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KEK Preprint 94-98
September 1994
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*Submitted to the 17th International Linac Conference (LINAC94),
Tsukuba, Japan, August 21 - 26, 1994.*

National Laboratory for High Energy Physics, 1994

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HIGH-INTENSITY SINGLE-BUNCH BEAM OF THE PF 2.5-GEV LINAC

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Abstract

In preparing for the KEK B-factory (KEKB), a high-intensity single-bunch beam was accelerated for the first time in the PF 2.5-GeV linac, and some beam characteristics were measured. The time structures of the beam were observed by utilizing a streak camera. A bunch length of 10 ps (FWHM) was obtained for a 4×10^{10} e^- (6 nC) beam. The energy spectrum and emittances were also measured at the end of the pre-injector (~ 45 MeV). The typical energy spread was 0.6% (FWHM). The emittances were about 70 (π mm mrad). A double SHB system is also discussed concerning the KEKB injector linac.

Introduction

The KEKB requires a sufficient number of positrons, for which an intense single-bunch electron beam containing more than 6×10^{10} electrons should be accelerated up to the production target for a long distance [1]. Before starting the linac upgrade for the KEKB, it has become necessary to experimentally investigate the fundamental acceleration ability of the PF 2.5- GeV linac, and to clarify issues which should be improved when the linac is reformed to the KEKB linac. Such preparation has been performed in two stages: The pre-injector of the 2.5-GeV linac was extensively upgraded so as to be able to accelerate high-intensity beams during the summer of 1992 [2]. A 476-MHz sub-harmonic buncher (SHB) as well as a new grid pulser of the electron gun was introduced in the summer of 1993 to make a single-bunch beam.

System Configuration

The layout shown in Fig. 1 is the first half of the new pre-injector. A 476-MHz SHB has been installed between the electron gun and the prebuncher. The SHB was introduced to reduce the beam pulse duration (~1 ns) from the gun to a value of less than one period of the acceleration frequency (~ 350 ps). This SHB is being used only for acceleration tests of a high-intensity single-bunch beam, which is not injected into the storage rings. This is because the linac and the rings are being operated at completely independent accelerating frequencies.

The resonant frequency of the SHB was selected to be 476 MHz, because a power source already existed and the existing cavity dimensions were applicable [3]. A cross-sectional view of the SHB cavity is shown in Fig. 2.

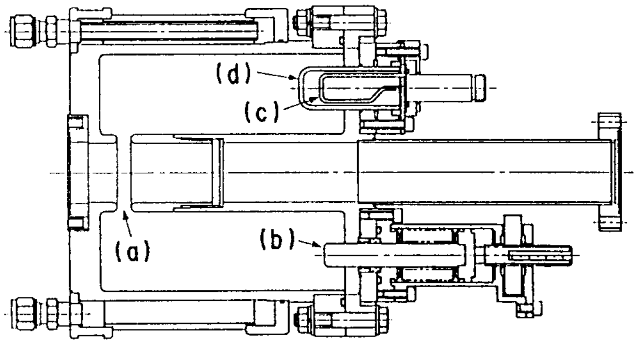

Fig. 2 SHB cavity: (a) Acceleration gap, (b) tuner, (c) coupler, and (d) ceramic window.

Single-Bunch Beam Characteristics

After installing the SHB, we measured the high-intensity single-bunch beam characteristics, such as the bunch purity, bunch length, energy spread, transmission rate, and emittances.

Single-Bunch Purity and Bunch Length

Simulation calculations have been performed with "PARMELA". They predicted that a single-bunch beam can be obtained if the beam pulse duration is less than 1 ns; however, a small satellite accompanies each side of the main bunch if the

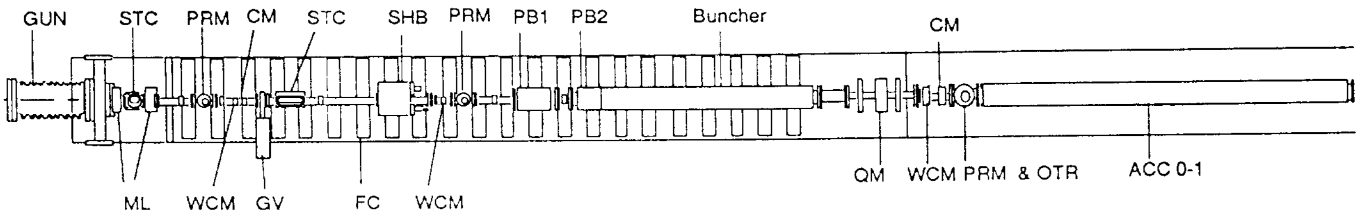

Fig. 1 New system configuration of the pre-injector. A 476-MHz SHB has been installed.

beam duration is more than 1 ns. Figure 3a shows a typical simulation result calculated by assuming a rectangular beam (1-ns, 10 A) at the SHB-entrance.

