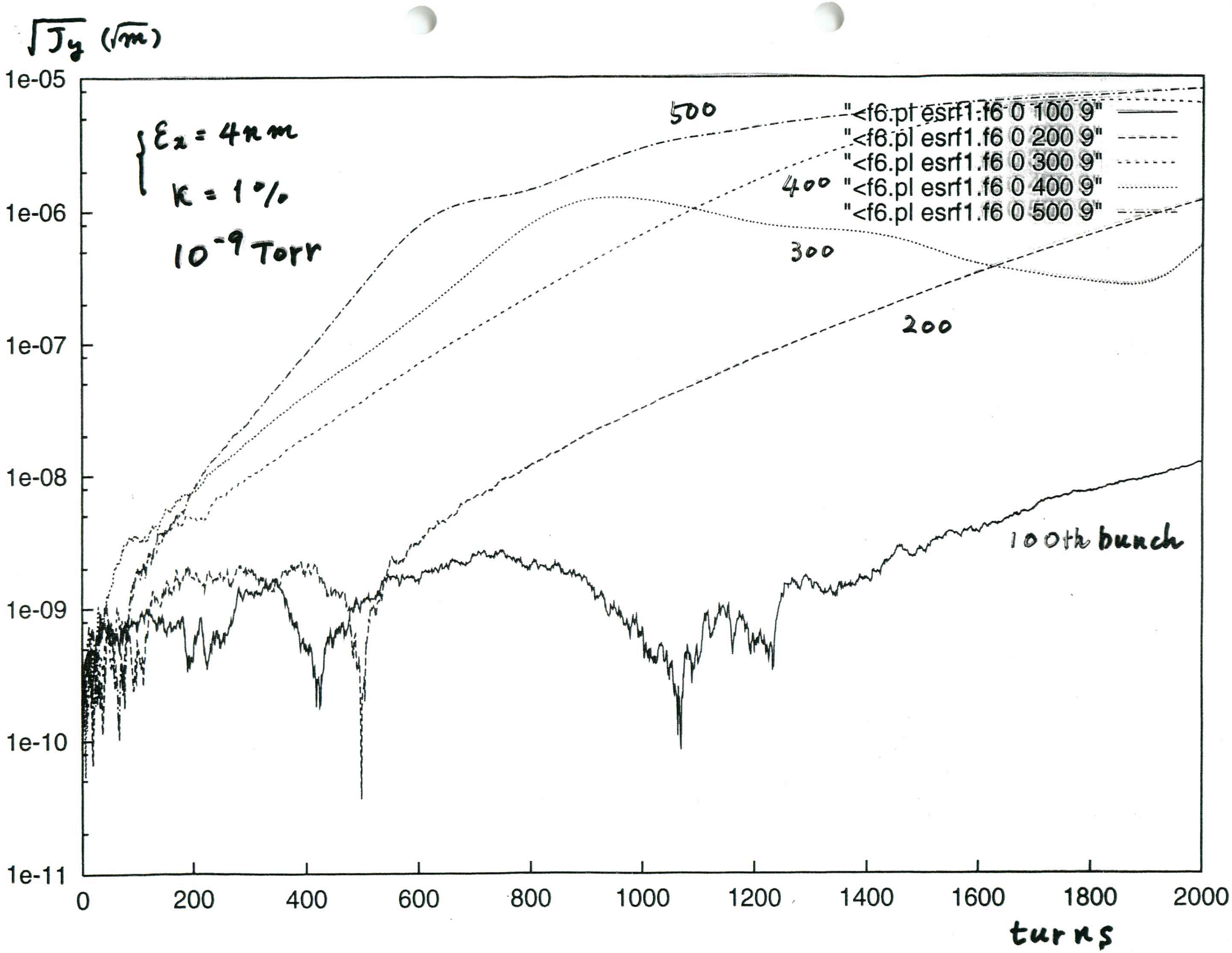
Two simulation codes, one based on "strong(ions)-strong(beam)" model and the other based on "weak(ions)-strong(beam)" model, are developed.

1) Bunch train and bunch gap

Assuming a bunch train of 512 bunches,

Vacuum(Torr)	10^{-7}	10^{-8}	10^{-9}
Growth rate(turn)	~1	~10	~100

If making a gap of 100 bunches, the effect of conventional ion trapping and the effect by forward bunch train is negligibly small.



$\sqrt{J_y}$ ($\sqrt{m}$)
ε_x = 4nm
κ = 1%
10^{-9} Torr
"<f6.pl esrf1.f6 0 100 9"
"<f6.pl esrf1.f6 0 200 9"
"<f6.pl esrf1.f6 0 300 9"
"<f6.pl esrf1.f6 0 400 9"
"<f6.pl esrf1.f6 0 500 9"
500
400
300
200
100th bunch
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
0
200
400
600
800
1000
1200
1400
1600
1800
2000
turns

2) ESRF case

A simulation was carried out based on ESRF parameters(→ Fig.). Amplitude of the oscillation saturates after ~1000 turns(2.7ms).

1-3 Experiment in TRISTAN AR

An experiment was carried out in TRISTAN AR for the search of the FII in last Nov.-Dec..

Machine parameters of AR are

Energy	2.5 GeV
Circumference	377 m
RF frequency	508 MHz
Harmonic number	640
Emittance	45nm

1) Experimental procedure

Train of 100 bunches with 2 ns spacing was stored in AR with the help of the transverse bunch feedback system. (In this fill pattern the gap is 540 bunches.)

Spectra of the vertical bunch oscillation and the vertical oscillation patterns along the train were compared before and after the leak of the nitrogen gas.

Oscillation-spectra were measured by the spectrum analyzer HP8562E(13.2GHz) connected with a vertical button pick up.

The vertical oscillation patterns were recorded by the BPM system which is capable of storing the vertical beam position of every bunch up to 1600 turns.

2) Preliminary results

Before the leak of the nitrogen gas the total current of 360 mA was stored. Average vacuum pressure measured by the vacuum gages was 1.0 x10^{-8}Torr. Vertical betatron sidebands were observed by the spectrum analyzer and disappeared when the beam current decreased to 260mA.

After the leak of the nitrogen gas the total current of 190 mA was stored. Average vacuum pressure was 2.5x10^{-8}Torr. The pressure near the injection point of the gas is being analyzed from the data of the Q-mass filter. Observations are

i) the vertical oscillation was observed in the synchrotron light monitor,

ii) strong upper and lower vertical betatron sidebands were observed below 10 revolution harmonics($\rightarrow$ Fig.),

iii) The oscillation of each bunch taken by the BPM were Fourier-analyzed. Amplitudes and phases of every bunch were plotted($\rightarrow$ Fig.)

The data shows that

The amplitude of the tail of the train is 2-3 times larger than that of the head,
The phase changes smoothly from the head to the tail and total phase shift is about 2-4 rad.

