OBSERVATION OF TRANSVERSE COUPLED BUNCH INSTABILITY AT KEKB

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Abstract

Transverse coupled bunch instability was experimentally studied in low energy positron ring (LER) and high energy electron ring (HER) at KEKB. The oscillations of bunches were recorded by a bunch oscillation recorder for the total of 4096 turns. The data were analysed to obtain the mode distribution and the growth rate of oscillation. The result of the analysis is presented in this paper.

1 INTRODUCTION

KEKB is a two-ring asymmetric electron-positron collider at 8.0 GeV electron energy and 3.5 GeV positron energy. Several measures are taken to suppress the transverse coupled bunch instability (TCBI) at KEKB[1]. ARES and superconducting RF cavities are used to sufficiently damp higher order modes (HOMs). Most of the vacuum ducts are made of oxygen free copper. Its high electrical conductivity helps to suppress the resistive-wall instability. The large circular vacuum duct of LER with an inner diameter of 94 mm also helps to reduce the growth rate of the resistive-wall instability. In LER solenoids are installed around the ring since September 2000 [2] in order to remove the electron cloud which causes the enlargement of the beam size. The solenoids also work to suppress the TCBI due to the electron cloud. A train gap of a contiguous rf buckets that are unoccupied by the beam is introduced to avoid the TCBI by ions. Furthermore a transverse bunch by bunch feedback system is installed to damp the TCBI in both rings [3].

In present operation condition shown in Table 1 the TCBI is well suppressed by the bunch by bunch feedback system in both rings. However, the TCBI may be still limitation in high current operations with shorter bunch spacing to achieve high luminosity at KEKB. The main objective of this study is to obtain the information on the causes of the TCBI from the bunch oscillations in HER and LER.

2 DATA ANALYSIS

A bunch train filled with 1153 bunches was injected in the ring. The bunch spacing was 4 rf buckets and the train gap was 10% of total rf buckets. The bunch oscillations were recorded turn-by-turn for 4096 turns by a bunch oscillation recorder (BOR) after turning off the transverse bunch by bunch feedback system in horizontal or vertical direction. The BOR is a high-speed data recording system developed at KEKB to investigate the nature of the instabilities in both rings [4].

The bunch oscillation data were analysed by the procedure as described below:

1. The betatron frequency was determined by taking bunch-by-bunch Fast Fourier transform (FFT) of the bunch oscillations.
2. The correction was done to those transformed data by multiplying with $e^{-i\omega\beta\Delta t}$ since the beam signal was observed at fixed location at time t=0, where ω_β is the betatron frequency and Δt is $4*(n-1)/f_{rf}$ for the bunch number n.
3. The inverse FFT is then applied to the extracted betatron oscillation in order to obtain a snapshot data.
4. The mode distribution is then obtained by taking turn-by-turn FFTs of the snapshots after padding zeros for a train gap in the snapshots.
5. The growth rates of oscillation amplitudes were calculated from fits to the growth part of each bunch oscillation.

Table 1. The main machine parameters of KEKB

Machine Parameter	LER	HER
Energy	3.5 GeV	8.0 GeV
Circumference, C	3016.26 m	
Revolution frequency, f_{rev}	99.39 kHz	
RF frequency, f_{rf}	508.887 MHz	
Harmonic number, h	5120	
Beam current, I_b	900 mA	800 mA
Number of bunches	1153	
Bunch spacing	4 rf buckets	
Train gap	10% of total rf buckets	
The number of bunch trains	1	
Transverse tune, ν_x/ν_y	45.51/43.56	44.52/41.58
Transverse damping time, τ_x/τ_y	43 ms	46 ms

3 RESULTS

3.1 HER

Figures 1 and 2 show the mode distributions of HER at 700 mA for horizontal and vertical directions respectively. The mode distributions calculated for the resistive-wall wake are also shown in the figures. The wake function of a circular pipe was used. As the radius of the pipe we used 52mm horizontally and 25mm vertically considering the racetrack shape of the vacuum duct (104 mm in width and 50 mm in height). For the calculation we applied formalism by K. Thompson and R. Ruth [5] to take into account of the train gap. The peak positions in observed mode distributions are close to calculated ones both in horizontal and vertical cases.