The bunch purity and lengths were measured at the end of the pre-injector (~ 45 MeV) utilizing a streak camera. Figure 3b shows a typical picture produced by the streak camera. It provides the time structure of a beam compressed from a 1-ns beam emitted from the gun. A satellite bunch was observed at each side of the main bunch. The amount, however, is thought to be negligibly small. (N.B. The direction of abscissa in Fig. 3a is opposite to those of Figs. 3b and 4.)

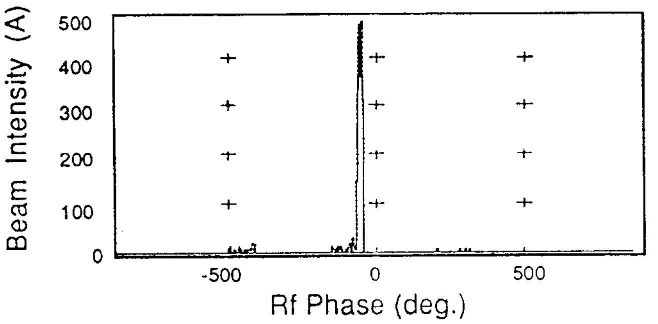

Fig. 3a Bunch structure at the end of the buncher. An initial beam of 1 ns/10 A is assumed.

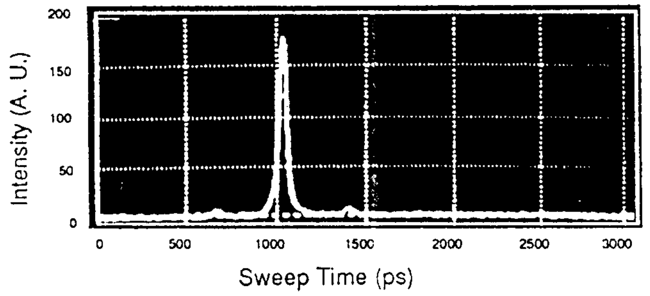

Fig. 3b Time structure of a 6-nC beam observed with a streak camera.

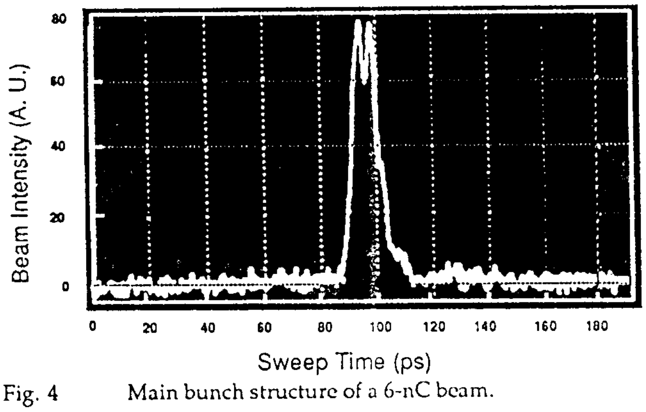

Fig. 4 Main bunch structure of a 6-nC beam.

The main bunch structure is shown in Fig. 4, which is a single-shot picture produced by the streak camera. The observed bunch length (FWHM) is about 10 ps, which is thought to be sufficiently short [4] if the measuring system resolution is taken into account.

Energy Spread

The energy spectrum of a single bunch beam was measured at the end of the pre-injector. The energy spread of the 6-nC beam was observed as 0.6% (FWHM), which is sufficiently small, as predicted. Beam intensity is the current passed through a slit located after the analyzer magnet. The spectrum was measured while slowly changing the analyzer magnet field. It therefore generally includes beam instabilities.

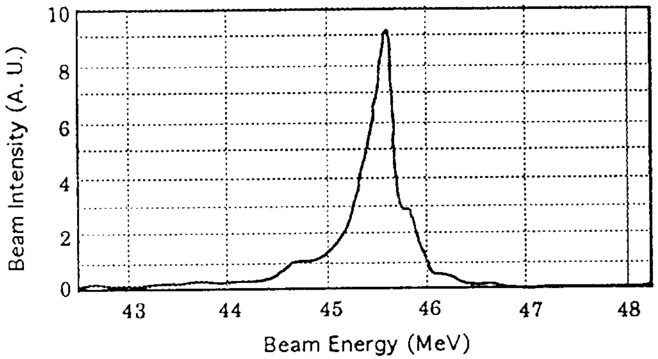

Fig. 5 Energy spectrum of a single-bunch beam measured at the end of the pre-injector.

Single-Bunch Beam Acceleration in the PF Linac

A 6-nC single-bunch beam was accelerated to the end of the linac. More than 80% of the electrons were transmitted to the center of the linac (3rd sector, 3-42). A part of the beam was, however, gradually lost, especially, in the second half of the linac (4th and 5th sectors). This is thought to have been caused by wake fields, and an insufficient adjustment of the beam transport. Issues regarding wake-field effects will be investigated elsewhere [4]. It is obvious from our experiment that operation becomes difficult, and a finer adjustment is required as the beam intensity increases. This means that adequate improvements, such as fine alignment, precise position detection and quick beam control, will be inevitable for the KEKB linac.