3) Tentative summary

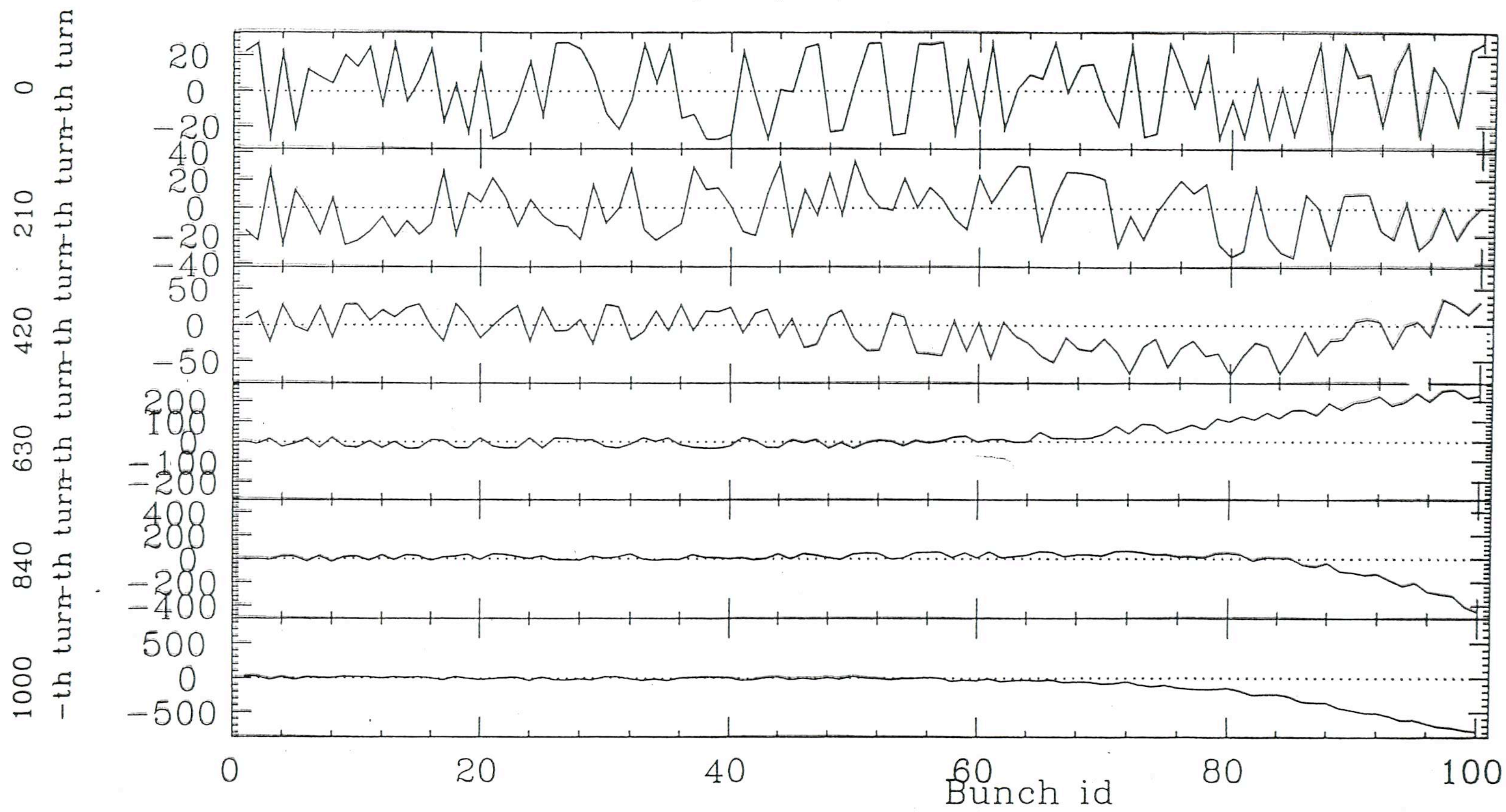
i) The oscillation observed with the gas-input is probably ion-related one.

ii) The amplitude pattern and phase change along the train and the betatron sidebands near small revolution harmonics may be explained by the FII.
Further data analysis and further simulation study including conventional ion trapping effect are needed to identify the observed instability as the FII.

Simulation by the 'weak-strong' model

2ns spacing, 100 bunches, 200mA, 1×10^{-7} Torr

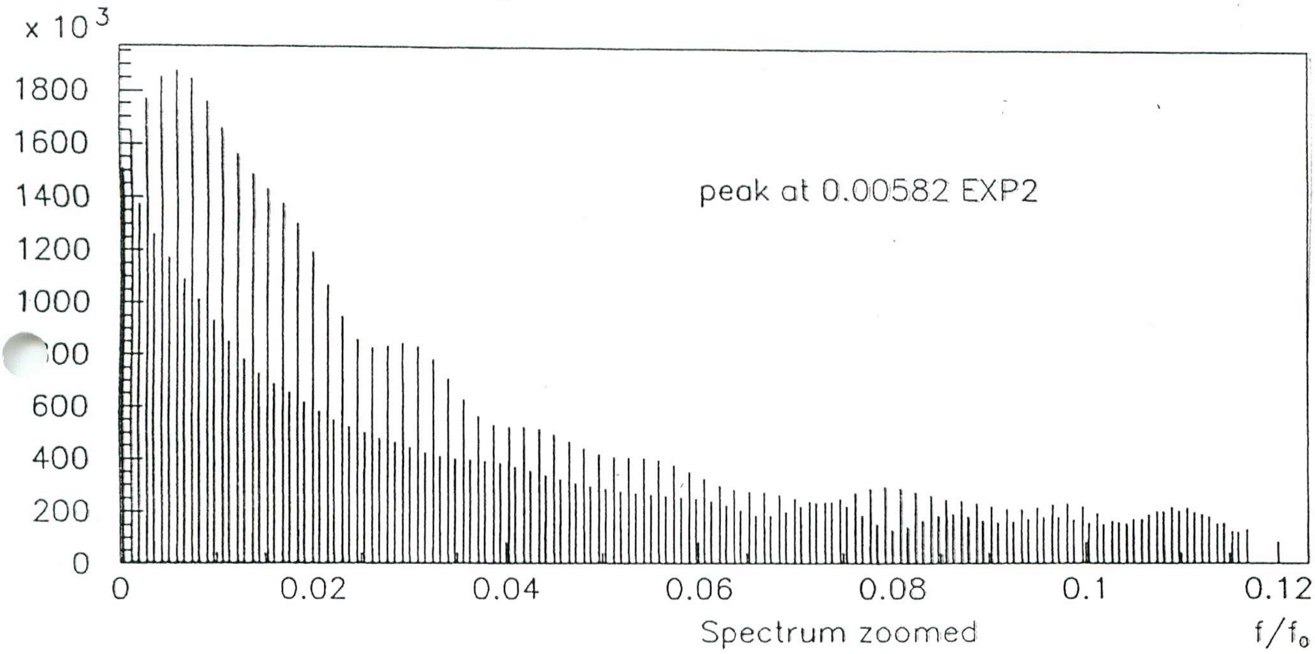
Electron Center-of-Mass Motion <y> (μm)



MB=100 LAT=1 NCEL=1 DAMPT=0 ENERGY=2.5D9 ANE=1.58D10 LPE=−1 TB=0.6 EMIT=4.435D−8 4.435D−9
SIGZ=0.0106 SIGE=0 NPE0=1000 NIC=11 LIONP=0 SHFTIP=0 CNPI=50. NPIMAX=10000 PRESS=1.D−7
TEMP=300. NKI=1 ZI=1. MI=28. SIGI=1.8D−22 NTURN=1000 LAMP0=2 AMP0=0 0.1 LDQ=0 APERT=0.016
0.016 NBINXY=64 64 DXYBIN=0.3 0.3 IG0=3 GCUT=3. LZEROE=1 LZEROI=1 IONIZ1=0 FSPCTR=0
DTKCK=0 0

Spectrum of bunch oscillation (simulation)

