FEASIBILITY STUDY OF AN ORBIT FEEDBACK SYSTEM FOR THE KEKB FACILITY

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Abstract

An orbit feedback system is vital for maintaining an optimum collision condition at a B factory where two beams circulate in separate rings. For this purpose the beam-beam deflection technique, pioneered at the SLC[1], may be utilized particularly for detecting an orbit offset at the collision point. To study feasibility of this technique at the KEKB rings we carried out a beam test using a pair of stripline monitors installed in the TRISTAN. The main purpose of the study is to see whether we can detect orbit offsets which are artificially introduced using electro-static separators with sufficient accuracy or not. We succeeded to detect these offsets with enough accuracy using these two beam monitors and have had a confidence that this method will work well also in the KEKB case.

I. INTRODUCTION

A conceptual design of the orbit feedback system for the future B Factory was described in a previous paper[2]. As was shown in this paper, we can detect an orbit offset and a crossing angle by using only two monitors which are located on the both sides of the interaction point (IP) and can measure the position of the two beams separately. Fig. 1 shows the geometry of the two monitors A and B around the IP. The monitors are installed between the IP and the final focus quadrupoles so that we can be free from complexity arising from mechanical position drifts of these magnets. We can get the following expression from measured position data using the monitors;

$$\Delta y_{12} + \Delta y' L = \frac{(y_{1A} - y_{2A}) + (y_{1B} - y_{2B})}{2}, \qquad (1)$$

where Δy_{12} denotes the offset at the IP, $\Delta y'$ the beam-beam dipole kick and L a distance between the IP and the monitors, respectively. We assumed that the kick angles of the two beams have the same absolute value and the opposite sign. y_{1A} designates the vertical position of beam 1 at the location of monitor A and so on. With the rigid Gaussian model, the coherent beam-beam kick is given by the Bassetti-Erskine formula[3]. If we assume no horizontal offset and take flat beam limit, the kick is expressed as

$$\Delta y' = -\frac{\sqrt{\pi} N_* r_e}{\gamma \sigma_x} \left[exp\left(\frac{\Delta y_{12}^2}{4\sigma_x^2}\right) \left\{1 - Erf\left(\frac{\Delta y_{12}}{2\sigma_x}\right)\right\} - \left\{1 - Erf\left(\frac{\Delta y_{12}}{2\sigma_y}\right)\right\}\right], \quad (2)$$

where

$$Erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

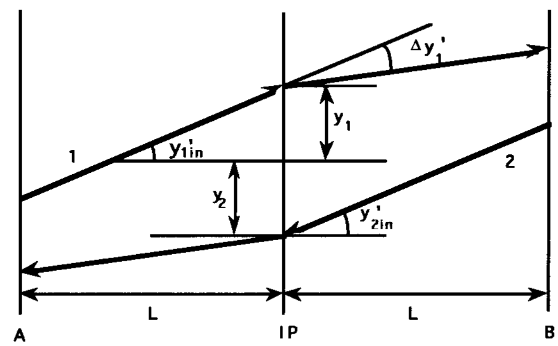

Figure 1. Conceptual Scheme of the Monitor System.

is the error function. In this expression, σ_x and σ_y denotes the horizontal and vertical beam sizes at the IP, respectively. And N_* means the number of particles in the counter-rotating bunch.

In principle, we can know the orbit offset at the IP using equations (1) and (2). A good point of this method is that subtraction of the measured data seen in equation (1) contributes to cancel out spurious offsets which are possibly included in the position data, provided that the offsets are common for the two beams. For example, the effect of a mechanical position oscillation of the monitors can be canceled out. If the offsets included in measured data are different for the two beam, we can not avoid a spurious orbit offset arising from these offsets in the measured data. Even in this case, however, we can know the actual zero-offset point by scanning the orbit offset artificially and fitting the data using (1) and (2). Once the actual zero point is found, the (actual) orbit offset can be obtained as a slip from this zero point. To maintain the optimum collision condition for the orbit offset, we only have to make a feedback loop so that the orbit offset thus obtained is minimized.

