GROWTH AND SUPPRESSION TIME OF AN ION-RELATED VERTICAL INSTABILITY

Tsukasa Miyajima*, Yukinori Kobayashi and Shinya Nagahashi
High Energy Accelerator Research Organization, Tsukuba 305-0801, Japan

Abstract

In the KEK Photon Factory electron storage ring, a vertical instability has been observed in a multi-bunch operation mode. The instability can be suppressed by octupole magnetic fields in routine operation. Since the instability depends on a vacuum condition in the ring, it seems that it is an ion-related phenomenon. In order to study a dynamical behavior of the instability, we measured the growth and the suppression time of it with a pulse octupole magnet system, which can produce the octupole field with rise and fall time of around 1.2msec. Using the system, we obtained the result that the growth process of the instability was rather slow in comparison with the suppression process, and the growth time depended on the fill pattern of the bunch train and the bunch current.

INTRODUCTION

In the Photon Factory electron storage ring (PF-ring), a vertical instability is observed in a multi-bunch operation mode. The instability can be suppressed by Landau damping which caused by octupole magnetic fields [1]. Since the instability depends on a vacuum condition in the ring, it seems that the instability is caused by ion trapping effect. The operating parameters in the routine operation are near the threshold of it.

In order to study the dynamical behavior of the instability, we use a pulse octupole magnet system [2]. The principal parameters of the pulse octupole magnet system are shown in Table 1. Using the system, we can measure the growth and the suppression times of the instability by measuring the response of beam spectrum from the button-type electrode, when the octupole field rises or falls. In order to investigate the dependence of the response of beam instability on the ring conditions, we performed the experiments under two conditions : one is the beam condition with a constant bunch number of 280 and the other is with a constant bunch current of 1.6mA. In this paper, we describe the results of the response of beam spectrum, and calculate the delay time, the growth and the suppression rate of the instability.

The principal parameters of the PF-ring are shown in Table 2. In the PF-ring, there are four DC octupole magnets and these magnets are changed together. In the multi-bunch operation mode, the PF-ring is operated with 280 bunches, and the empty buckets for ion-cleaning is 32 buckets. In this case, the DC octupole field strength at the threshold of the instability is about $K_{3,th} = (L/B_0\rho)\partial^3 B_x/\partial y^3$ = 158 $1/\mathrm{m}^3$, and the instability is suppressed when the DC octupole field strength is larger than $K_{3,th}$. On the other hand, the instability is grown when the field strength is smaller than $K_{3,th}$. Here B_x is the horizontal component of the magnetic field, L is the effective length of the octupole magnet and $B_0\rho$ is the magnetic rigidity of the electron.

* tsukasa.miyajima@kek.jp

Table 1: Principal parameters of the pulse octupole magnet system.

Parameter	Value
Maximum field gradient (peak)	11700 T/m^3
Maximum peak current	$\pm$100A
Maximum peak voltage	$\pm$285V
Bore diameter	80 mm
Core length	0.20 m
Effective length	0.22 m
Self inductance	3.34 mH

Table 2: Principal parameters of the Photon Factory storage ring under the present low-emittance optics.

Parameter	Symbol	Value
Beam energy	E	2.5 GeV
Circumference	C	187 m
Harmonic number	h	312
Betatron tune	ν_x, ν_y	9.60, 4.28
rf frequency	f_{rf}	500.1 MHz
Revolution period	τ	624 nsec
Emittance	ϵ_x, ϵ_y	36, 0.36 nmrad
Energy spread	σ_ϵ	0.00073
Beam size	σ_x, σ_y	0.58, 0.04 mm
Radiation damping time	$\tau_x, \tau_y, \tau_\epsilon$	7.8, 7.8, 3.9msec

EXPERIMENTS

In order to observe the behavior of the beam instability, we measured the beam spectrum from a button-type electrode using a real-time spectrum analyzer. Fig.1 shows the beam spectra in the vicinity of the second harmonic of the rf frequency f_{rf} when the instability is excited and suppressed. When the instability is excited, 6 peaks of the betatron sideband are observed, for example $2f_{\mathrm{rf}} - f_{\mathrm{rev}} - f_{\beta_y}$. Here f_{rev} is the frequency of the revolution and f_{β_y} is the vertical betatron frequency.