2 ns spacing, 100 bunches, 200 mA, 1×10^{-7} Torr



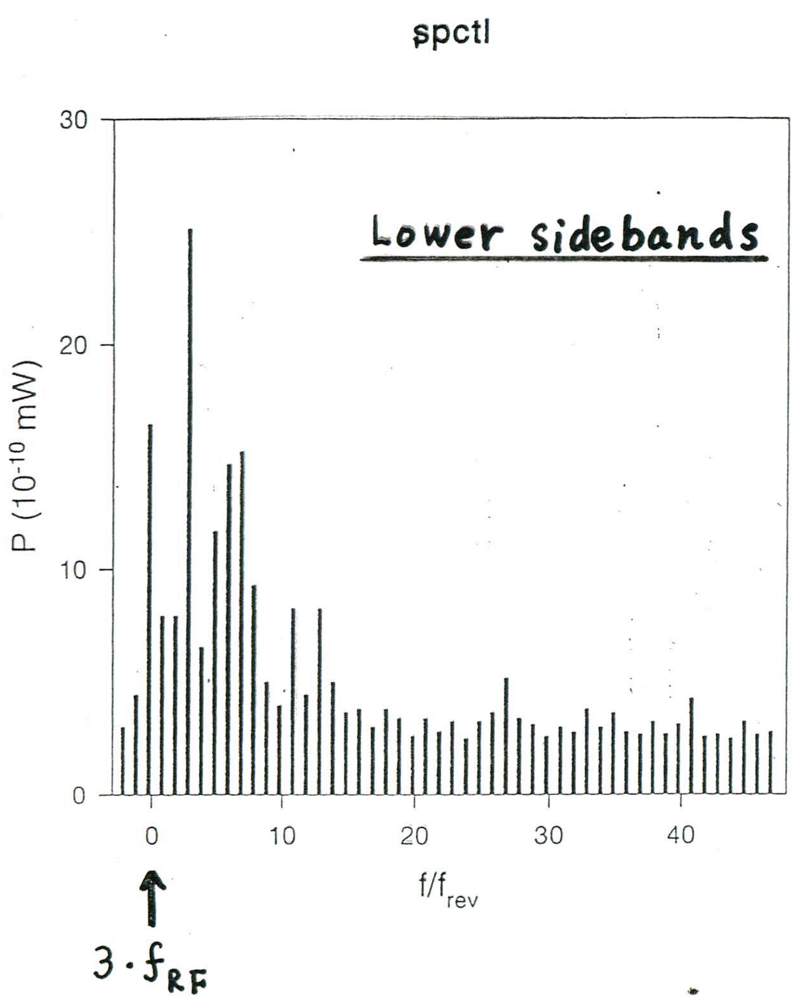
Phase advance (head-tail)

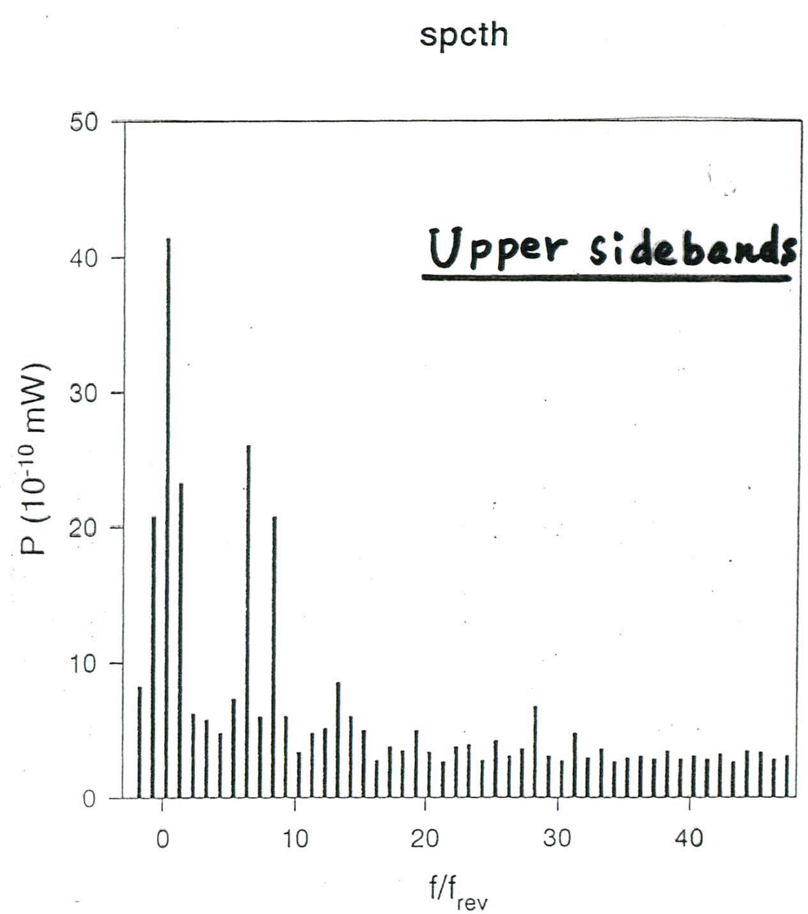
$$\sim 2\pi\mu \frac{L_{train}}{C} = 2\pi\mu \frac{0.6 \times 100}{377} \sim \mu$$

↑ mode

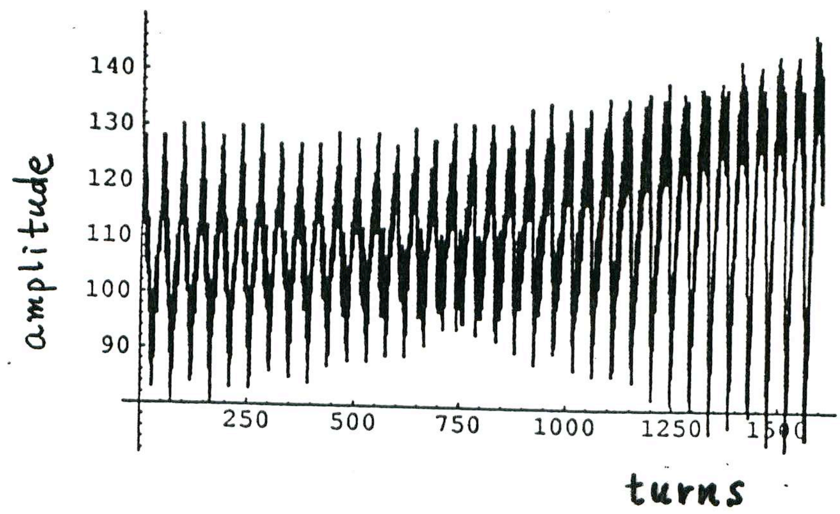
Spectrum of bunch oscillation (vertical) : measured

Beam current 184 mA

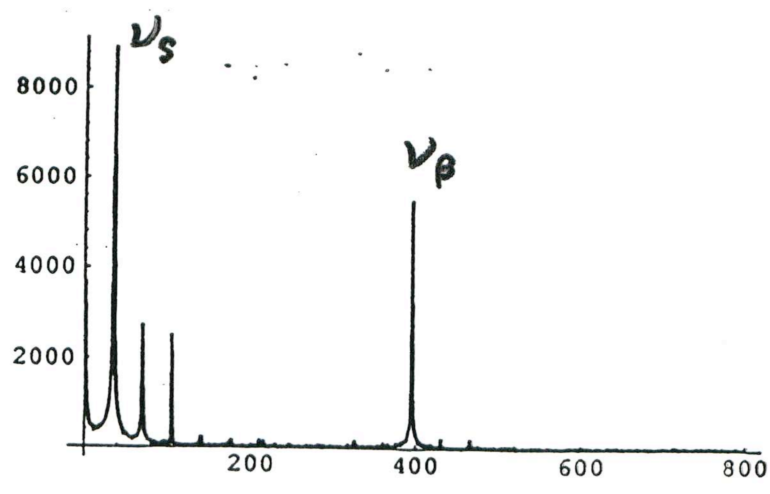




Vertical position of a bunch (measured)