The growth rates of bunch oscillation in HER were obtained from the amplitude growth at various beam currents. Fig. 3 shows an example of the amplitude growth taken from the snapshot of HER at 400 mA.

Fig. 4 shows the average growth rates over the bunches as a function of beam current in horizontal direction. The average growth rates nonlinearly increase with beam current. The growth rate calculated for the resistive-wall wake is also shown in Fig. 4. As can be seen in Fig. 4 the measured growth rate is observed to be much higher than the calculated one.

Fig. 5 presents the average growth rates of bunch oscillation for vertical direction as a function of beam current. The growth rates nonlinearly increase with the beam current. The measured growth rates are found to be close to the calculated values when the beam current is less than 500mA, while at 700 mA the measured growth rate is much higher than the calculated one.

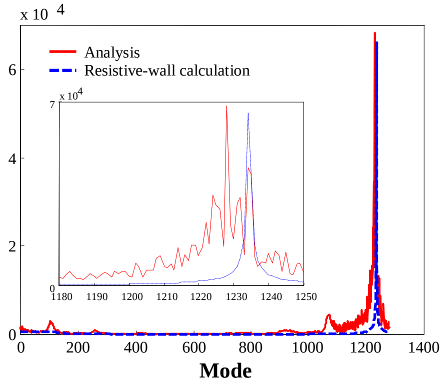

Fig. 1 The horizontal mode distribution of HER at 700 mA

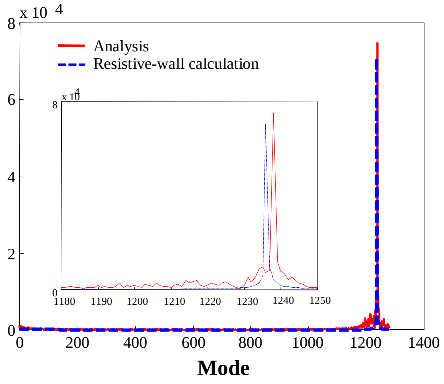

Fig. 2 The vertical mode distribution of HER at 700 mA

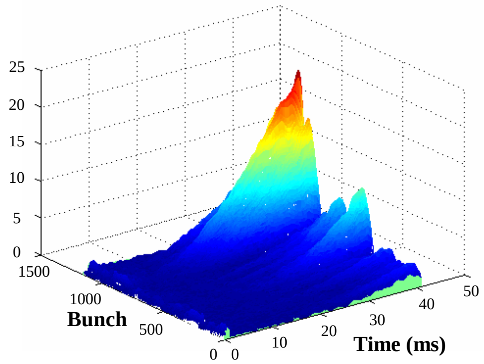

Fig. 3 The horizontal amplitude growth of bunch oscillation in HER at 400 mA

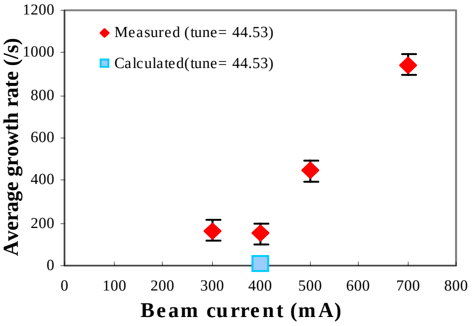

Fig. 4 The horizontal average growth rates in HER as a function of beam current

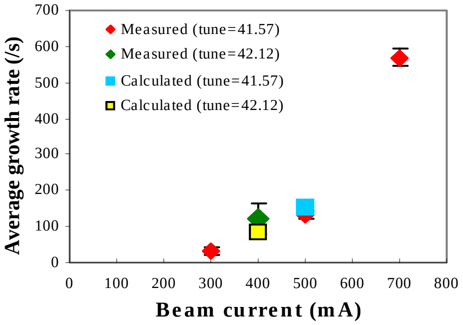

Fig. 5 The vertical average growth rates in HER as a function of beam current

3.2 LER

In LER the comparison was made between the mode distributions of solenoids-on and solenoids-off in horizontal and vertical cases to see the effect of the electron cloud on the TCBI. The horizontal and vertical coupling was corrected prior to the measurement both in the case of solenoids-on and solenoids–off. Fig. 6 compares the mode distributions of LER in horizontal direction for solenoids-on and solenoids-off. It is seen that the distributions of unstable modes are totally different in solenoids-on and solenoids-off cases. The mode distributions in vertical direction for solenoids-on and solenoids-off are illustrated in Fig. 7. It can also be seen that the mode distribution is changed according to solenoids-on and solenoids-off showing the different modes of the instability in each case.