We performed the experiments under following two conditions. One is the condition with a constant bunch number of 280 bunches and the other is with a constant bunch current of 1.6mA. Under the experimental conditions, we can investigate the effects of fill pattern and the bunch current. It seems that these effects relate to the phenomena of the

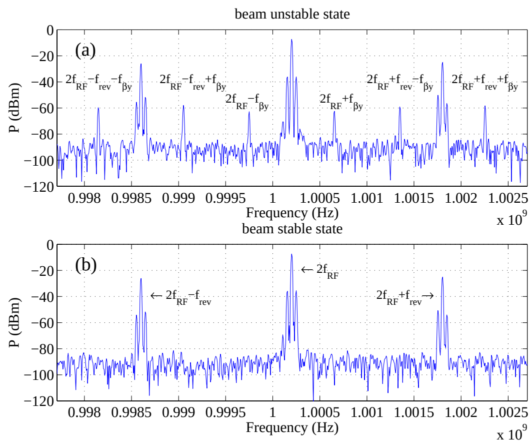

Figure 1: Beam spectrum from a button-type electrode when the pulse octupole magnet was excited at $K_{3,p} = 315$ 1/m^3. The beam current was 432mA with 280 bunches. (a) The spectrum of the beam unstable state when the vertical instability was excited. (b) The spectrum of the beam stable state when the instability was suppressed.

ionization and the ion trapping.

For the measurement of the growth time, we adjusted the DC octupole magnets to $K_{3,dc} = 208$ 1/m^3, then the initial condition is stable state without beam instability. Under the condition, the instability was observed when only the pulse octupole magnet was excited. Thus, we excited the pulse octupole magnet from zero to $K_{3,p} = -315$ 1/m^3 during 1.2 msec. Fig. 2 shows the response of the power spectrum at $2f_{\rm rf} - f{\rm rev} + f_{\beta_y}$ to the excitation current of the pulse octupole magnet in the growth process of the instability. The peak of the instability was appeared after 12msec from the excitation of the pulse octupole field. The instability was exponentially grown afterwards. We defined that the time of 12 msec is the delay time in the growth process of the instability. In addition, we defined the growth rate of the instability as the slope of the power spectrum. Then, the growth rate was calculated to be 4dBm/msec.

On the other hand, for the measurement of the suppression time, we adjusted the DC octupole magnets to $K_{3,dc} = 131$ 1/m^3. Under the initial condition, the peak of the instability was always appeared. However, when we excited the pulse octupole magnet from zero to $K_{3,p} = 315$ 1/m^3, the peak was rapidly disappeared. Fig. 3 shows the response of the power spectrum at $2f_{\rm rf} - f{\rm rev} + f_{\beta_y}$ to the excitation current of the pulse octupole magnet in the suppression process. We found that the instability suppression was almost simultaneous with the excitation of the octupole field.

In the experiments, we measured the beam spectrum 10 times under the same experimental condition.

RESULTS

Fig.4 shows the delay times and the growth and the suppression rates of the instability for a constant bunch number