II. MONITOR SYSTEM

We newly developed a beam position monitor system for this experiment. We chose stripline type monitors[4], since we have to measure the positions of two beams separately. In addition, the high signal level of the striplines in comparison with button type electrode may also contribute to better position resolution. We employed two monitor chambers with four stripline electrodes. The two monitors are installed around one of the IPs named Nikko. Eight output signals from a monitor chamber are sent to the local control room through its own coaxial cable, and then their signals are selected by RF switches, processed by a common front-end circuit. The signal detector consists of a triple stage super-heterodyne circuit, a synchronous detector and 20bits ADC. A picked up frequency was chosen 521MHz that is the 5267th harmonics of the revolution frequency (99.3KHz).

Table I
Typical machine parameters of the TRISTAN.

Distance between IP and $\mathrm{PM}^{\dagger)}$(m)	1.65
Emittance, $\varepsilon_y/\varepsilon_x$ (nm)	$1.2/80$
Beta function at IP, β_y^*/β_x^*(m)	0.04/1.0
Beam size at IP, $\sigma_y^*/\sigma_x^*(\mu\mathrm{m})$	6.9/283
Angular divergence, $\sigma_{y'}/\sigma_{x'}$ (μrad)	173/283
Beam-beam parameter, ξ_y/ξ_x	0.024/0.012
Beta function at PM, $\beta_y^\dagger/\beta_x^\dagger$(m)	68.1/3.72
Beam size at PM, $\sigma_y^\dagger/\sigma_x^\dagger(\mu\mathrm{m})$	286/546
Bunch length, σ_l (mm)	15

†): Position Monitor

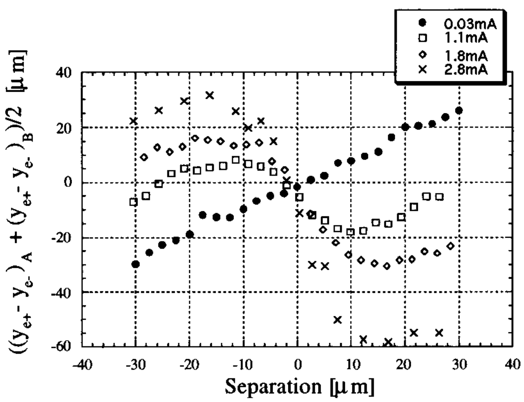

Figure 2. Beam-beam deflection measurement.

With the choice of this pick-up frequency, we aim at obtaining better directivity between the two beam signals. The monitoring system can measure beam position with high resolution of a few micron. We confirmed that this position resolution is actually achieved by seeing reproducibility of the beam position measurements. The overall measuring time is about 3 sec. The time is mainly determined by that necessary for A/D conversion, typical value for which is around 120msec per conversion.

III. EXPERIMENT

The TRISTAN is an electron-positron single ring collider operated at around 30GeV. For the time being, a high energy physics(HEP) experiment is being carried out at 29GeV. The present machine study was done at the same energy and with the same optics as those of the HEP experiment. Typical machine parameters related to the present experiment are shown in Table 1.

The orbit offsets were created using the electro-static separators fed by bi-polar power supplies. The maximum amount of full separation is about $\pm 30\mu m$. In this study, we employed one electron bunch and another positron bunch and took data at four different beam currents; $i.e.$ averaged bunch currents of 0.03, 1.1, 1.8 and 2.8 mA. At each current point, we scanned the offsets at intervals of $2.5\mu m$ or $5\mu m$ with recording the beam positions of the two beams. Before we moved from one offset value to the next, we reset the orbit bump and took the beam positions in this situation as the reference values. And when we moved on to the next offset, we regarded shifts from these reference values as new position data. With this procedure, we can remove possible position offsets different for the two beams, although we found this procedure is not necessary for our experiment. In addition to the position measurements, we also measured beam-beam tune shifts for a cross check.

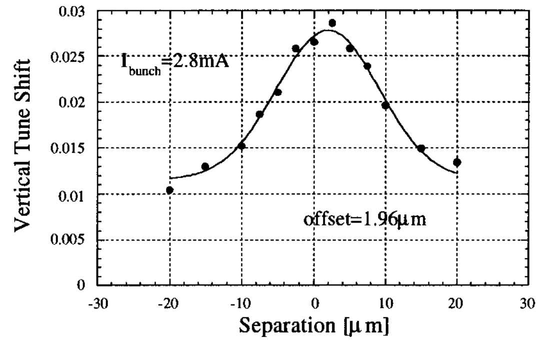

Figure 3. Measurement of the beam-beam tune shift.

