OBSERVATIONS OF TWO MICROBUNCHES AFTER A 180-DEGREE ARC SECTION AT THE KEKB LINAC

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Abstract

The KEKB linac [1] continuously injects 8-GeV electron and 3.5-GeV positron beams into the KEKB rings: HER (high energy ring) and LER (low energy ring). The energy spread of the 8-GeV electron beam, which is accelerated to an energy of 1.7-GeV at a 180-degree arc section and reaccelerated after this arc to a final energy of 8 GeV, is optimized by adjusting rf acceleration phases so as to assure efficient injections. When rf phases after the arc are slightly changed or drifted for some reasons, the beam not only shows larger energy spreads but also indicates two clusters on a beam profile monitor located at large energy dispersions. In this connection, a longitudinal beam profile was measured before and after the arc section with streak-camera systems utilizing OTR (Optical Transition Radiation). The observed bunch shape clearly shows a two-microbunch structure, suggesting that it could be generated in the arc section. Various experimental data as well as some CSR-related speculations are presented.

INTRODUCTION

In high-luminosity machines like the KEKB factory, stable beam injections are absolutely essential to retaining the optimum luminosity. The injection efficiency is quite dependent upon the quality of injected beams, especially upon the energy spread. Thus the energy spread of the electron beam for the KEKB has been always kept at a minimum enough for stable injection by adjusting rf acceleration phases.

The KEKB electron beam is accelerated to an energy of 1.7-GeV at a 180-degree arc section and reaccelerated after the arc to a final energy of 8 GeV (Fig. 1). During tuning processes of the energy spread, we have found that the energy profile at the end of the linac shows peculiar behaviour, splitting into two clusters if the rf phases after the arc are not optimized, while we have not observed the same phenomenon before the arc section. Although the phenomenon itself is quite stable and reproducible, we examined as a first step the rf system looking for some unstable components, but did not find any causes attributed to the rf system. Meanwhile we have taken various observation data concerning this phenomenon, which are reported in this paper together with some CSR-related speculations.

EXPERIMENTAL CONFIGURATION

A schematic view of the experimental setup is shown in Fig. 2. The parameters relevant to the 8-GeV single-bunched electron beam are summarized in Table 1. The energy profile of the beam is observed by a screen monitor using an alumina fluorescent plate (AF995R, Desmarquest Co.) located at the 8-GeV energy-analyzer line; the energy separation of the two clusters is measured by changing rf phases of appropriate accelerator sections corresponding to an energy range of about 5 GeV. The time structure of the bunch is investigated with streak-camera systems (Hamamatsu Photonics K. K.) utilizing OTR located before and after the arc, which have a time resolution of two or three picoseconds.

Table 1: Beam Parameters

Energy	8 GeV
Acceleration Frequency	2856 MHz
Charge	1 nC (single bunch)
Bunch Length (σ)	4.7 ps (single bunch)
Energy Spread (σ)	0.05 %
Emittance $\gamma\beta\varepsilon$ (σ)	0.31 mm
Maximum Repetition	50 pps
Energy at the Arc Section	1.7 GeV

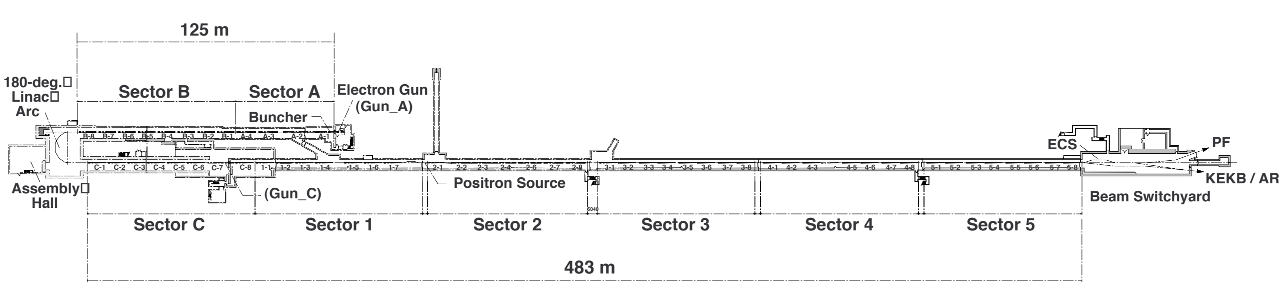

Figure 1: Layout of the KEKB linac. The KEKB electron beam is accelerated to an energy of 1.7-GeV at a 180-degree arc section and reaccelerated after the arc to a final energy of 8 GeV.

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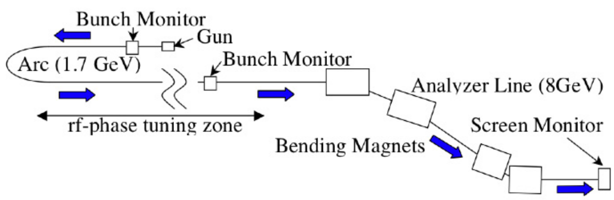

Figure 2: Schematic view of the experimental setup. The longitudinal phase space of the single-bunched electron beam is diagnosed by two methods: one with the bunch monitors before and after the arc, the other utilizing the 8-GeV energy analyzer line located at the end of the linac.