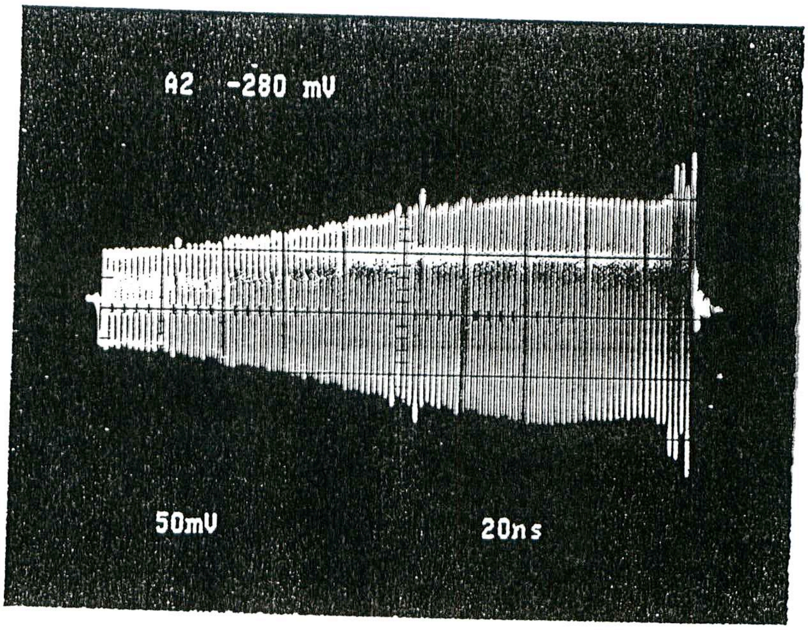


Fourier analysis



Bunch current

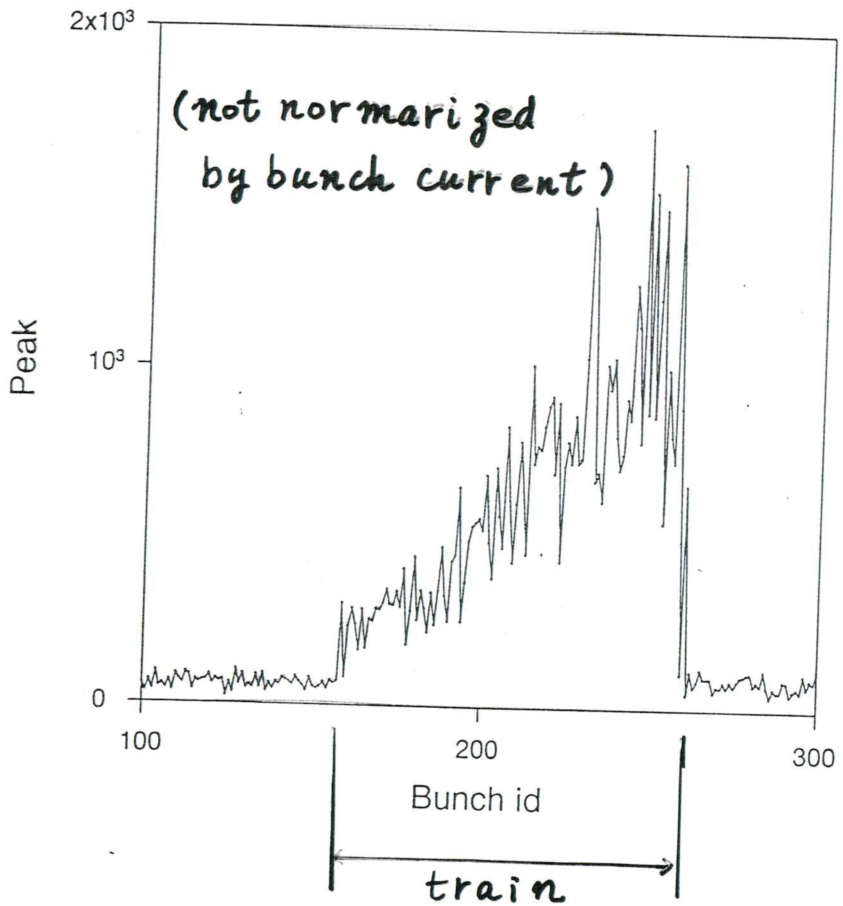
2ns spacing , 100 bunch



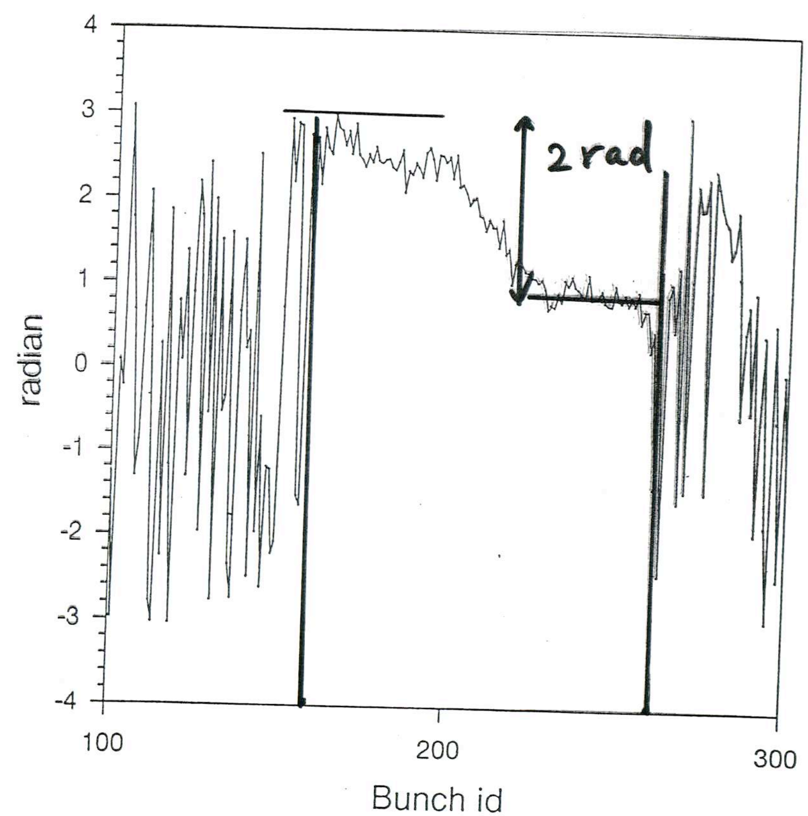
Amplitude and phase along the bunch train (measured)

