BEAM DIAGNOSTICS BY GATING A SINGLE BUNCH AT KEKB

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Abstract

A fast gate module has been developed at KEKB, which can pick up a signal of one bunch along a bunch train. The gate module was attached to a tune measurement system and to a turn-by-turn beam-position monitor system. Continuous monitoring of the betatron tune is an indispensable tool to keep the machine in a stable condition. A measurement of the tune along a bunch train is helpful to estimate the photoelectron cloud density in the Low-Energy Ring (LER). A large tune shift was observed in the High-Energy Ring (HER). The bunch phase is shifted along a train, which can be explained using a periodic transient beam-loading effect.

1 INTRODUCTION

KEKB [1] is a multi-bunch, high-current e+/e- collider. The collider consists of two storage rings: the LER for the 3.5-GeV positron beam and the HER for 8-GeV electrons. Both rings store more than 1000 bunches, where the harmonic number is 5120 with an RF frequency of 509 MHz. Since KEKB operates with the horizontal betatron tune close to a half integer, the tune is very sensitive to the luminosity. The beam life is also sensitive to the tune. Moreover, an orbit deviation causes a change in the tune. Therefore, it is eagerly required to measure the tune at all times in both rings. Monitoring the tune of an individual bunch is useful for understanding the beam dynamics. The LER suffers from an increase of the vertical beam size [2,3]. The increase of the size is caused by a photoelectron instability. The electron cloud density can be estimated from tune shift under the hypothesis that electrons produced by photo-emission and/or secondary emission are attracted by successive positron bunches and result in a shifting of the coherent betatron tune of positron bunches. Thus, measuring the tune along a bunch train is helpful to estimate the photoelectron cloud density. Bunches are usually stored with a 4-bucket spacing (8 ns), forming a single train. The train of bunches is followed by an empty gap. The gap, which occupies 10 percent of the circumference, is required not only for using the abort kicker, but also for clearing ions and photoelectrons. It is predicted that the gap causes a bunch-by-bunch phase shift due to transient beam loading [4,5].

2 GATING A SINGLE BUNCH

Considering the transient response of an electric switch, the rise and fall times do not show the same response. Thus, a ringing waveform with exponential decay is frequently observed at a transition from *on* to *off* states. In order to improve the switching response, two commercially available switches are connected in series. Two pulses are prepared for each switch, which are complementary to each other, but are shifted by cable delay. The delay time determines the gate duration. The length of the delayed cable was adjusted to determine the optimum duration of the gate. A gate duration of 6 ns was obtained with an insertion loss of 3 dB, which is used for normal operations with a 4-bucket (8 ns) bunch spacing. A gated bunch allows the execution of signal processing over a revolution period. Thus, a precise measurement is expected together with the averaging method.

The dynamic response of the gate module was tested using a beam pulse. The intensity response of the gate shows good linearity with the bunch current. The measured phase, however, indicated a large variation as the current increased and the direction of the variation depended on the polarity of the input pulse. Monitoring the bunch intensity should compensate the phase variation. The on/off isolation of the gate module was investigated using bunches in the HER. We have confirmed that the S/N ratio is more than 32 dB, when three buckets from a bunch separate the gate timing. The gate module can cut off the neighboring bunches of a train.

3 GATED TUNE MEASUREMENT

The tune is measured with a swept-frequency method using a tracking analyzer (Anritsu, MS420K). Figure 1 shows the betatron tune measurement system using the gate module. The output signal of the tracking analyzer is swept in frequency corresponding to a fractional part of the betatron tune (1 ~ 50 kHz) and is modulated by a pulse synchronized with a revolution frequency of 99.39 kHz. The amplitude-modulated pulse having a width about 50 ns is combined with a feedback signal, and both signals are guided to deflector electrodes after amplification. The deflector consists of four stripline electrodes mounted in a vacuum chamber. The timing of the deflection pulse is adjusted using a delay module with an interval of 2 ns. Bunches picked up by a button electrode are selected to one by the gate module. The amplitude of a gated bunch signal is sampled and detected by a self-triggered pulse. Only the oscillatory part of the gated pulse is detected, owing to a feedback gain control formed in a detector circuit. Thus, the oscillation amplitude is independent of the bunch intensity and the beam orbit. The resolution of the tune

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measurement is mainly determined by the bandwidth of the tracking analyzer, which is estimated to be ±0.0004 in the present configuration. A smoothing technique for the spectrum may improve the resolution.

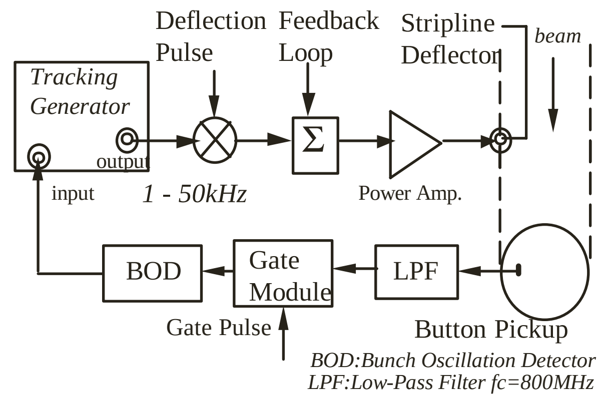

Figure 1: Scheme of the gated tune measurement system.