From the measured position data, we calculated the right hand side of equation (1). Fig. 2 shows results of the offset scans. At the very small beam current of 0.03mA, where the beam-beam effect is almost negligible, the left hand second term of (1) can be ignored and the right hand side should be equal to the offset itself created by the separators. The values obtained at the experiment is roughly equal to the offsets except around 5% disagreement. We used this measurement for calibration of orbit bump height. With high bunch currents the curves in Fig. 2 have negative slopes in a small offset region due to the beam-beam kick. However, with a large offset the beam-beam kick saturates and the slopes come back to positive due to the left hand first term of (1). The curves in Fig. 2 have some offsets in the horizontal and vertical direction in the graph. This means that the two beams have some position offset at the IP, even when the offset artificially introduced by using separators is zero. The horizontal offsets in Fig.2 correspond directly to the position offset at zero artificial offset. The vertical offsets can be attributed to the effects of the beam-beam kick at the zero artificially offset. In this study, we found that the horizontal offset at zero artificial offset is around $2\mu m$ for these values which are almost the same for there curves. This $2\mu m$ offset was also observed in the measurement of the beam-beam tune shift, the result of which is shown in Fig. 3. With the scanning method tested here, we found that we can know the position offset at the IP with an accuracy of around $1\mu m$ which is about 15% of the beam size when the beam-beam parameter is rather large.

We made further corrections for the data plotted in Fig. 2. First, orbit bump height is corrected using the measurement at 0.03mA. Second, we removed the horizontal and vertical offsets of the curves in Fig. 2. Third, beam current change during scanning was corrected. And fourth, the COD changes due to the beam-beam kick were taken into account. This correction is not very large and is about $1.5\mu m$ at maximum. The corrected data are plotted in Fig. 4. In Fig. 4, theoretical values calculated with (1) and (2) are also shown. In the calculations, we needed the horizontal and vertical beam sizes at the IP. These values were obtained also from the beam-beam tune shift mea-

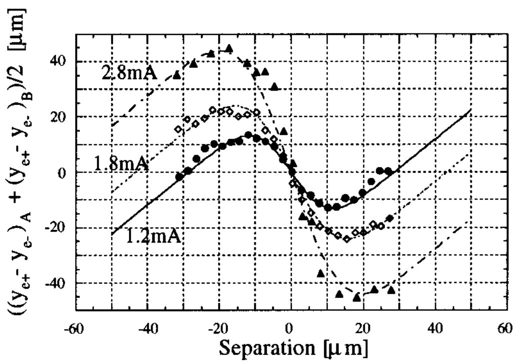

Figure 4. Beam-beam deflection data with some corrections.

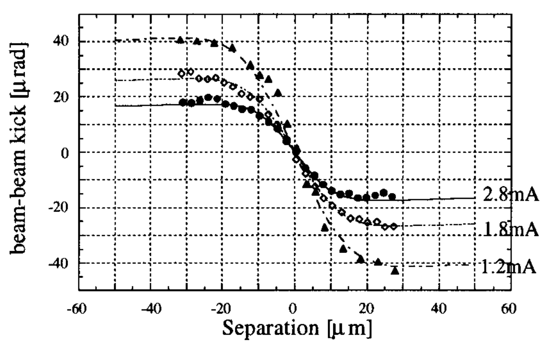

Figure 5. Beam-beam kick as function of the orbit offset.

surement. The horizontal and vertical emittance can be calculated with the beam-beam parameters. As for the beta functions, we employed the calculated values. When we translated the beam-beam tune shift values to the beam-beam parameters, we used so-called Yokoya factors, 1.33 for the horizontal direction and 1.24 for the vetical[5]. The calculated curves seem to well reproduce the measured values.

We can also see the direct relation between the orbit offset and the beam-beam kick angle by using data shown in Fig. 4. As is seen in equation (1), the beam-beam kick can be obtained by subtracting Δy_{12} from the right hand side. Fig. 5 shows the the relation thus obtained. Theoretical curves are in good agreement with the measurements, which means that the Bassetti-Erskine formula gives the correct beam-beam force.

IV. CONCLUSION

We investigated feasibility of the beam-beam deflection technique in the ring collider. We tried to see if we can detect the orbit offset of the two beams which are artificially introduced with enough accuracy or not. With a pair of stripline type monitors, we could detect the orbit offset with an accuracy of $1\mu m$ or less particularly when the beam-beam parameters are rather large. Then, we think that this technique is quite feasible for the orbit feedback system of the KEKB.

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