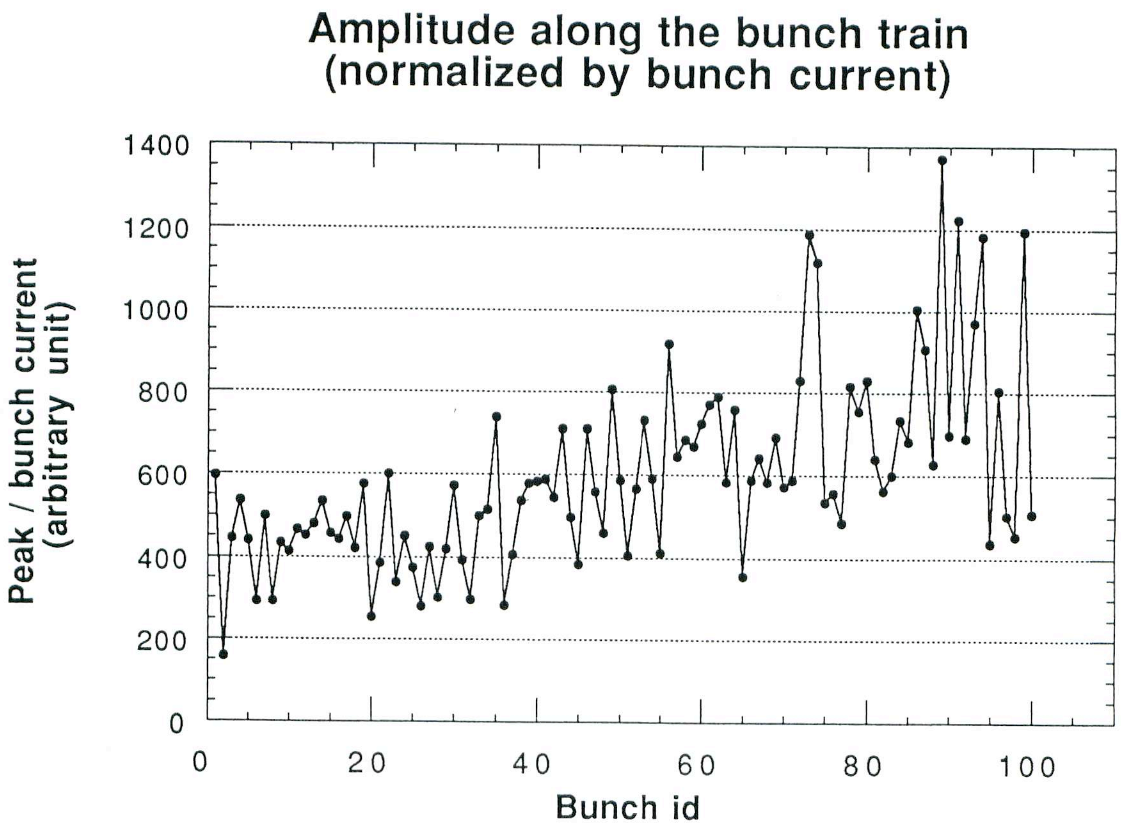
Beam current 100 mA

Amplitude



Phase





Amplitude along the bunch train
(normalized by bunch current)
Peak / bunch current
(arbitrary unit)
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
Bunch id

1-4 Summary

1) The simulation study shows that, assuming a bunch train of 512 bunches and a pressure of 10^{-9} Torr, i) the growth rate is about 100 turns which is marginal value for the bunch feedback system and ii) a gap of 100 bunches is enough to avoid conventional ion trapping and the effect of forward bunch train.

2) An experiment for the search of the FII was carried out in TRISTAN AR. After the leak of the nitrogen gas the strong vertical oscillation was observed. The oscillation may be explained by the FII. Further data analysis and simulation study are required to identify the observed instability as the FII.

Beam-photoelectron instability

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*)The experiment in BEPC is a joint experiment with Z.Y.Guo, H.Huang, S.P.Li, D.K.Liu, L.Ma, L.F.Wang, J.Q.Wang, S.H.Wang and C.Zhang in IHEP.

2-1 Introduction

A vertical Instability was observed in a positron beam in KEK PF(M. Izawa et al., Phys.Rev.Lett. 74, 5044(1995))

Characteristics of the instability are

1)Coupled oscillation,
2)Low threshold current(15-20mA),
3)Broad distribution of betatron sidebands,
4)3) is not observed in a electron beam,
5)The threshold current depends on bunch spacing.

M. Izawa et al. proposed that

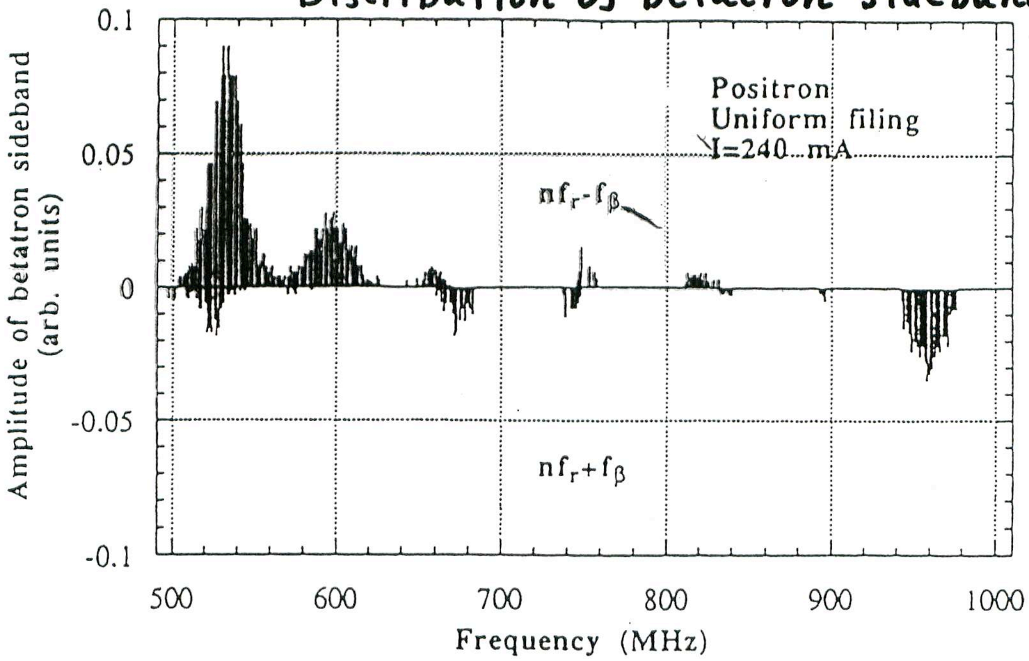
1)the instability is caused by electrons,
2)the force, which causes the instability, has a semi-long range about 10 bunch spacing($\rightarrow$ Fig.).

The Beam-Photoelectron instability(PEI) is proposed to explain the instability in KEK PF(K. Ohmi, Phys.Rev.Lett. 75, 1526(1995)).