When the tune of a collided bunch was monitored, its spectrum was distorted by the beam-beam force, which confused the tune measurement due to several peaks. Thus a non-collided bunch, called *a pilot bunch*, is intentionally injected in the abort gap to monitor the tune of both rings. Each pilot bunch is placed at an edge in the abort gap to minimize the damage to the Belle when the beam is aborted. Figure 2 demonstrates the measured tune spectra of the pilot bunch. Since a fractional part of all tunes is above a half integer, a higher frequency means a lower tune. Each peak corresponds to the tune. One may see that the horizontal tune spectrum of the LER is especially broad, which makes the tune measurement ambiguous. This broadening is caused by a high damping rate due to the beam feedback system [6] and because the symmetrical spectrum for a half integer is overlapping. This monitor was installed in the KEKB operation console on February 28, 2001 and has contributed to increasing the luminosity.

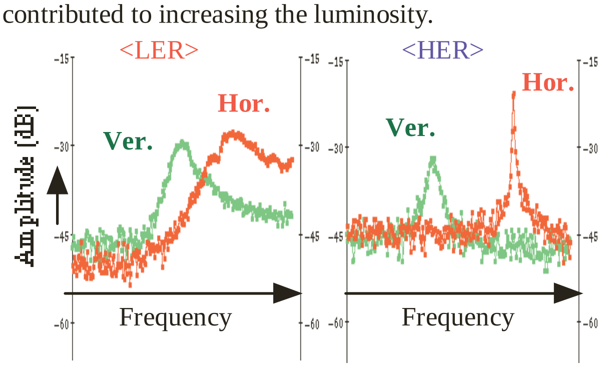

Figure 2: Spectra of the betatron tune of the pilot bunch. Each peak shows a horizontal tune of 44.520 and a vertical of 44.591 at the HER, and 44.517 in the horizontal tune and 43.567 in the vertical tune at the LER.

In addition to monitoring the tune in collision runs, the gated tune meter is helpful for understanding the beam dynamics. The cloud density near the beam could be estimated from the tune shift [7]. Since the deflection pulse has a width of 50 ns and a rise time of 20 ns, a few forward bunches are also kicked. This perturbation may disturb the electron cloud being measured. It was confirmed by changing timing of the deflection pulse that the variation in the measured tune stayed within the measurement errors of ±0.0004 . We found that the perturbation of the forward bunches had a negligible effect.

The tune along a train was measured with the solenoids on and off, as shown in Fig. 3. The train contains 32 bunches with a 4-bucket spacing. Assuming that the tune shift is proportional to the cloud density, the cloud density grows up along the train and tends to saturate in both directions. We can also see that the cloud rapidly decays after passing through the train and makes a long tail. A remarkable effect of the solenoids appears in the horizontal tune shift, where the tune shift reduces to about half. It is noted that the horizontal and vertical tune shifts are similar in the case of the solenoids being off and that the horizontal tune shift increases and the vertical shift decreases, comparing with the previous report [8] based on a measurement in 2000. The vertical tune shift was much larger than the horizontal one before. The total tune shift summed up that in both directions is not much different between them. These results suggest that the distribution of the electron cloud near the beam changed from a flat shape to a round distribution. But, it is impossible to measure the distribution of the cloud at this stage.

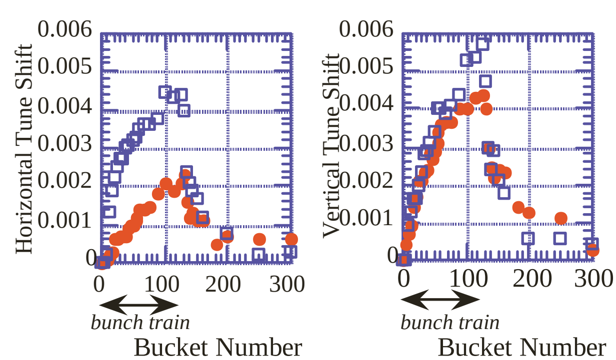

Figure 3: Horizontal (left) and vertical (right) tune shifts along a train as a function of the bucket number at the LER with all solenoids on (dots) and off (squares). The bunch current is 0.3mA. After the train, the tune was measured for each bunch placed to observe.

Figure 4 represents the tune shift as a function of the beam current measured at the HER. The tunes of typical bunches in a train are plotted for each current. The horizontal tune of each bunch increases with a rate of 0.026 /A as the beam current. On the contrary, the vertical one decreases with –0.037/A and the tune shift exceeds the synchrotron tune at the present current. This large tune shift would require careful management of the high beam current. The tune shift is suspected to be due to a quadrupole field generated by the resistive-wall of chambers having asymmetric cross sections as reported from the ESRF [9]. More investigation is needed.