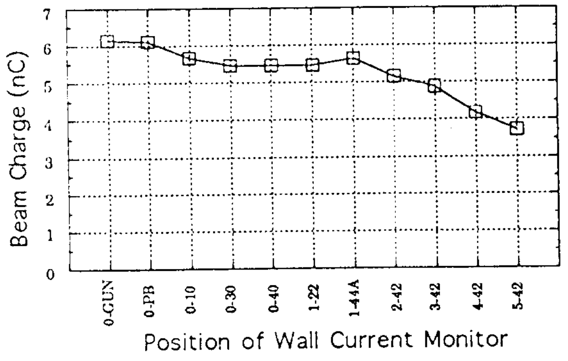

Fig. 6 Single-bunch beam accelerated in the PF linac.

Emittance

The beam emittances were measured just downstream from the buncher by a method using a quadrupole magnet and a profile monitor (screen: Desmarquest AF995R). The beam sizes were measured at different strengths of a quadrupole magnet by using a random shutter camera. In the thin-lens approximation, the squared beam radius makes a parabolic curve with respect to the Q-mag strength. The parabolic curve is fitted to the data with some free parameters, from which the beam emittance is calculated. Here, the beam sizes are defined by the full width at half maximum (FWHM) in the beam-density distribution. The normalized emittances of the single-bunch beam are $\gamma\beta\varepsilon_x = 67$ (π mm mrad) and $\gamma\beta\varepsilon_y = 73$ (π mm mrad). These are close to the values predicted by PARMELA [5]. Consistent results were obtained in recent measurements, which have been reported elsewhere [6].

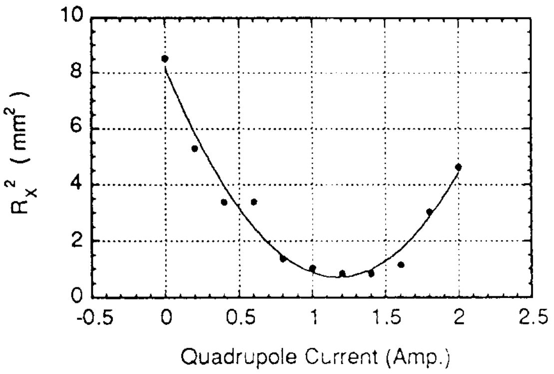

Fig. 7 Squared beam radius vs. Q-mag strength.

Double-SHB System for KEKB

In the KEKB, single-bunch beams must be injected into ring rf buckets with an accuracy of better than 30 ps from the center. This specification will be satisfied only when the accelerating frequencies of both the linac and the ring are multiples of a common subharmonic. The common subharmonic was searched under the following conditions: both multiples be products of small prime numbers; the ring frequency should be in 508.58±0.3 MHz in order to utilize TRISTAN rf components; and the linac frequency (2856 MHz) should not be changed.

A common subharmonic (10.385 MHz) has been proposed. This frequency determines the possible SHB frequencies naturally, as listed in Table 1 [7]. A double SHB system with different frequencies is under consideration. A layout plan is shown in Fig. 8. This system has a feature. A typical simulation (Fig. 9) shows that the peak intensity of this system becomes twice as high as that of Fig. 3a. Consequently, this double SHB system will be suitable for obtaining a higher-density, single-bunch beam.

Table 1 Frequencies of the linac and the KEKB rings

Equipment	Multiple	Frequency (MHz)
Common	1	10.385
SHB1	11	114.240
SHB2	5x 11	571.200
Linac	5x5x11	2856.000
Ring	7x7	508.887

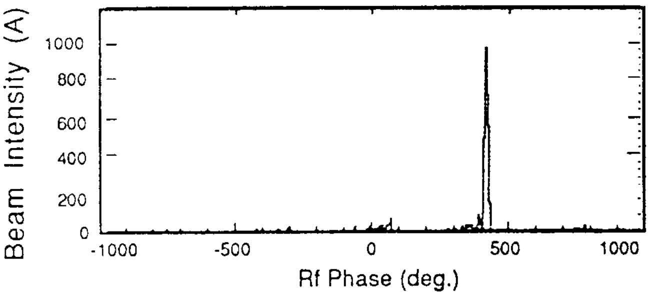

Fig. 9 Bunch structure simulated for the double-SHB system. An initial beam of 2 ns/10 A is assumed.

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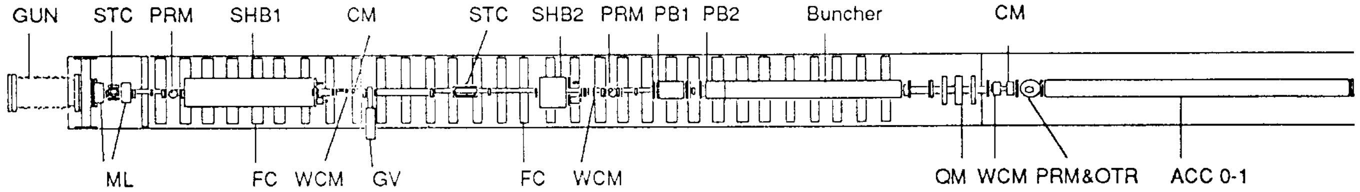

Fig. 8 Layout plan of the new pre-injector for KEK B. The double-SHB system is under consideration.