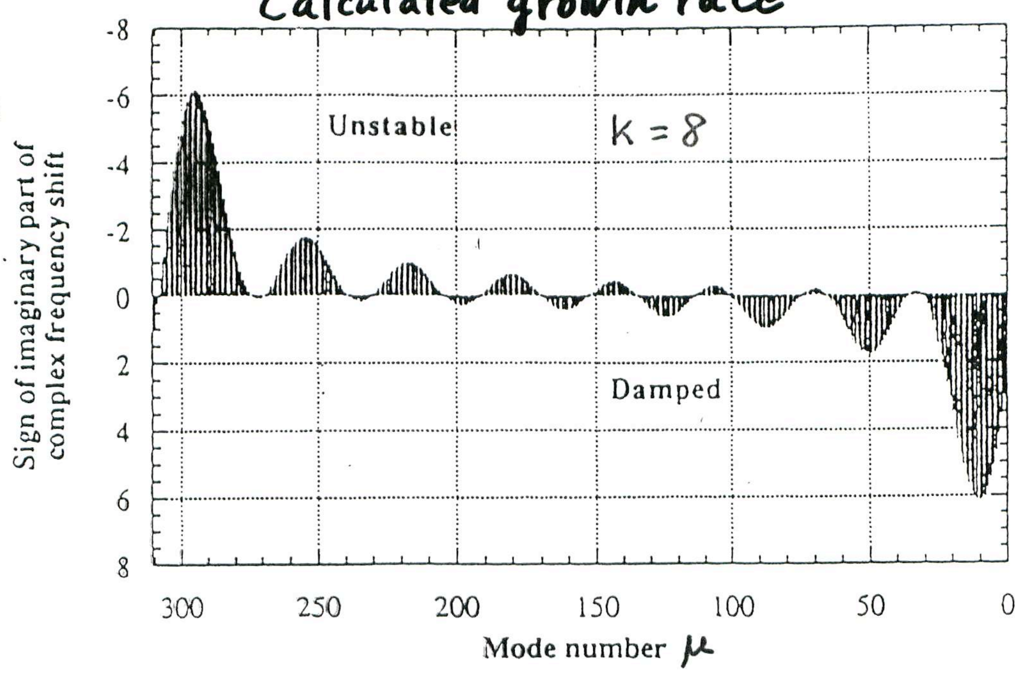
The PEI is caused by the photoelectrons which are produced by the synchrotron radiation hitting the vacuum duct.

KEK PF

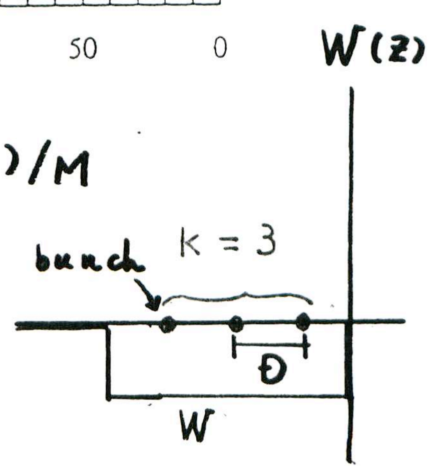
Distribution of betatron sidebands



Calculated growth rate



$$\tau_g^{-1} \propto \sum_{P=1}^{K} W(-PD)\, e^{i2P\pi(\mu+\nu_\beta)/M}$$



In KEKB-LER a naive simulation shows that the growth time is 0.1ms which is too short to be cured by the bunch feedback system.

2-2 Simulation study

1) Space charge and image charge effect

Space charge between photoelectrons and image charge of photoelectrons on a vacuum duct disturb the photoelectrons approaching the beam.

The simulation iincluding above effects shows that

> the growth rate of the instability is about 1.1 ms which is 10 times smaller than that without above effects if production rate of photoelectrons is larger than 0.02 .

2) Effect of solenoidal field

One possibility to cure the instability is to apply a solenoidal field.

This field seems to be more suitable than a vertical magnetic field to guide secondary electrons and electrons by reflected light which are produced on upper and lower wall of vacuum duct.

The simulation shows that

i) For primary photoelectrons,

If kinetic energy of photoelectrons < 50 eV, solenoidal field of 20 G prevents the photoelectrons from approaching the beam(→ Fig.).

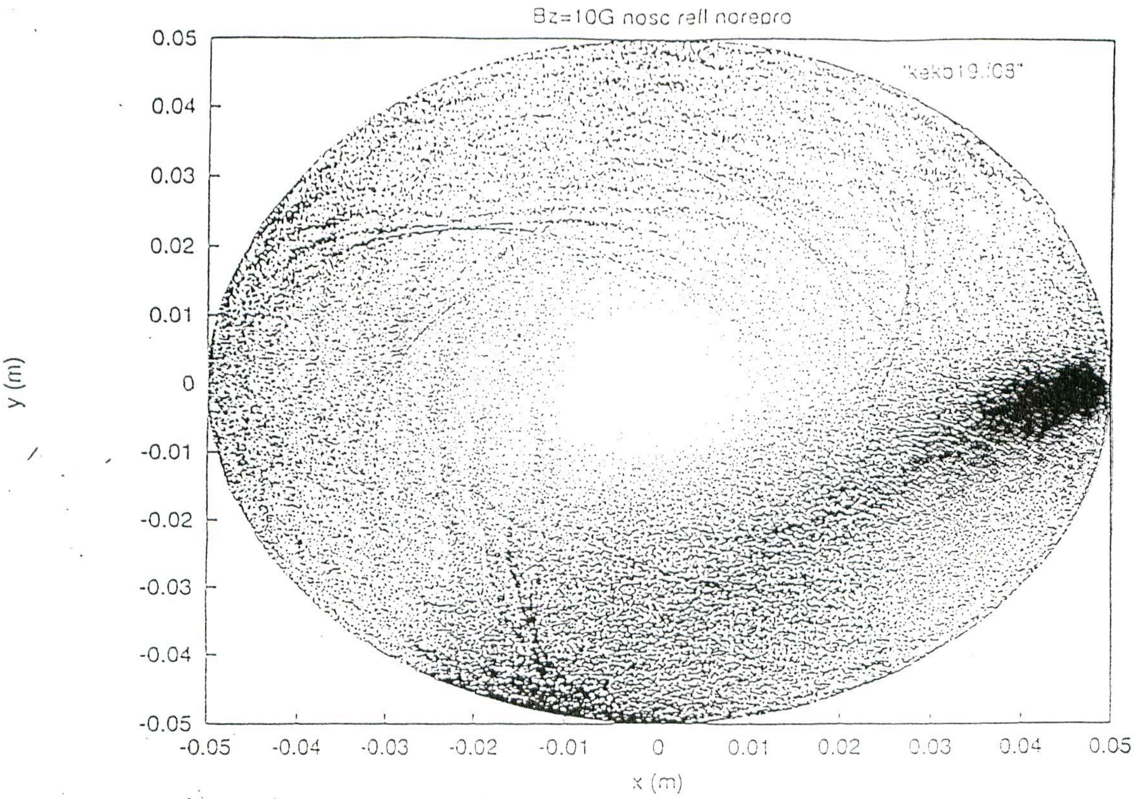
ii) Including secondary electrons and reflected light,

Solenoidal field of 20 G is still enough to block the photoelectrons(→ Fig.).