The average growth rates of bunch oscillation in LER for horizontal and vertical directions as well as solenoids-on and solenoids-off cases are presented in Fig. 8. The observed growth rates are very large and proportional to the beam current. The horizontal growth rates are higher than the vertical ones. Comparing the growth rates between solenoids-on and solenoids-off, the improved growth rates are observed due to solenoids-on in both horizontal and vertical directions. At the beam current of 600 mA, the growth rates improved 38% in horizontal direction and 34% in vertical direction due to solenoids-on. It suggests that the solenoid field have partly removed the electron cloud which contributes to the amplitude growth of the bunch oscillations.

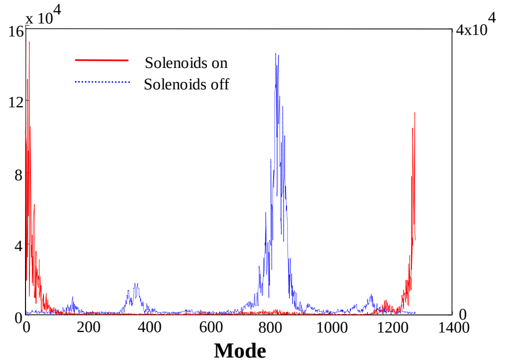

Fig. 6 The horizontal mode distribution of LER at 600mA

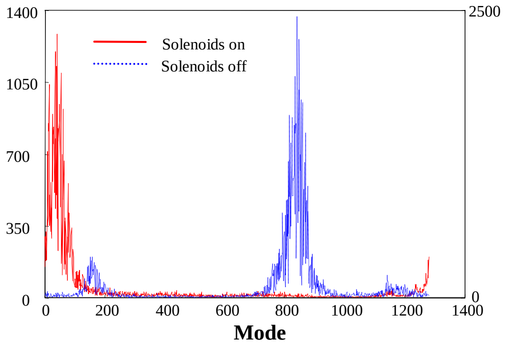

Fig. 7 The vertical mode distribution of LER at 600mA

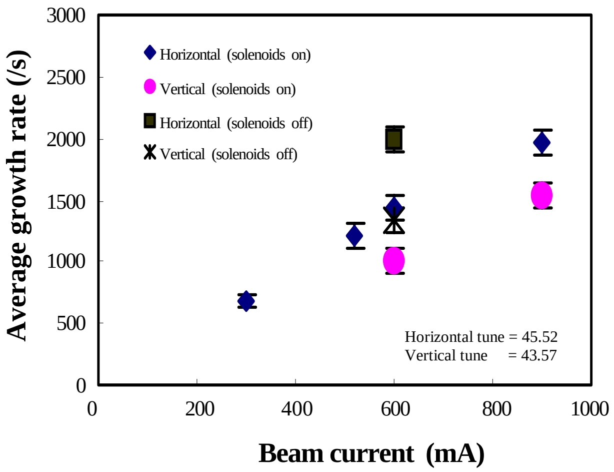

Fig. 8 The average growth rates in LER

4 SUMMARY

In HER, the data were compared with the calculation based on the resistive-wall wake. The peaks in observed mode distribution were close to calculated ones both in horizontal and vertical cases, but the peaks did not appear at exactly same positions as those predicted. The observed vertical growth rate was consistent with the calculation below 500mA, but higher than that from the calculation at 700mA. The observed horizontal growth rates were much higher than the calculated growth rates. Thus more studies are needed to conclude that the instability is caused by the resistive-wall wake.

In LER, the data were taken with turning on and off the solenoids. Totally different mode distribution appeared with solenoids-on and solenoids-off both in horizontal and vertical directions. The growth rates were proportional to the beam current and improved with solenoids-on. The observed difference in mode distributions between solenoids-on and solenoids-off and the improvement of amplitude growth rates due to solenoids-on indicate that solenoids have removed a portion of the electron cloud.

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