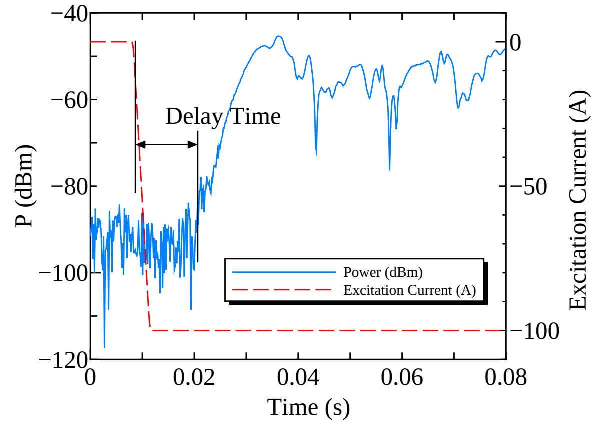

Figure 2: The response of power spectrum at $2f_{\rm rf} - f{\rm rev} + f_{\beta_y}$ (solid line) to the excitation current of the pulse octupole magnet (dashed line) in the growth process of the instability. The pulse octupole excitation current of -100A corresponds to $K_{3,p} = -315$ 1/m^3. The beam current was 432mA with 280 bunches.

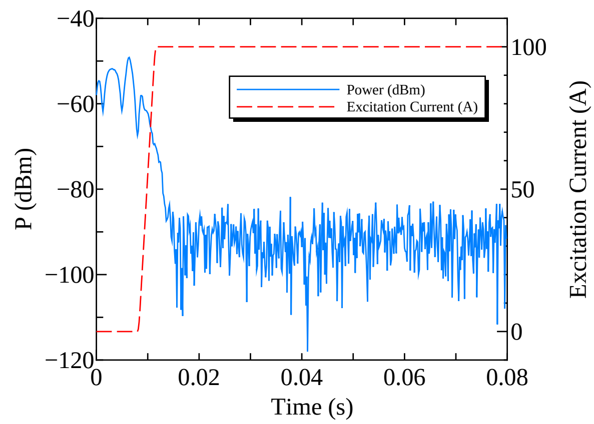

Figure 3: The response of power spectrum at $2f_{\rm rf} - f{\rm rev} + f_{\beta_y}$ (solid line) to the excitation current of the pulse octupole magnet (dashed line) in the suppression process of the instability. The pulse octupole excitation current of 100A corresponds to $K_{3,p} = 315$ 1/m^3. The beam current was 432mA with 280 bunches.

of 280. The error bars shown in the figure include only the statistic error. In the measurement, three beam currents were selected; 100, 200 and 432 mA. Here, the delay times and the rates were calculated from the spectrum of $2f_{\rm rf} - f{\rm rev} + f_{\beta_y}$. In the growth process of the instability, the delay time increases as the beam current decreases. On the other hand, the delay time is almost zero and doesn't depend on the beam current in the suppression process. The absolute value of the growth rate is smaller than the absolute value of the suppression rate. Namely, the suppression process is slower in comparison with the growth process.

Fig.5 shows the delay times and the growth and suppression rates for a constant bunch current of 1.6 mA. In the measurement, three bunch numbers were chosen; 100, 200

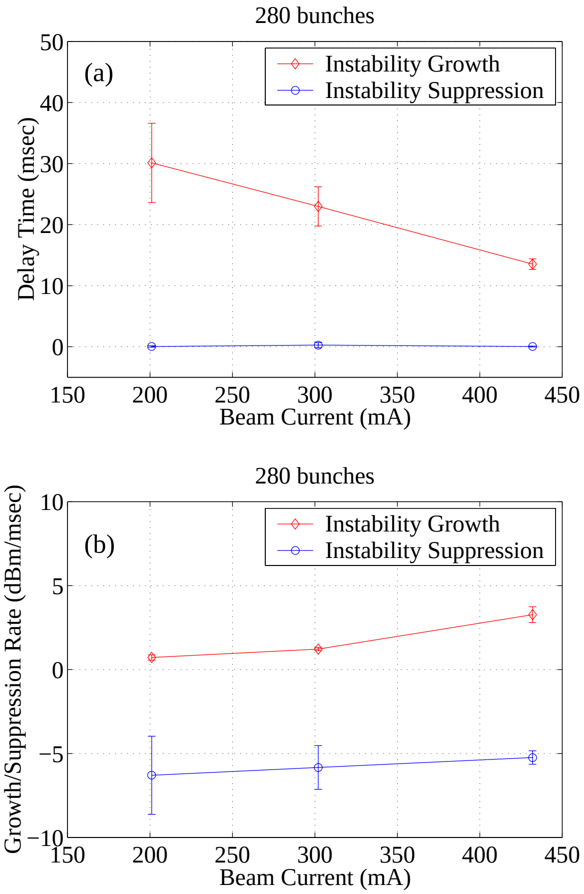

Figure 4: The delay times and the instability growth and suppression rates for a constant bunch number of 280. (a) The delay time for the instability growth and suppression. (b) The instability growth and suppression rate.