EXPERIMENTAL RESULTS

Observation on the Screen at Large Dispersions

Fig. 3 shows the photographs of energy profiles observed on the screen monitor located at the energy-analyzer line in two cases: Fig. 3a for the single bunch in optimum rf acceleration phases and Fig. 3b for those split into two clusters in non-optimum rf phases. Since the alumina fluorescent plate has a long image lag when irradiated by charged beams, the beam repetition was decreased to 0.5 Hz so as to check if two clusters shine at the same time. This has verified that the observed phenomena are not caused by some energy-jitter effects but due to the real two independent clusters with different energies.

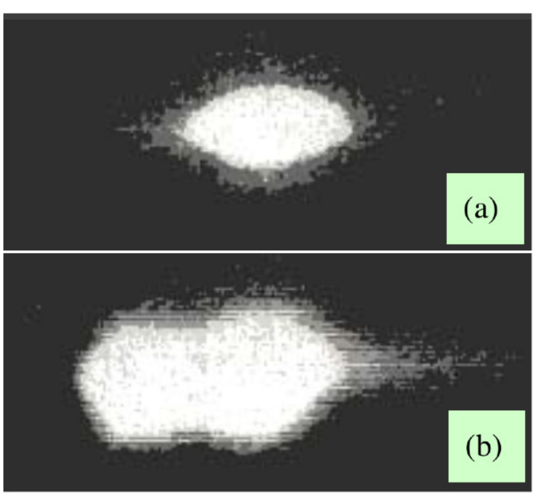

Figure 3: Energy profiles observed on the screen monitor at large dispersions: (a) for the single bunch in optimum rf acceleration phases and (b) for those split into two clusters in non-optimum rf phases.

Measurements of the Bunch Structure

This fact has pushed us to figure out time structures of the bunch with streak-camera systems utilizing OTR located before and after the 180-degree arc section. The results are shown in Fig. 4; one observed before the arc (a), the others after it (b, c). Fig. 4b and 4c clearly

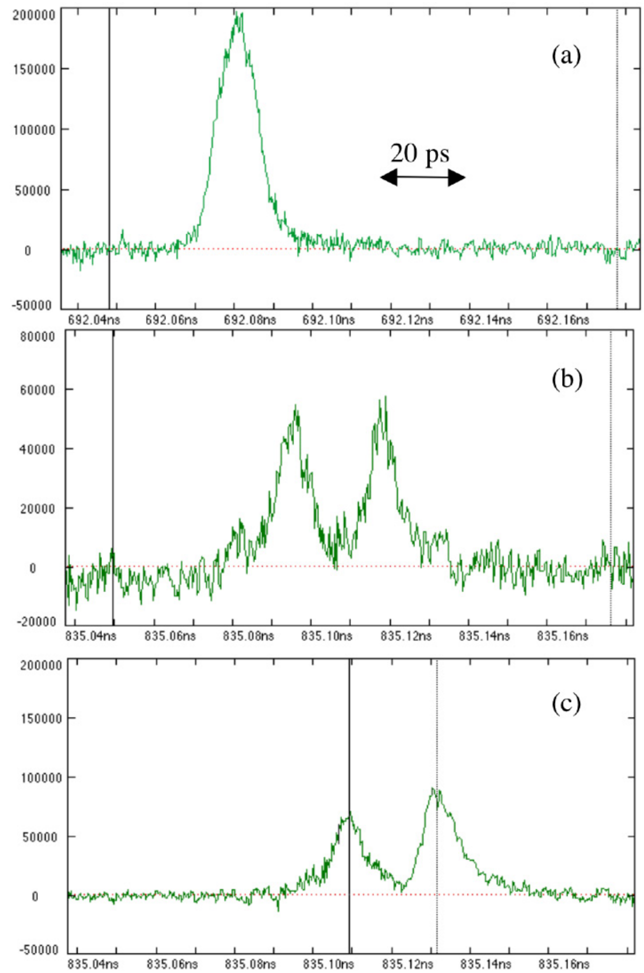

Figure 4: Bunch structure measured with streak-camera systems utilizing OTR located before and after the 180-degree arc section: (a) observed before the arc, (b) and (c) after the arc. (a) and (b) are the cases for a charge of 1 nC, while (c) is for 2 nC.

indicate a two-microbunch structure with a time interval of about 20 ps irrespective of rf phases, while the bunch shape before the arc (Fig. 4a) has just a single peak. Since the measurements were carried out in integration modes of the streak camera systems to improve S/N ratios for a small charge of 1 nC or 2 nC, it remains unclear whether the results could conclude the actual existence of two microbunches after the arc, which might hint that the phenomena should take place during passage through the arc.