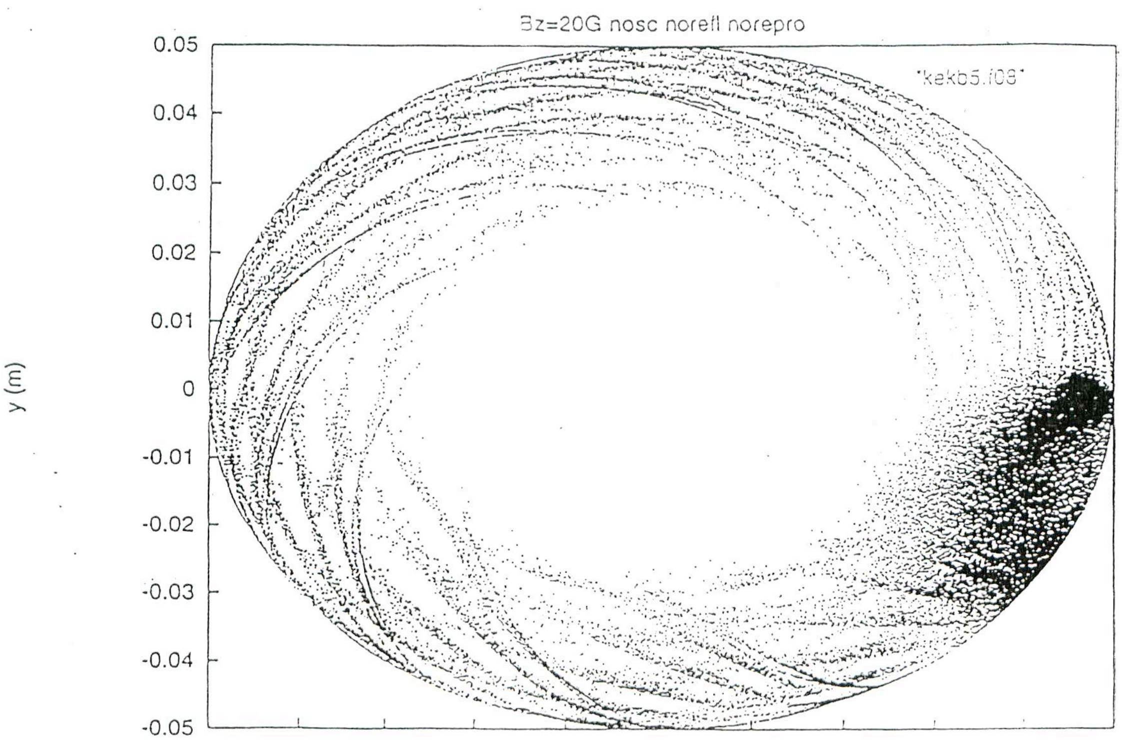
Design of solenoid system started to estimate a scale of the system.

B_z=20G → 2000 AT/m

Distribution of photoelectrons (only primary e^-)

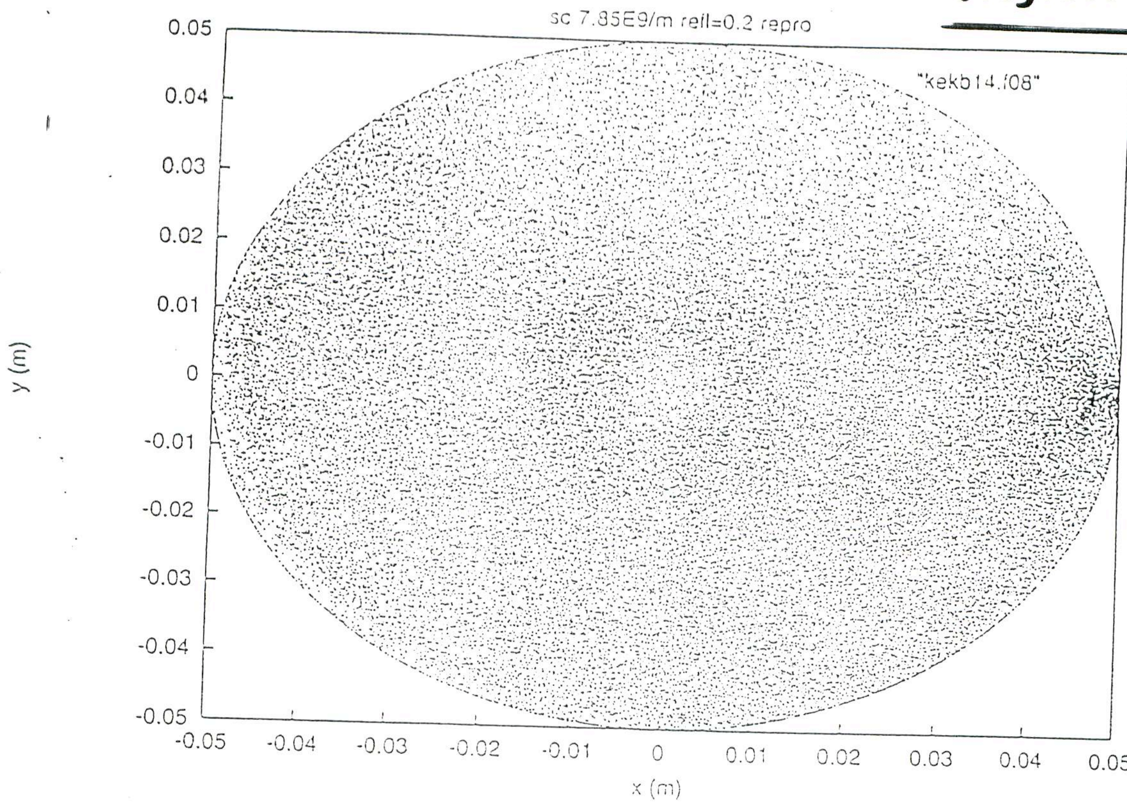


$B_z = 10\,G$

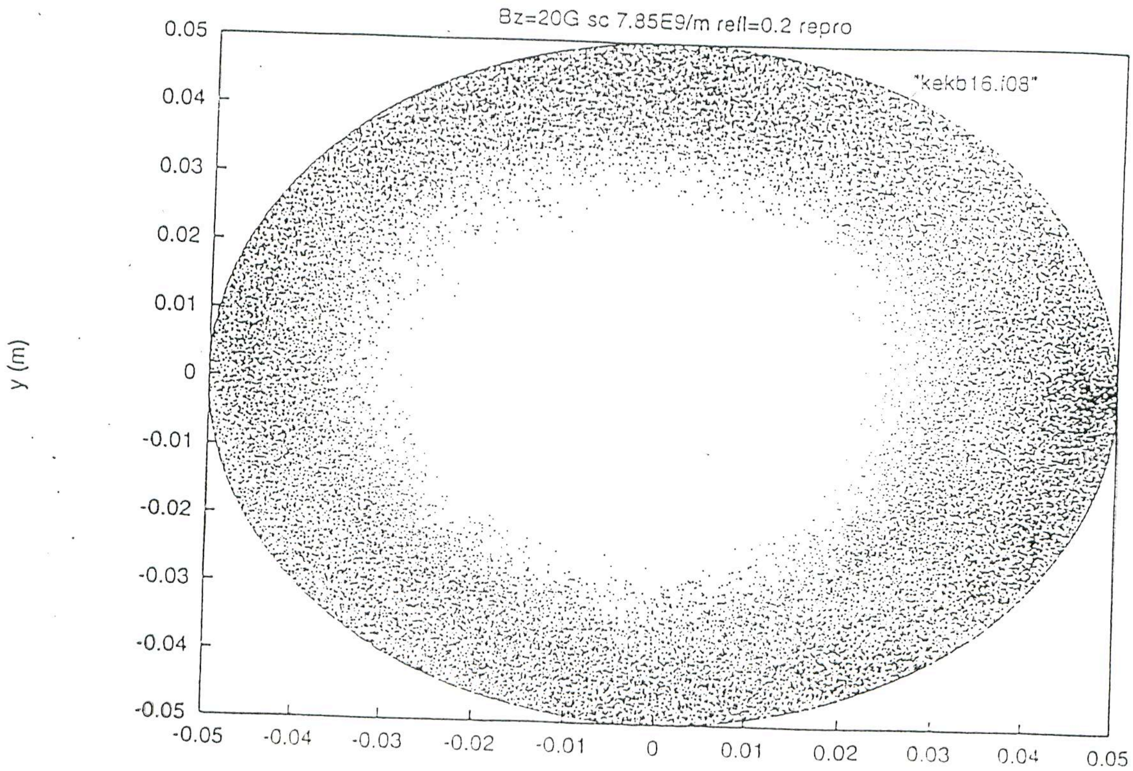


$B_z = 20\,G$

Distribution of photoelectrons with secondary e⁻ / reflective light



$B_z = 0$



$B_z = 20G$

2-3 Experiment in BEPC

A series of experiments on the PEI is in progress in Beijing Electron Positron Collider (BEPC) with the collaboration between IHEP and KEK.