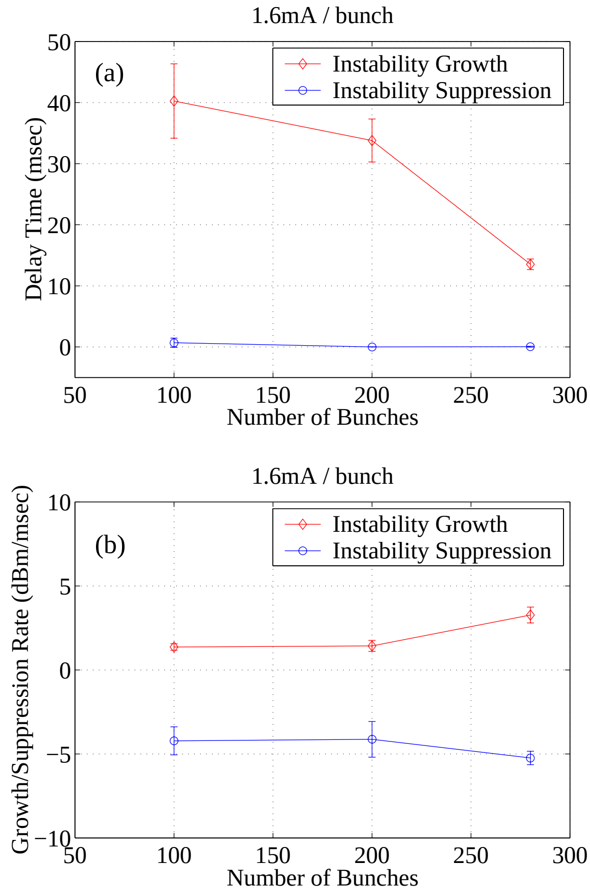

Figure 5: The delay times and the instability growth and suppression rates for a constant bunch current of 1.6mA. (a) The delay time for the instability growth and suppression. (b) The instability growth and suppression rate.

and 280 bunches. In the growth process, the delay time increases as the bunch number decreases. On the other hand, the delay time almost zero in the suppression process. This is the same as the result for a constant bunch number of 280.

As a result, we obtained that the instability was slowly grown in comparison with the suppression, and the delay time depended on the fill pattern of the bunch train and the bunch current of the beam.

DISCUSSION

In the growth process of the instability, the larger delay time was observed in comparison with the suppression process. The delay time depends on the bunch current and the fill pattern of the bunch train, namely, the gap of the bunch for the ion-cleaning. Therefore, it seems that the process of the ionization and ion-trapping is slow, and the time scale of the process is several tens of msec.

On the other hand, in the suppression process of the instability, the delay time was less than few hundreds of μsec. We guess that it is the decoherence process of the coherent motion of the beam due to the tune spread, which is produced by the octupole field. Because it is much faster process, it was simultaneously observed with the excitation of the octupole field.

We are now going to investigate the phenomenon in detail using this system, and to prepare another system for the measurement of bunch-by-bunch profile.

REFERENCES

[1] Y. Kobayashi, *et al.*, "Measurement of the Beam Decoherence due to the Octupole Magnetic Fields at the Photon Factory Storage Ring", EPAC98, Stockholm, June 1998.

[2] T. Miyajima, *et al.*, "Pulse Octupole Magnet System at the Photon Factory Storage Ring", PAC2003, Portland, May 2003.