We also checked the charge dependence of the phenomena anticipating the wake-field issue, but the time interval of the two microbunches shows weak or no dependence on the charge (Fig. 4c).

Energy Separation as a Function of rf Phases

In order to clarify the two-microbunch structure, we have examined whether the energy separation of the two clusters seen by the screen monitor at large dispersions really varies with rf phases. Fig. 5 shows unequivocal dependences of the energy separation of the two clusters on the rf acceleration phases confirming the existence of two microbunches.

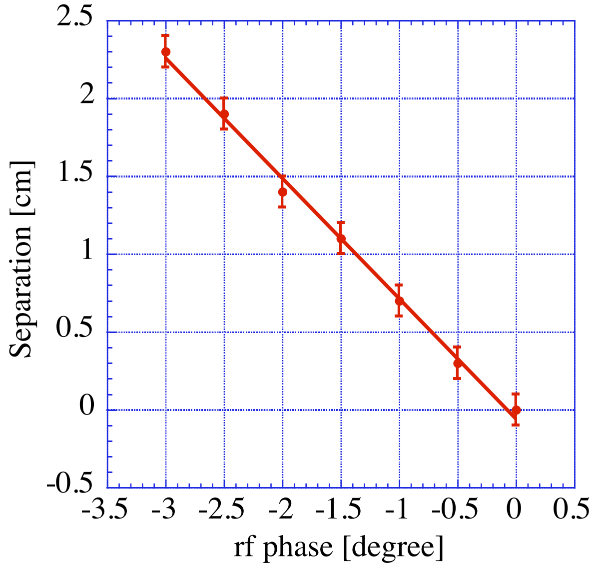

Figure 5: Energy separation of the two microbunches as a function of the rf phases. The data points are fitted with the function x given in the text.

DISCUSSIONS

Cross-Check of the Measurements

The measurements by the bunch monitor after the arc (Fig. 4b) shows that the time interval of the two microbunches is about 20 ps, which should be compared with the value obtained from the rf-phase dependence of the energy separation of the two clusters (Fig. 5). If the two microbnches really exist, their energy separation δE is written as,

$$\frac{\delta E}{E} = \frac{E_{rf}}{E_0}(\cos\phi_2 - \cos\phi_1),$$

where E_{rf} is the corresponding energy of the sections for rf phase tuning, E_0 the total energy (8 GeV), ϕ_1 the rf phase of the first microbunch, ϕ_2 that of the second microbunch. The observed separation on the screen (x) is proportional to δE,

$$x = A\eta_x \frac{\delta E}{E},$$

where η_x is the dispersion function at the measurement point, A the calibration factor. Defining the following quantities,

$$\phi_{rf} = \frac{\phi_1 + \phi_2}{2}, \ \delta\phi = \phi_2 - \phi_1,$$

x is represented by

$$x(\phi_{rf}) = -2A\eta_x \frac{E_{rf}}{E_0} \sin\frac{\delta\phi}{2} \sin\phi_{rf}.$$

The data points in Fig. 5 are fitted with this function on the assumption that

$$A = 0.8, \ \eta_x = 400 \ cm, \ E_{rf} = 5.25 \ GeV,$$

from which we obtain $\delta\phi$:

$$\delta\phi = 12 \pm 1 \ [\text{degree}],$$

corresponding to the time interval δt :

$$\delta t = 12 \pm 1 \ [\text{ps}].$$

This is to be compared with the value (20 ps) obtained by the bunch monitor, showing a certain amount of difference, which should be attributed to the uncertainties concerning the calibrations of the streak camera systems and the factor A.

Some Speculations on CSR Effects at the Arc

The experimental results suggest that the observed phenomena might originate at the arc section, which is designed to be achromatic and isochronous. The CSR effects could be primarily not the issue because the bunch length is not so small and not even compressed in the arc. During passage of the arc, however, it might happen that an initial density fluctuation with a characteristic length much shorter than the bunch length could radiate coherently, leading to microbunching phenomena observed in our linac if the CSR effects are enhanced in the arc [2]. The simulations based on the CSR effects are in preparation and will be reported elsewhere.

CONCLUSIONS

We have observed peculiar phenomena in the energy profile of the KEKB 8-GeV electron beam during rf phase tuning, splitting into two clusters like microbunches. In order to check the existence of microbunches, we performed a series of experiments. The results surely indicate that microbunching happens at the 180-degree arc section when the rf acceleration phases are not optimized for an energy spread. Further experiments as well as some simulations related to CSR effects are to be carried out in the near future.

REFERENCES

[1] I. Abe et al., “The KEKB injector linac”, Nucl. Instr. and Meth. A499 (2003) 167.
[2] M. Huning et al., “Observation of longitudinal phase space fragmentation at the TESLA test facility free-electron laser”, Nucl. Instr. and Meth. A475 (2001) 348.