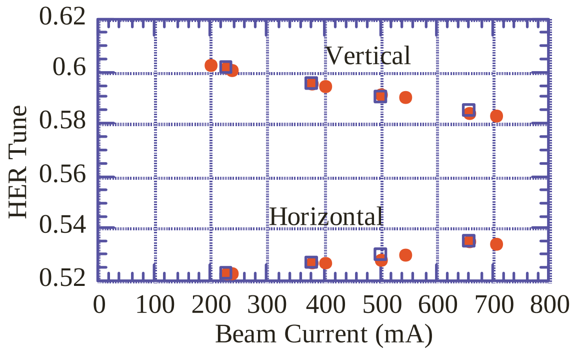

Figure 4: Tune as a function of the beam current in the HER, presenting two tunes measured at the bucket number of 1(head, dots) and 4609(tail, squares) in a train.

4 BUNCH PHASE MEASUREMENT

The gate module was attached to the turn-by-turn beam-position monitor [10], which employs an I/Q (In-phase and Quadrature phase) demodulator working at an RF frequency of 509MHz. A beam signal picked up by a button electrode is gated by a pulse synchronized with the revolution frequency. The two detected signals, represented by $V_{\sin}$ and $V_{\cos}$, as shown in Fig. 5, are sampled by the revolution pulse and stored in the memory of an ADC. The amplitude ratio of two orthogonal components gives a phase difference between the beam and the RF as

$$\varphi_b - \varphi_{rf} = \tan^{-1}\left(-\frac{V_{\sin}}{V_{\cos}}\right),$$

where φ_b and φ_{rf} are the beam and the RF phases, respectively. Assuming that the RF phase is constant, the beam phase is obtained from the amplitude ratio. Since the amplitude data are detected using a 14-bit ADC every turn (10μs) and are averaged over 32,000 turns, a high resolution is expected in the phase measurement. We have determined that the average values were settled within ±0.1 degree. The phase resolution corresponds to a time resolution of less than 1ps. A drift of the phase, however, was observed over a long time.

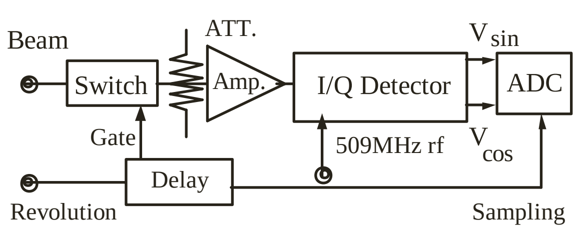

Figure 5: Schematic bunch phase detection.

The amplitude and phase of the accelerating voltage are modulated by the bunch gap, since the beam-loading effect is different between the gap and the beam. As a result, the synchronous position is shifted bunch-by-bunch along a train [11]. The phase shift of each bunch is calculated using a simulation code, which was developed to study the beam-cavity system of KEKB including feedback loops [5].

The bunch phase was measured along a train during collision. The train contains 1153 bunches with a 4-bucket spacing. Figure 6 represents variations of the measured phase shift (dots) together with a simulation result (lines) based on the transient beam loading as a function of the bucket number. Signals from four pick-up electrodes are averaged at each bucket of the measured data. The intensity-dependent phase error of the gate module is less than 0.3 degree since the individual bunch intensity is uniform within ±5%. It is seen that the measured phase shift rapidly increases until the bucket number of around 101. After the number of 601, it gradually increases up to the last bunch of the train. The measured phase shift and the simulation result are quantitatively in good agreement, except at the leading part of the train.

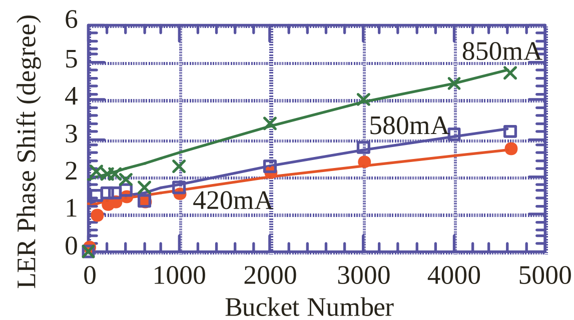

Figure 6: Bunch phase along a train in the LER.

5 SUMMARY

The gated tune meter is useful not only for monitoring the tune during collision but also for estimating the electron cloud density in the LER. A large tune shift was observed in the HER, which is suspected to be due to a quadrupole field generated by resistive-wall of the chambers, and requires more investigation. We have measured the bunch-by-bunch phase along a long bunch train. The measured phase shift in a train agrees with a calculated one, except at the leading part of the train. The authors would like to thank Prof. K.Oide for his support.

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