Machine parameters of BEPC are

Energy	1.55-2.2 GeV
Circumference	240 m
RF frequency	200 MHz
Harmonic number	160
Current	40-150mA
Damping time(trans.)	50 ms @ 1.55GeV

1) First experiment(June 1996)

Beam parameters in the experiment were

Beam energy	1.55GeV,
Nominal betatron tune	5.79/6.71(hor./ver.),
Nominal chromaticity	4.0/4.0(hor./ver.).

Positron / electron beam of 158 bunches were stored in the ring.

Spectra of the beam oscillation were observed by a spectrum analyzer connected to a button pick up.

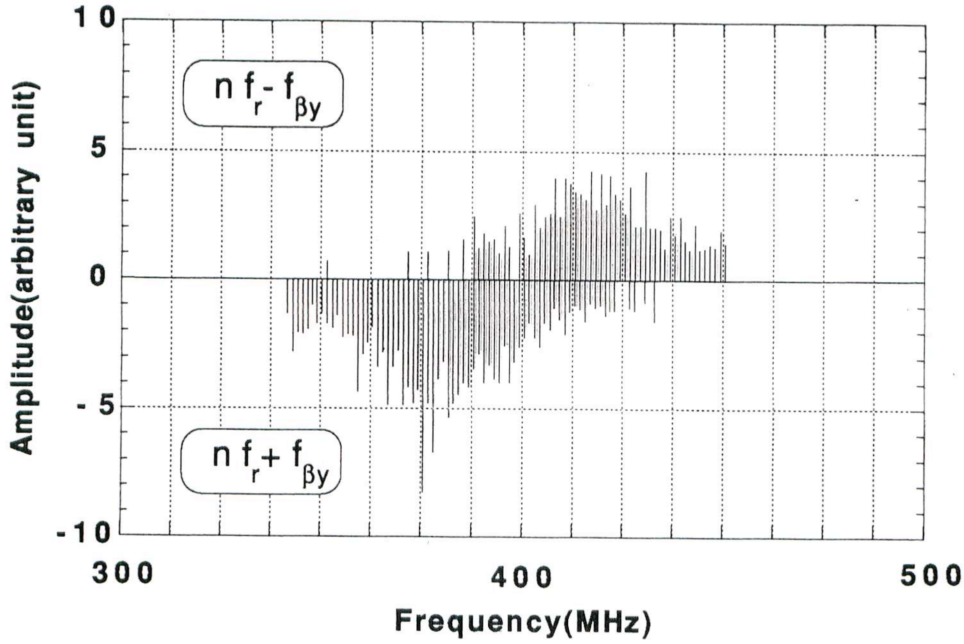
In positron filling vertical betatron sidebands which has a broad frequency distribution were observed. Threshold current was about 9.4mA($\rightarrow$ Fig.).

The broad distribution of vertical betatron sidebands were not observed in electron filling.

In filling of 80 bunches with equal bunch spacing no vertical betatron sidebands were observed even when the current of 38mA was stored.

These observations are very similar to that in KEK PF.

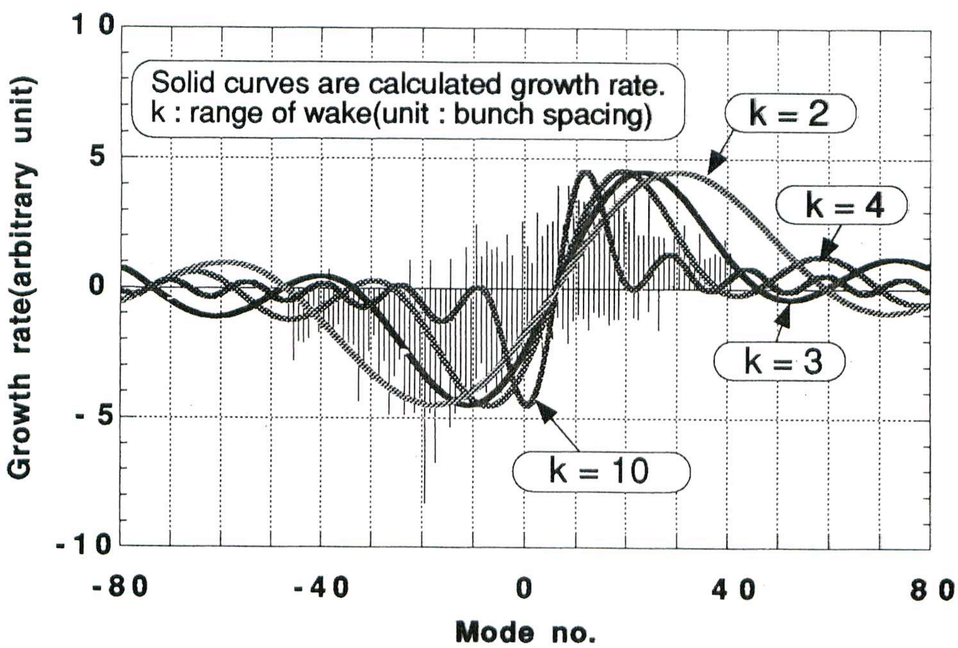
Observed distribution of vertical betatron sidebands

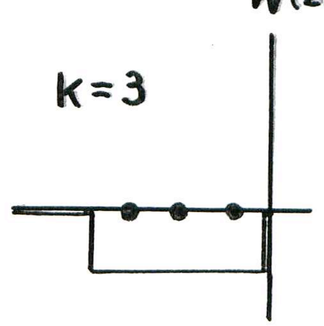


e^+ 158 bunch

9.4 mA

Calculated growth rate by the phenomenological model





2) Second experiment(Dec. 1996)

Effect of various parameters on the vertical betatron side bands were recorded.

Investigated effects included:

o Beam energy	o Chromaticity
o Emittance	o Bunch spacing
o RF frequency	
× RFvoltage	× Distributed ion bumps
× Betatron tune	× Horizontal magnetic field

(o:Effective on vertical betatron side bands
×: Ineffective on them)

Data analysis is now in progress and the results will be compared with the simulation. At present it is not clear whether the results can be explained by the PEI or not.

Next experiment is scheduled in this March.

2-4 Summary

1) The simulation study shows that, taking into account the effect of space charge and mirror charge , the growth rate of the instability is about 1.1 ms which is the marginal value for the bunch feedback system.

2) According to the simulation the design of solenoid system, which prevents the photoelectrons from the beam, started.

3) A series of experiments on the PEI is in progress in Beijing Electron Positron Collider (BEPC) with the collaboration between IHEP and KEK. Observed vertical oscillation in positron filling is very similar to that in KEK PF.
Effect of various parameters on the vertical betatron side bands were recorded in the second experiment. The data will be compared with the simulation quantitatively.